Use of Evolutionary Computation in the Analysis and Optimisation of Turbulence Models

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Abstract: The identification of the perfect set of parameters for a turbulence model in a flow simulation is a rather elaborate process and therefore users tend to run their computations using standard values taken from literature. These do not always give the best results in all cases. In order to automate the process of finding optimized values, an evolutionary approach is introduced here. A better set of parameters is evolved using genetic algorithms. It is explained how they works and results obtained on different test cases using different turbulence models are presented. The test results show a clear improvement of the accuracy of a simulation when the new values are used in the model.

Keywords: Numerical Algorithms, Computational Fluid Dynamics, Turbulence Modeling

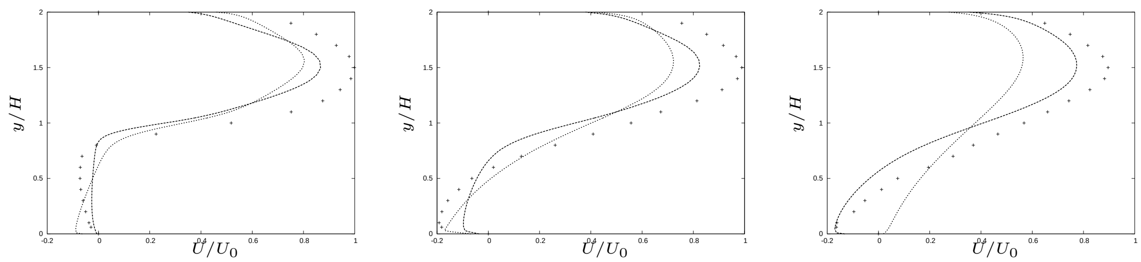
1 Introduction

Turbulence models based on the Reynolds-Averaged Navier-Stokes equations have proved extraordinarily successful in the practical application of CFD [1]. The standard k-ε model [4] is probably the single most extensively used turbulence model, whilst other variants, together with other eddy viscosity models, form the backbone of industrial CFD. The equations usually include a significant number of arbitrary constants whose values have to be determined. The standard k-ε equations for example contain five numerical constants whose values have been determined via an extensive and laborious process of validation against experimental and in some cases DNS data. Whilst the coefficients seem to exhibit some degree of universality across a range of flows, and are often assumed to possess this property, this is merely an assumption, and there are plenty of examples where fine-tuning the coefficients can improve the accuracy of the model on a particular type of problem [6]. More sophisticated turbulence models (non-linear models, second moment closure etc.) often require even more coefficients to be determined.

2 Problem Statement

In the past, tuning the coefficients in turbulence models has been done manually, by repeated recalculation of test cases and comparison with experimental or DNS data. This is time consuming and probably not very reliable, and makes it difficult to quantify the quality of the coefficients. This project deals with the a-priori estimation of the best coefficients in a given turbulence model by adopting evolutionary procedures and thereby optimizing the performance

of the simulation. Evolutionary Algorithms, especially Genetic Algorithms (GA), have shown their ability to optimize complex functions [2] on a wide range of problems.
Adaptation of these concepts to optimization problems was first established by Holland in the 1970's [3]. It proved a reliable approach for problems that eluded analytical solution, today even more so, since more powerful computers allow more elaborate calculations. To demonstrate the capabilities of the method developed for this project, Figure 1 compares the results of the fittest set obtained from the optimization procedure to those obtained by using the standard model coefficients, showing a significant improvement with respect to the velocity profiles.



(a) $x/H = 1$ (b) $x/H = 3$ (c) $x/H = 6$

Figure 1: normalized velocity profiles at three points in streamwise direction. Re=11,000. '+' marks the experimental measurements by Makiola [5], the dotted lines are the results of a simulation using the standard coefficients and the dashed lines are results using the set with the highest fitness obtained by the GA. The geometry was a backward facing step with step height H in a channel, the simulation was in 2d.

3 Conclusion and Future Work

Results on simple test cases using both two- and one-equation models show a significant improvement of the solution. The flexibility of the software allows different models to be tested and the fitness funtion to be easily modified. Further simulations will look at additional flow features like turbulence intensity and shear stresses simultaneously, i.e. carry out a multi-objective optimization. If the results prove reliable, more case setups and other models will be investigated, using increasingly complex geometries and flow patterns. The intention is to develop a general procedure for tuning coefficients in turbulence models, and to explore and quantify the range of valid and useful coefficients across a range of basic canonical flows, thereby improving the quality of CFD solutions.

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