

Mitteilung

Fachgruppe: Numerische Aerodynamik

Experimental investigation and data-driven turbulence modeling for
flow separation and reattachment

C. Grabe*, T. Knopp, A. De Vincenzo, R. Geisler, M. Costantini, D. Schanz, A. Schröder.
DLR, Institute of Aerodynamics and Flow Technology, Bunsenstrasse 10,
D-37073 Göttingen, Germany

Introduction

The reliable prediction of turbulent boundary-layer separation and reattachment using the Reynolds-Averaged Navier-Stokes (RANS) equations is a long-standing area of research. No generally accepted solution has yet been established, however, the need for a solution for flows at high Reynolds numbers remains necessary from an aeronautical perspective and is therefore the subject of this work.

To evaluate the prediction quality of RANS turbulence models requires representative experimental data. This includes the measurement of relevant quantities on the surface (pressure, skin friction) as well as in the flow field (velocities, Reynolds stresses). While existing experimental data are widely used for validation, there is an unresolved anomaly between the prediction of flow over the backward-facing step (BFS, sudden geometry change) and backward-facing rounded steps (continuous geometry change). While flow reattachment is usually well predicted by standard RANS models for the BFS, they lack prediction accuracy for curved steps. To shed some light on this apparent contradiction, a new, parametric backward-facing ramp experiment was designed and measured in the course of the DLR-project ADaMant. The ramp geometry was selected over a rounded step because there is comparatively less reliable reference data. The details of this experiment, which comprises three ramp angles (25°, 45° and 90°), are given in [1]. This work shows first steps towards the comparison with numerical simulations using standard RANS models building on the evaluation of the measured data [2]. To improve RANS turbulence models for flow separation and reattachment, a data-driven approach was investigated based on the Field Inversion and Machine Learning (FIML) technique [3]. In this two-step approach, the RANS turbulence model is augmented by an extra term that is optimized using a gradient-based approach to yield the target distribution of a quantity of interest (e.g. the skin friction coefficient) for a certain testcase. In a second step this extra term, which initially depends on the coordinates of the testcase used for optimization, is then trained to depend on flow features, identified as relevant to predict the flow correctly. With the second step the augmented model is applicable to other testcases. In the current work, Field Inversion was performed for a curved step testcase and a BFS testcase optimizing an augmented Spalart-Almaras (SA) turbulence model. After investigating methods to identify relevant flow features, also known as feature engineering, the Machine Learning step was replaced by a turbulence modeling step to modify the SA-neg model.

Results

The first part covers the status of evaluation of the ADaMant ramp-family experiment. While the experiment covered three different ramp geometries at four different Reynolds numbers (based on the length of the flat plate upstream of the ramp, $Re = 1.2, 1.6, 2.2$ and 2.7×10^6) the numerical study focussed on the three geometries for one Reynolds number only ($Re = 1.6 \times 10^6$). For all three geometries, the pressure distributions are compared to the experimental data. Additionally, velocity profiles and qualitative flow features from the experiment and the numerical simulations are presented and discussed. The comparison of the pressure distribution for the 90° ramp and a fully-turbulent SA-neg simulation is depicted in figure 1.

In the second part the results from the data-driven turbulence modeling activity are presented, focussing on the results from the Field Inversion step, the different feature engineering approaches tested and the final modification of the SA-neg turbulence model for the cases investigated. Figure 2 shows the skin friction distribution of two training testcases used in this study, a Curved Step (CS) [4] and a Backward-Facing Step (BFS) [5], comparing the reference data

(LES data for the CS, experimental data for BFS), the simulation results obtained with the original SA-neg turbulence model and the modified SA-neg turbulence model. Besides classical quantities typically used as features in turbulence modeling, the work of Arun and Colonius [6] on the normality-based framework is also considered.

In the future, after full analysis of the ADaMant ramp experiment, it will be included into the training for the data-driven turbulence modeling approach in order to derive a modified turbulence model for reliable prediction of flow separation and reattachment.

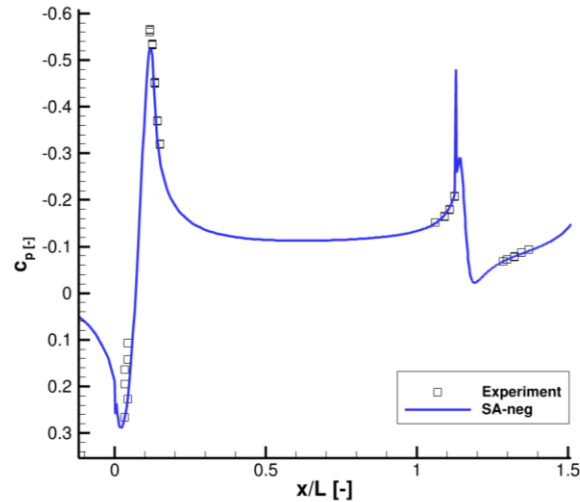


Figure 1. Comparison of pressure distribution: experimental data and RANS simulations using the SA-neg model (SA-neg) for the 90° ramp case and $Re = 1.6 \times 10^6$. L: Length of the flat plate, ramp positioned at $x/L = 1.24$

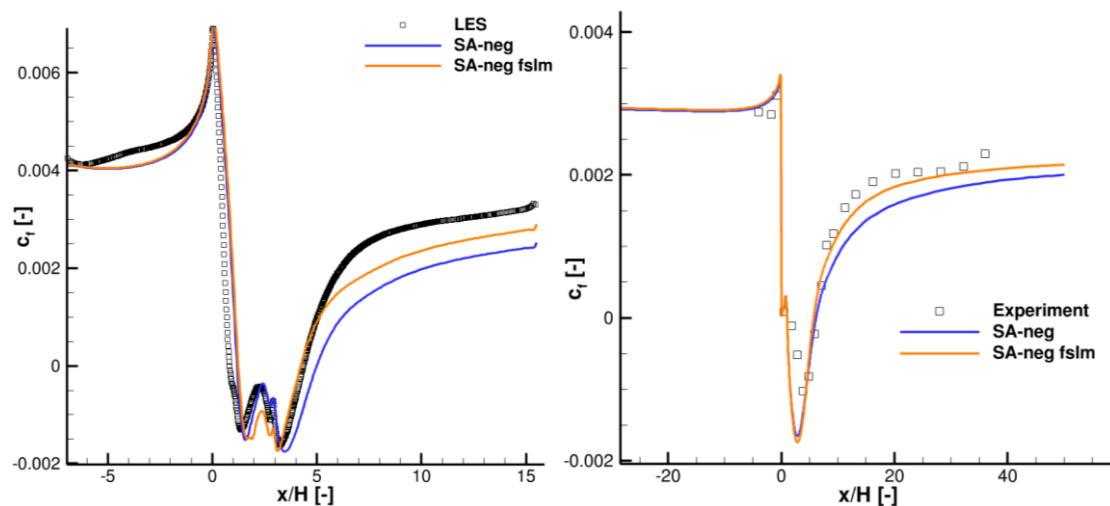


Figure 2. Skin-friction distribution for two training testcases, Curved Step (CS) on the left and Backward-Facing Step (BFS) on the right. Comparison between reference data, simulations using the original SA-neg turbulence model and the modified SA-neg turbulence model (fsIm: feature shear layer modification). H: Height of the step.

References

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