Mitteilung

Projektgruppe/Fachkreis: Numerische Simulation

Characterization of Off-Surface Separation Caused by Adverse Pressure Gradient in a Turbulent Wake

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Abstract

An important factor that can limit the performance of a multi-element high-lift system is the behavior of the turbulent wakes generated by the leading-edge device and the main wing when exposed to the adverse pressure gradient (APG) above the flap. The momentum deficit of the wakes represents a weak region of the flow where the APG can cause reversal flow. This mechanism is also known as off-surface separation and can lead to wing stall also without boundary-layer separation [1]. A number of studies have proved that numerical RANS predictions of such phenomenon are not accurate. For instance, the work carried out by Driver and Mateer [2] showed that the one-equation SA model and the two-equation k-ω SST model have the tendency to underpredict flow reversal of wake flows at APG. Tummers et al. [3] found out that the RANS misprediction is due, in part, to a deficiency in the transport equation for the dissipation ε, which is not sensitive to turbulence anisotropy and produces too high dissipation levels. Building on such findings, the present publication intends to characterize in more detail the behavior of turbulent wakes in adverse pressure gradient by means of high-fidelity scale-resolving numerical data (IDDES: Improved Delayed Detached Eddy Simulation) and ultimately identify the source of the inaccuracy that affects RANS solutions.

A physically founded improvement of RANS models based on existing experimental data does not seem possible due to the uncertainties of the flow conditions in the wind tunnel and the lack of detailed data, including the terms of the Reynolds stress balance. For these reasons, the present work is based on zonal IDDES of the Driver and Mateer experimental set-up [2]. The test case was designed to investigate the effects of adverse pressure gradients on the development of the turbulent wake of a flat plate. The flat plate generating the wake is located at the symmetry plane of a long straight tunnel section. Downstream of the plate trailing edge, a diffuser generates the adverse pressure gradient. In the experimental set-up, flow separation from the diffuser walls was avoided by employing tangentially blown jets. Numerically, the geometry is simplified by replacing the tunnel walls with two streamlines identified during the experiments (see Figure 1). The Mach number in the wind-tunnel was constant and equal to 0.175 and the Reynolds number based on plate length was 10^7.

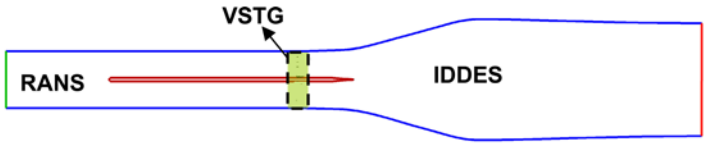

Fig. 1: Test case set-up by Driver and Mateer, as simulated by SPbPU.

The IDDES data employed to investigate the flow characteristics were provided by SPbPU within the framework of the joint German-Russian project "Wake Flows in Adverse Pressure Gradient" funded by DFG and RBRF (grants No. KN 888/3-1 and 17-58-12002)[4]. The zonal approach employed the SST RANS model until 100mm upstream of the plate trailing edge and a scale-resolving IDDES approach based on the same RANS model downstream. The Volume Synthetic Turbulence Generator (VSTG) approach was applied at the RANS-IDDES interface to accelerate the generation of resolved turbulent structures in the IDDES region and avoid the so called “grey-area problem”. The size of the numerical domain in span-wise direction was 0.03 meters (5 times the plate thickness) and span-wise periodicity was assumed. The computations were performed with the use of the incompressible branch of the SPbPU in-house code NTS. The resulting flow solution is shown in Figure 2, middle part.

In the first step of the analysis we assess the accuracy of different RANS models. In particular, expecting turbulence anisotropy to play an important role in determining the mean flow topology, the analysis focuses on Reynolds-Stress Models (RSM), namely the SSG/LRR-ω and three versions of the JHh-ε^h model. The comparison clearly shows the shortcomings of the current RANS modeling for such flow. The SSG/LRR-ω model tends to underpredict flow reversal whereas the JHh-ε^h models lead to a too large separation bubble (see Figure 2 top part, where only one JHh-ε^h model is reported). With all tested models, too high levels of turbulence dissipation rate ε are observed, in agreement with the findings of Tummers [3] (Figure 2, bottom part). The second step of the work is the characterization of the flow in order to identify the source of inaccuracy of the RANS solutions. As relevant flow parameters, the pressure gradient, deviation from equilibrium (production vs. dissipation of turbulent kinetic energy) and streamline curvature are subjected to close inspection. The effects of these quantities will then be correlated to the anisotropy of the Reynolds stresses and of the turbulent dissipation rate ε. Finally, the balance among the different terms of the Reynolds stress equations, the turbulent kinetic energy equation, and the ε equation will be considered to identify the dominant terms and their sensitivity to the relevant flow parameters.

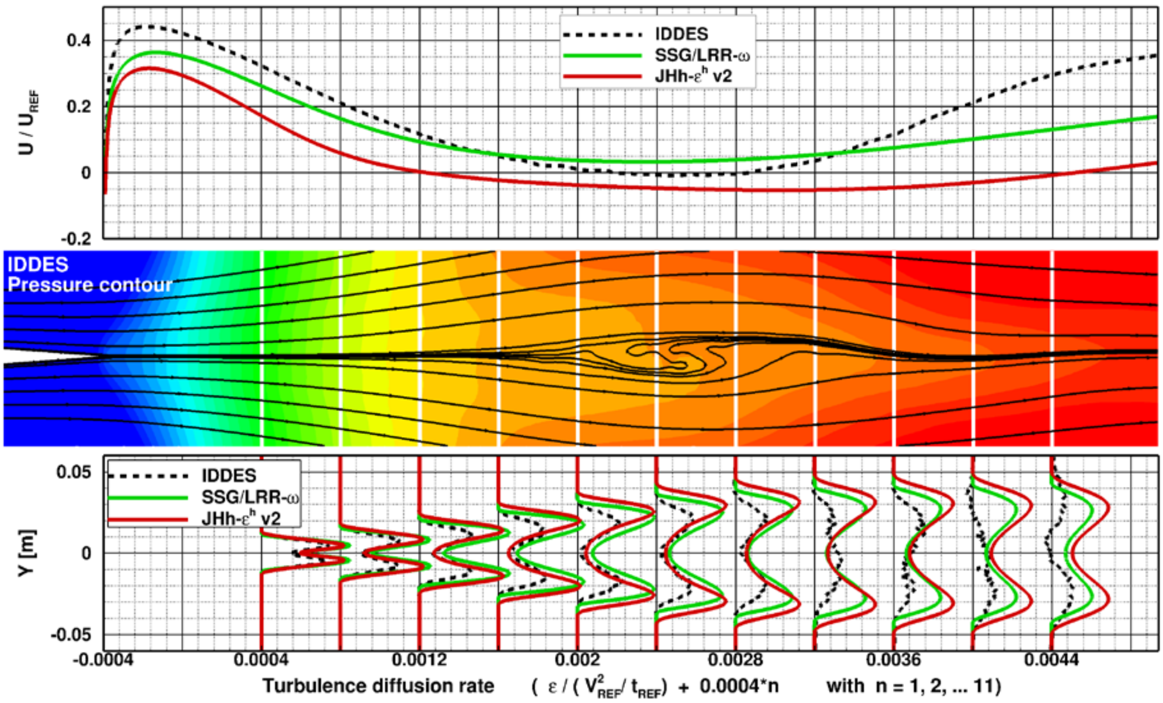

Fig. 2: TOP: Distribution of axial velocity along tunnel centerline.
MIDDLE: Pressure contour and streamlines from the IDDES solution field.
BOTTOM: Profiles of normalized turbulence dissipation rate along the wake.

Literature:

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