Mitteilung

Fachgruppe: Numerische Aerodynamik

Turbulence-resolving simulations of a coaxial jet based on Reynolds stress modelling

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Introduction

In the present work, the flow of a coaxial engine with an inner, heated core stream and a surrounding cold bypass stream is simulated at transonic flow conditions using a scale resolving simulation technique. The rotationally symmetric engine geometry has a central body and an industrially relevant short cowl engine exhaust design (cf. Fig. 1.). It originates from the CoJeN (Computation of Coaxial Jet Noise) project, funded by the European Union, which generated a database for coaxial jet flows. This database is used to benchmark our own results. Our work is funded by the German research organisation (DFG) and is part of the research unit FOR2895. One aim of the research unit is to simulate transonic flow about a transport aircraft configuration with an Ultra High Bypass Ratio engine and jet streams. We are particularly interested in whether and how an engine jet influences the dynamics of transonic shock fronts and whether it can trigger shock oscillations about the wing that are critical to flight safety (shock-buffet). As a preliminary step for the full aircraft-engine configuration with jet streams (for which no experimental data will be available), the present work is aimed to qualify and validate our method on a generic coaxial jet flow.

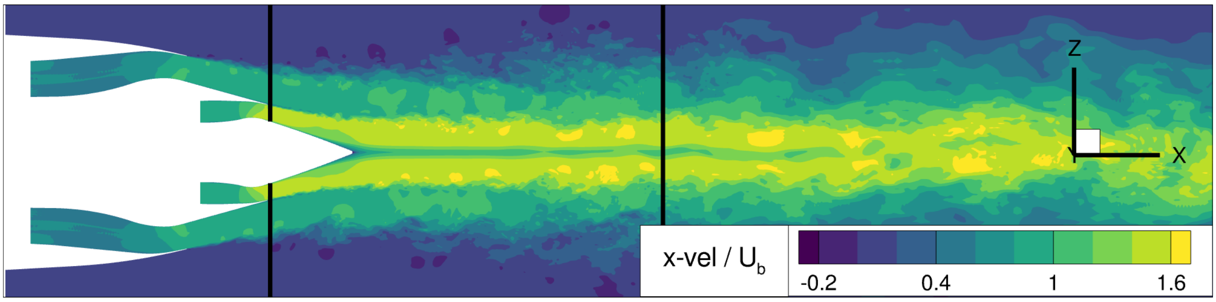

***Figure 1**: Slice with streamwise velocity snapshot from an RSM-IDDES simulation of the coaxial CoJeN jet. The velocity is normalized with the nozzle exit velocity of the bypass stream U_b. The black lines indicate the profile positions of Figure 2.*

The complexity of unsteady transonic flow phenomena around the target aircraft configuration (not part of this publication) requires a turbulence resolving simulation technique for preferably accurate numerical results. Since direct numerical simulation (DNS) and even large eddy simulations (LES) are computationally not manageable for the simulation of the entire configuration, we selected a more affordable hybrid RANS/LES technique which is based on the IDDES approach. Due to the complex corner regions at the engine-pylon as well as pylon wing intersections, a sophisticated RANS background model based on Reynolds stress modelling is employed [1]. This RSM-based IDDES has already been successfully applied to the same aircraft configuration with through flow nacelles [2]. In this work, the RSM-IDDES method is for the first time applied to a realistic engine flow with jet.

Proceeding and Results

As can be seen in Figure 1, the engine jets are prescribed within the engine at two annular boundaries. There, total pressures and total temperatures for the core and bypass jets are specified independently of each other. Furthermore, the turbulent intensity is also specified at the engine boundaries on the basis of experimental reference data. The latter is in contrast to other publications in this field, in which a definition of the boundary condition of the turbulent intensity is either not given or not calibrated with the aid of experimental reference data [3].

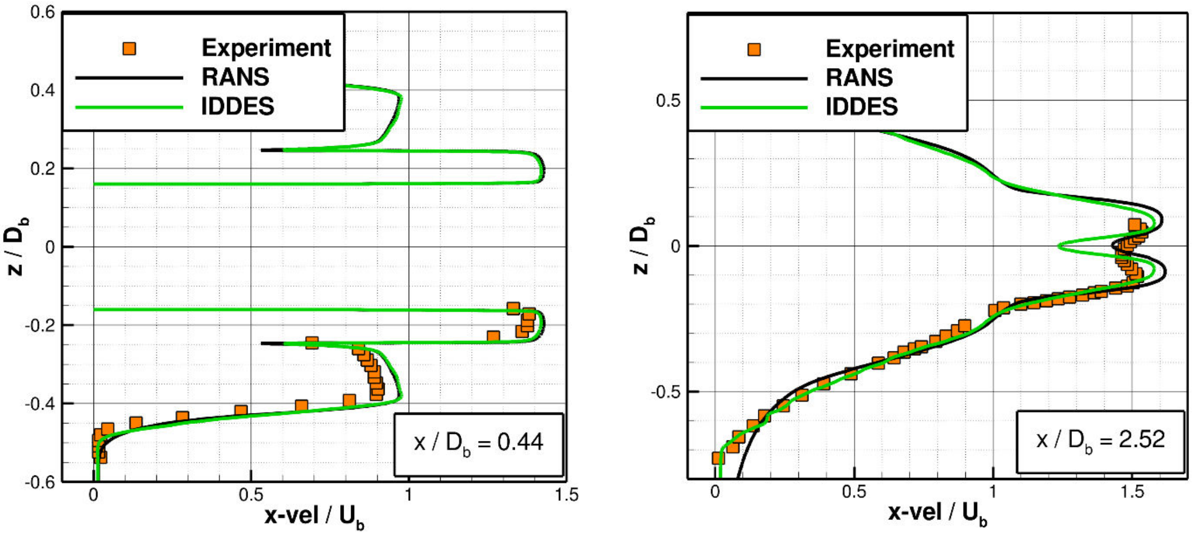

Figure 2: *Radial normalized x-velocity profiles of the jet at two different x – positions for a RSM - RANS and a temporal averaged RSM-IDDES solution with reference data [3].*

A hybrid mesh with 55 million points was constructed for the turbulence resolving simulations. Structured, highly resolved mesh regions are located in the vicinity of the engine as well as in the area of the jet flow, while an unstructured, coarse mesh is present in the far field. The local cell size is locally limited to 1/20 of the local geometric length scale (nozzle or jet diameter), which corresponds to the common LES meshing criterion for free shear flows. For the rotationally symmetric mesh, 450 points are used in circumferential direction, resulting into isotropic cells at the trailing edges of the engine and thus providing high resolution in these critical areas. Concerning the modes of the IDDES method, the DDES mode is active in the area of the engine close to the wall in such a way that the turbulent boundary layers are treated in RANS mode. Downstream of the trailing edges, the IDDES method automatically switches to LES mode. Starting from the trailing edges, the LES mode spreads out in a wedge shape in the direction of flow so that the entire flow is rapidly captured by LES.

Figure 2 presents radial velocity profiles at two positions in streamwise direction (see also Figure 1) of RSM - RANS and RSM - IDDES solutions. The early profile at $x\ /\ D_b\ = 0.44$ (D_b : bypass diameter) demonstrates very good agreements with experimental data [3] for both simulations. For a position further downstream, the agreements of both simulations are still acceptable. However, the IDDES simulation features a distinct drop in velocity in the wake region of the central body. In the final paper, it will be demonstrated that this drop can be attributed to a lack of turbulent mixing in the respective wake flow which can be avoided by the appropriate use of local, synthetic turbulence injection. Additionally, the publication will contain a detailed description and analysis of the different scale-resolving simulations and their sensitivities, providing velocity and Reynolds stress profiles and their comparison to experimental data at various positions.

References

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