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Effect of DDES and IDDES Modelling on the Simulation of Turbulent Flows for Aeroacoustics

Marc C. Jacob
ISAE – SupAero, DAEP
10, av. Edouard Belin, 31055 Toulouse
France

Björn Greschner / Frank Thiele
TU Berlin
Str. 17.Juni 135, 10623 Berlin
Germany

The main objective of the present investigation is the analysis of the modelling capabilities of shear layer and boundary layer flows by Improved Delayed Detached Eddy Simulation (IDDES [4]) and standard Delayed Detached Eddy Simulation (DDES [3]). There are significant differences in the boundary layer growth near the separation point whether the viscosity is resolved or not shortly after separation. This leads to significant differences in highly turbulent shear layer flows, such as airfoil wakes or separated flows downstream of blunt bodies. In particular, a strong impact on the prediction accuracy of the unsteady flow features and the aerodynamic sound generation is shown. The basic investigation of the IDDES and DDES is carried out on the NASA tandem cylinder benchmark case. In order to illustrate the advantages of IDDES for direct broadband noise simulations of complex flows, the technique is also applied to industrially relevant configurations such as a rotor-stator cascade.

The tandem cylinder flow has been studied in a series of experiments performed at NASA Langley Research Center [1,2]. It is a physically relevant test case for the noise generation due to turbulent structures that strongly interact with solid bodies. It can assess the capability of simulation codes and turbulence models to reproducing complex flow phenomena, such as shear layer rollup and massively unsteady flows including their noise radiation. The two cylinders, that are embedded in the potential core of a jet (Fig. 1), have identical diameters of $D = 0.05715$ m. The separation distance between the cylinders is 3.7D. The flow is at a Reynolds number $Re = 166000$, based on a free stream velocity of 44 m/s and the cylinder diameter. The corresponding Mach number is about $M = 0.1285$. Irrespective of the simple geometry the high Reynolds number tandem cylinder flow is a challenging task for CFD codes and turbulence models. One can observe a strongly accelerated and thin turbulent boundary layer on the upstream cylinder that separates shortly after the widest cross-section of the cylinder, as seen from the incoming flow. The shear layer rollup from both sides of the cylinder forms a periodic vortex shedding that is perturbed by small chaotic structures. The unsteady wake impinges on the downstream cylinder and generates a considerable amount of tonal and broadband noise. The IDDES shows small spanwise oriented vortical structures on the free shear layer directly after the separation. This feature is not reproduced by DDES computation, which predicts a much more stable shear layer. This yields a much larger recirculation area for the DDES with respect to the IDDES (Figs. 3 and 4) and the experiment. The reason is a strong reduction of the turbulent viscosity in the shear layer after the separation due to the early activation of the LES mode in the shear layer (Fig. 2). This becomes obvious in the time averaged plots of the turbulent viscosity for the DDES and IDDES in figures 3 and 4 and in the plot with the extracted profiles at the angular position of 115° (Fig. 2). All over the IDDES provides a more accurate picture of the unsteady separated flow (Fig. 5, left plot) and consequently a excellent far field sound estimate for frequencies above St=10 (black curve), provided the control surfaces for the Ffowcs-Williams Hawkings integral are well chosen (Fig. 5, right plot).

References

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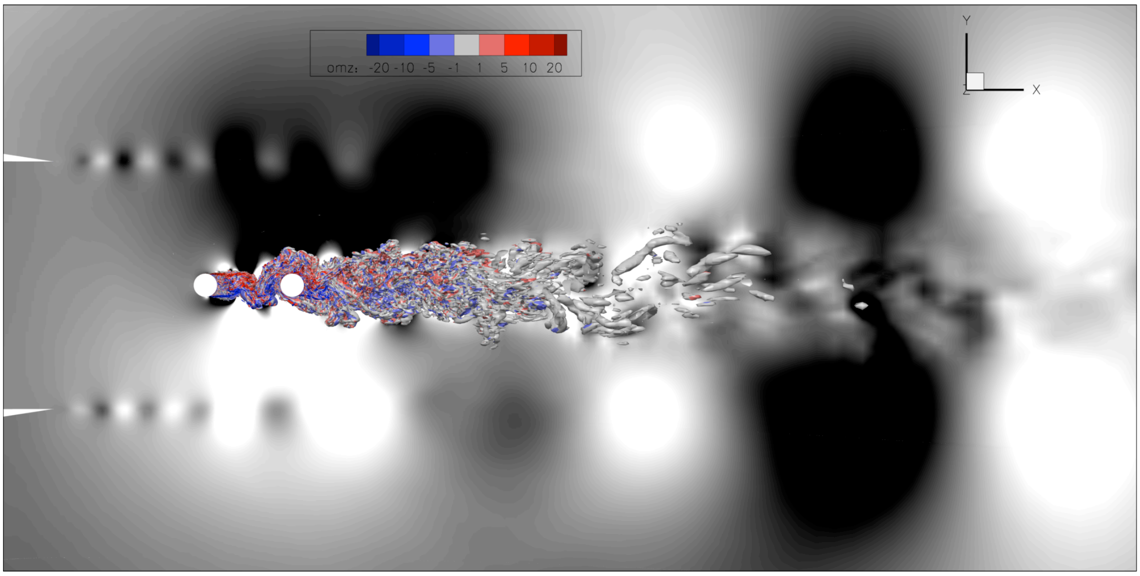

Figure 1: Overall view of the simulation domain showing the jet shear layers, cylinder wake eddies and pressure fluctuations as background colour.

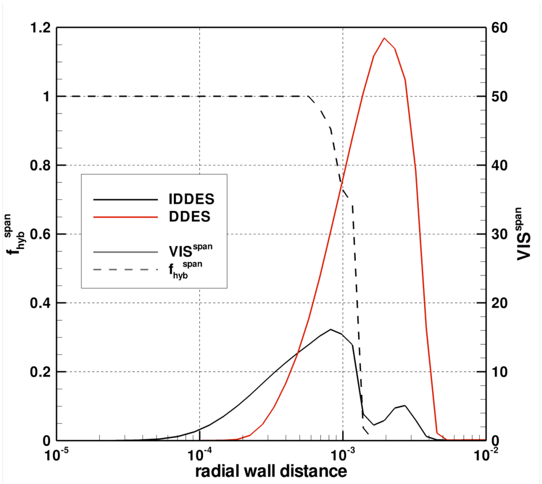

Figure 2: Comparison of shear layer viscosity ratio for upstream cylinder: line extracted at 115°, solid lines for viscosity ratio for IDDES (black) and DDES (red). Dashed black line shows blending function f_{hyb} for IDDES

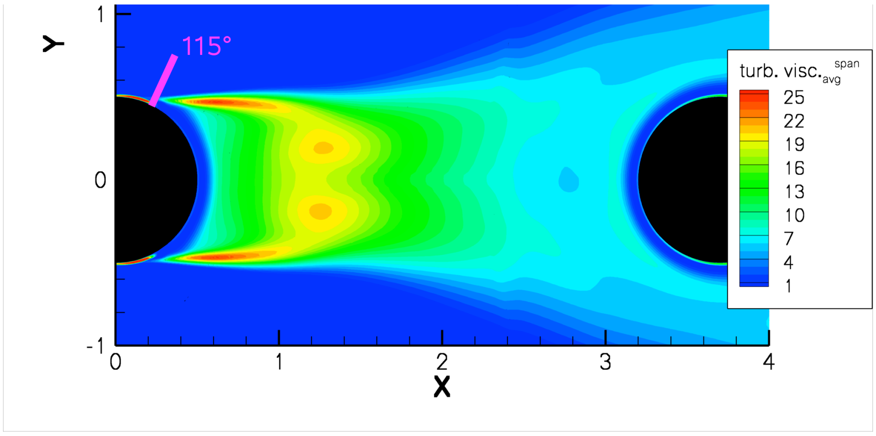

Figure 3: IDDES, time averaged turbulent viscosity. Position for line extraction at 115° is marked in purple.

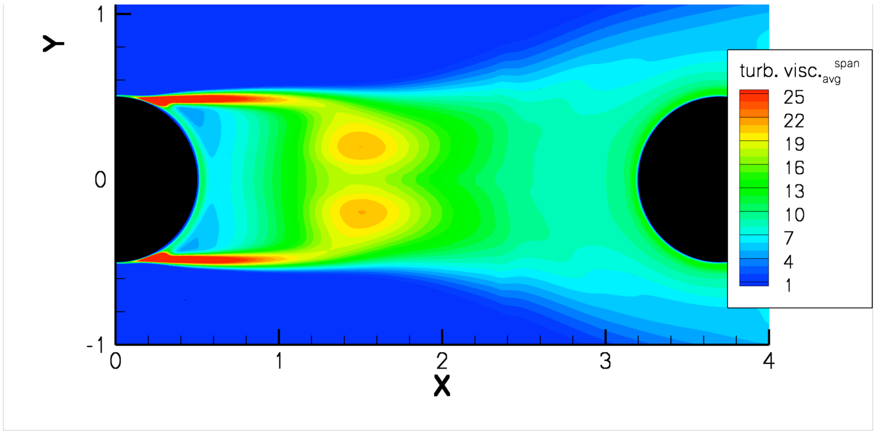

Figure 4: DDES, time averaged turbulent viscosity between cylinders.

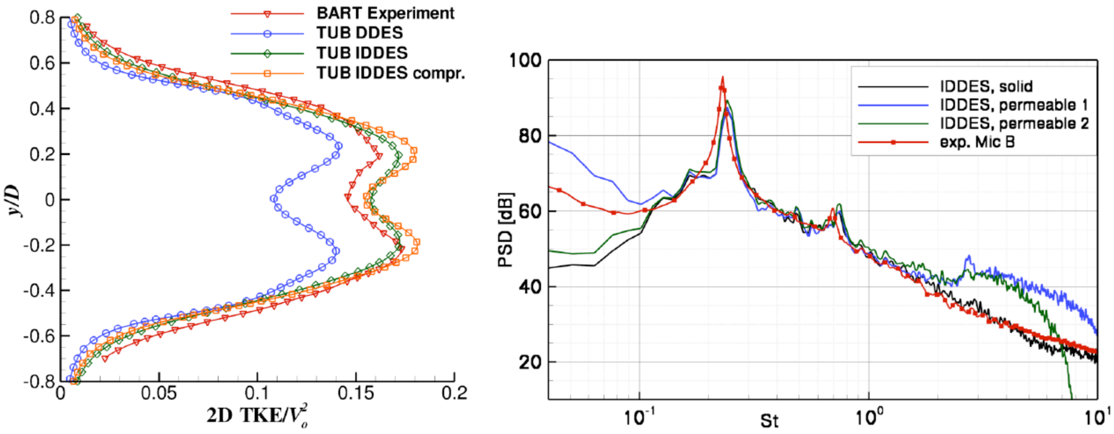

Figure 5. Left: Turbulent Kinetic Energy in the wake of the upstream cylinder; Right: Far field obtained from IDDES with various control surfaces for FWH computation.