Hybrid LBM/VLES: one method for industrial applications and fundamental studies

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The talk introduces the underlying theoretical elements of the Lattice-Boltzmann Method (LBM) hybridized with a Very Large Eddy Simulation (VLES) turbulence model implemented in the industrial CFD solver PowerFLOW [1-4].

A literature review is initially performed with examples of canonical flow solutions. Emphasis is given to the so-called grey area problem in shear layer flows. The same benchmark case used in the framework of the European project Go4Hybrid focused on Grey Area Mitigation for Hybrid RANS-LES Methods [5] is considered. This consists in a flat plate of 1 m length and 3 mm thickness, slanted towards 0.3 mm starting 50 mm upstream of the trailing edge, as in the experiments conducted by Delville [6]. The flat plate separates two streams of velocity 41.69 m/s and 22.51 m/s. Previous PowerFLOW simulations reported in [7] were performed by using a thicker trailing edge (2 mm instead of 0.3 mm). The local vortex shedding was the “triggering” mechanism resolving the grey-area problem associated with an overestimation of the unresolved eddy viscosity. Two shear layer characteristic quantities are plotted in Fig. (1): the vorticity and the momentum thickness. Overall, the agreement with experimental data is satisfying. New results are presented for the same case showing the impact of modelling parameters.

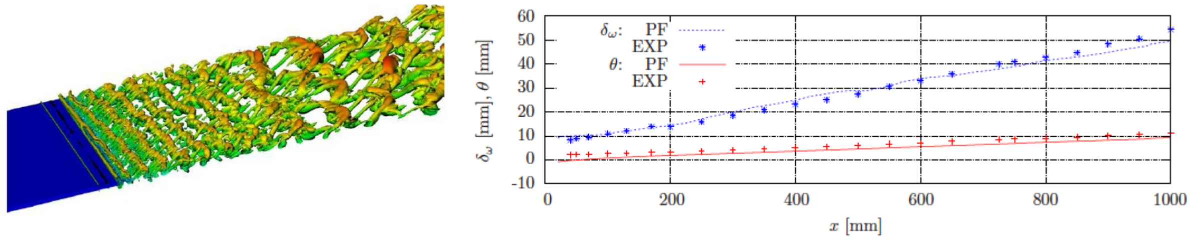

Figure 1: PowerFLOW simulation of shear layer mixing problem from Ref. [7]. On the left iso-λ_2 surfaces and on the right vorticity and momentum thickness downstream the trailing edge.

The second part of the talk is focused on the solution of problems of practical relevance for which hybrid models provides a clear advantage on Reynolds-Averaged models in terms of fidelity and on LES models in terms of computational performances. Benchmark aeroacoustic studies of aero-engine fan and jet noise are discussed. A subset of results for a fan-noise benchmark study [8,9] are reported in this abstract. Three Outlet Guide Vane (OGV) configurations of the NASA Source Diagnostic Test (SDT) have been considered at different operating condition characterized by both subsonic and supersonic tip velocities. The three stage geometries are shown in Fig. (2).

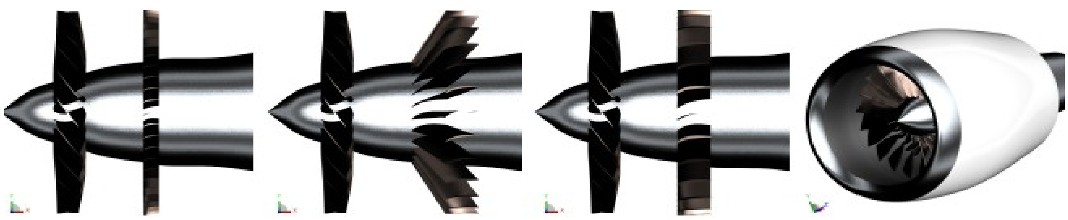

Figure 2: NASA SDT fan stage configurations. From left to right, baseline, low-noise and low-count OGV, and nacelle.

Figure (3) shows fine-scale resolved turbulent structures in the wake of the rotor for the approach case, and shock structures on the suction side of the fan for the sideline case.

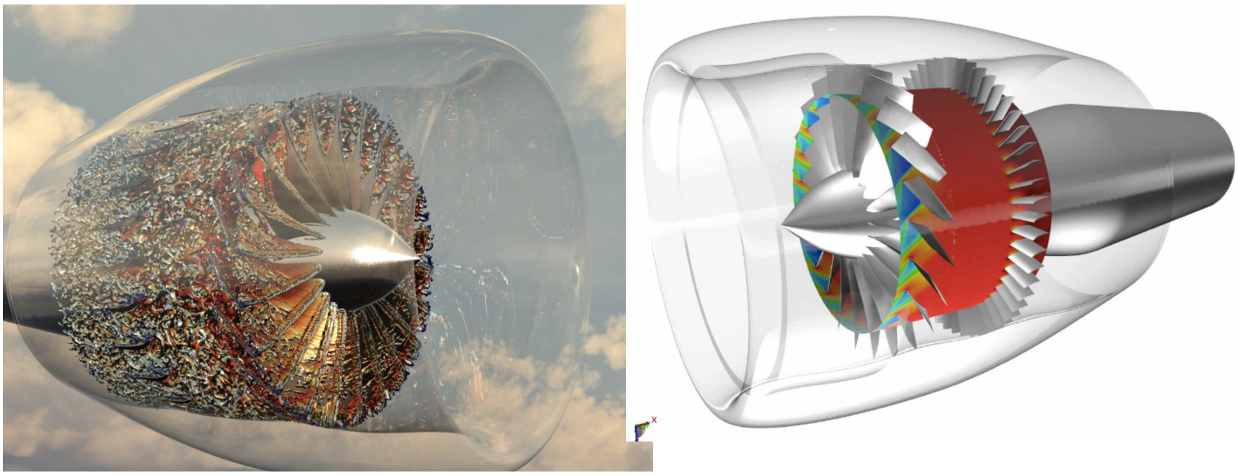

Figure 3: PowerFLOW prediction of turbulent flow structures in the NASA SDT engine at approach conditions (left) and shock structures at take-off conditions (right).

Figure (4) shows comparisons between measured and predicted stage performances for the three operating conditions and the baseline OGV. For all configurations and for the three conditions, the mass flow rate is predicted within an error of 1%, whereas the total pressure ratio across the full stage is predicted within an error of 0.4%. Figure (5) shows comparisons between LDV measurements and simulation results at inter-stage station #1 for the baseline configuration and approach conditions. Measurements are not available at sideline conditions due to limitations of the experimental hardware to measure high-speed unsteady flows. The axial and radial components of the phase-locked average velocity and the corresponding standard-deviation (SDV) values are plotted on an angular sector covering one rotor blade passage. The average field is fairly well predicted, whereas the SDV levels exhibit an overestimation close to the casing, and some lack of statistical convergence (averages performed over 10 rotor revolutions only instead of 120 for the experiments).

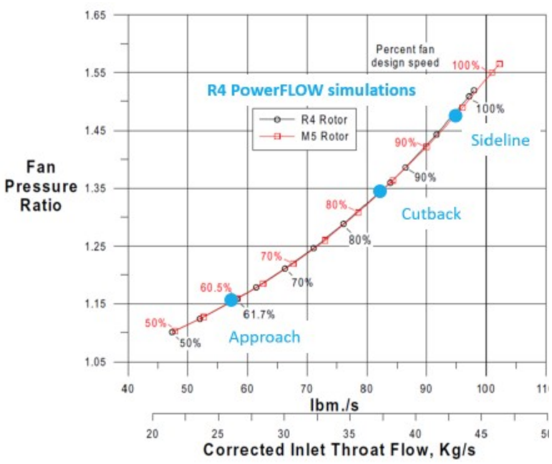

Figure 4: Measured and predicted fan stage performances for the baseline configuration (R4 rotor).

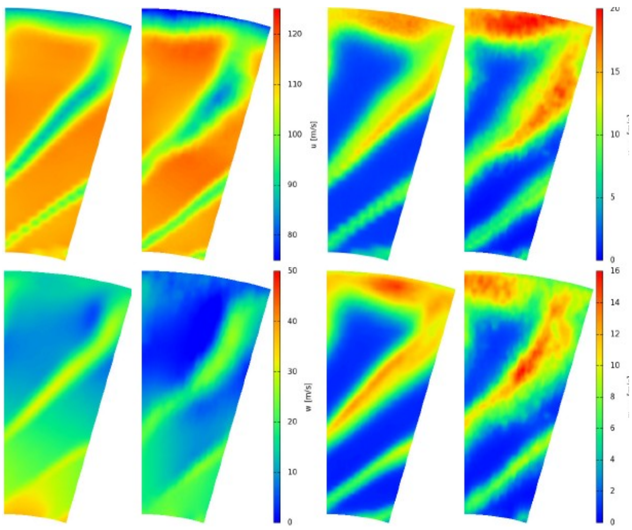

Figure 5: Phase-locked average (left block) and SDV velocity (right block) at station #1 for the baseline OGV [m/s]. Axial (top) and radial velocity (bottom). Measurements on the left, simulations on the right.

Figure (6) shows the Overall Sound Pressure Level (OASPL) measured and predicted along a sideline linear array and the reconstructed power level (PWL). Results are presented as differences (Δ dB) between the three OGVs. The relative numerical error is in the order of 1 dB, which is lower than the experimental uncertainty of $\pm$ 1 dB. Finally, Fig. (7) shows differences of PWL for the three OGVs and sideline conditions.

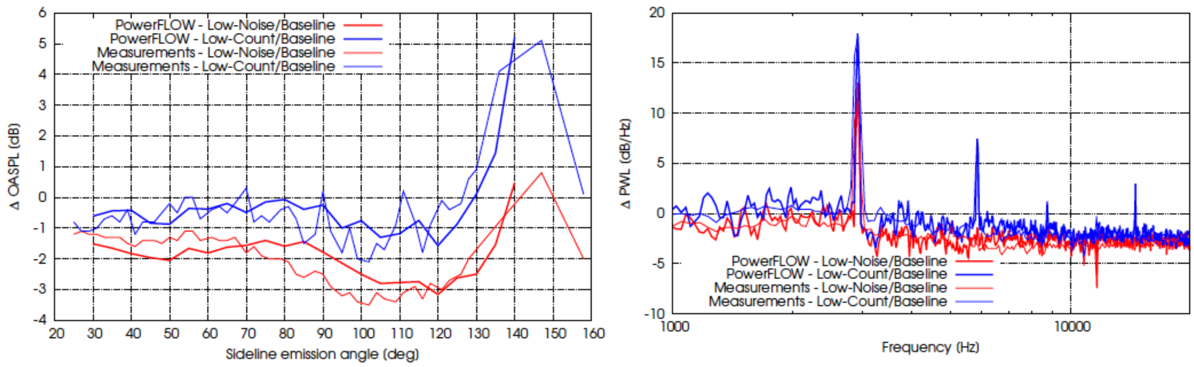

Figure 6: Relative noise levels at approach conditions. OASPL (left) and PWL (right).

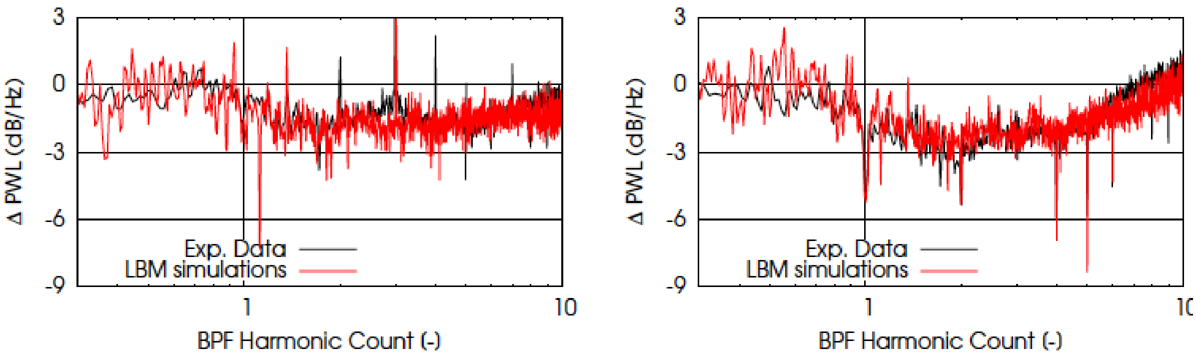

Figure 6: Relative PWL at sideline conditions. Low-Count/Baseline (left) and Low-Noise/Baseline (right).

The last part of the talk will highlight very recent results of low-Reynolds airfoil and propeller simulations with a focus on the simulation of transitional flow.

References

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