Compressible Large Eddy Simulation of UHBR Jet Installation Noise using Octree-Cartesian Grids: Wind Tunnel vs. Free Flying Aircraft Comparison

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Introduction

In recent decades, the successive increase in the bypass ratio (BR) of jet engines has been a guarantee for a continuous improvement in fuel efficiency as well as being one of the main drivers for a continuous reduction in noise emissions from transport aircraft during the take-off phase. However, for a given thrust, an increased bypass ratio inevitably requires an increased fan and engine diameter. Limited clearance to the ground already imposed some constraints on the integration of the present generation of BR≈12 engines of the A320neo and the Boeing 737MAX. For the planned next generation of ultra-high bypass ratio (UHBR) engines with BR>16 it becomes even harder to accomplish the low-wing integration. Specifically, the jet engine has to be mounted in very close proximity to the wing so that the bypass jet will interact with the deployed flap of the high-lift wing, which is known to cause a significant additional jet installation noise source characterized by a distinct broadband hump in the radiated noise spectrum towards the ground. Model scale experiments are a crucial element in the analysis of jet installation noise problems. However, experimental studies with jet simulators are costly and require in detail specific modifications of the full-scale geometry so that industry aims at extending the use of first-principles based scale resolving simulations of jet installation noise to bridge the gap between the wind tunnel setup and a realistic free flying aircraft. Specifically, the DJINN wind tunnel model operates at lower lift coefficient as being present at the aircraft during take-off and the aircraft slat is not included in the wind tunnel setup.

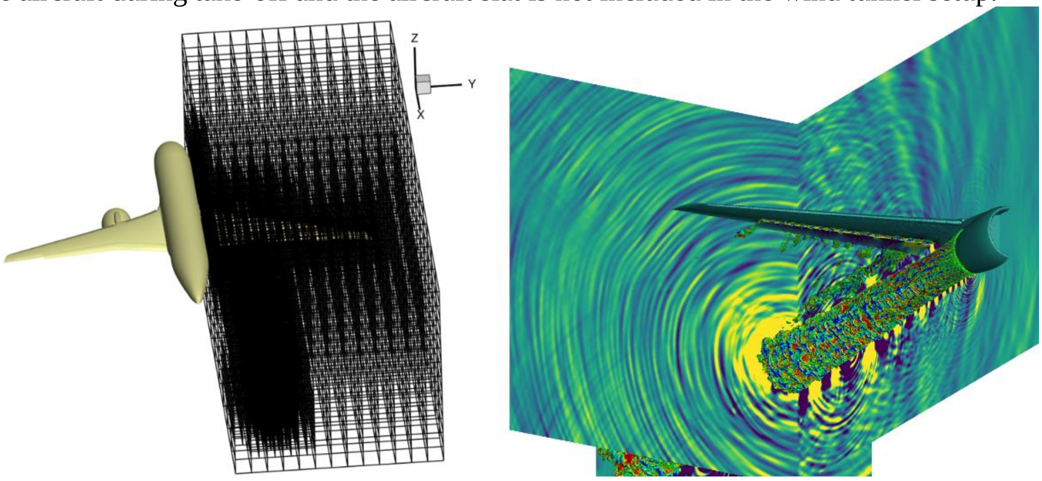

Fig. 1 PIANO-IBM St=3 grid of platform 1 real A/C, 8410 blocks, 380M points, 3 levels (left); pressure fluctuations (right)

The European DJINN project aims at pushing the limits of scale resolving simulation with regards to the resolved geometrical fidelity of the considered configurations as well as in terms of the spectral resolution limits from a Strouhal number based on the bypass jet velocity and bypass nozzle diameter of Sr≈3 towards Sr≈10.
Furthermore, the resolution of complex geometrical features of the high-lift wing in scale resolving simulation is pushed forward, including the engine pylon and a high-lift wing with differential flap setting, flap gaps and deployed slats. Furthermore, the inclusion of noise reduction measures on the aircraft and engine side requires their proper geometrical representation. This work report about results obtained with scale resolving simulation involving octree-cartesian grids that allow to mesh the complexity of the complex geometry with very small grid generation overhead.

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Numerical Method and Simulations

The compressible Navier-Stokes equations are solved using a 4th-order finite difference method based on the dispersion relation preserving (DRP) scheme proposed by Tam & Webb. The PIANO-IBM code is applied that utilizes a block structured octree-cartesian grid with binary coarsening/refining between adjacent blocks. The surface geometry is included using an immersed boundary method (IBM) based on a STL-representation of the surface geometry. A zonal large-eddy simulation is realized by solving the Navier-Stokes equations in non-linear disturbance equation (NLDE) formulation. Hereby, the independent primitive variables are split into an ensemble averaged steady mean-flow part and fluctuations. As the steady mean-flow part does not contribute to the partial time derivatives, the decomposition provides the set of equations that governs time evolution of fluctuations.

The steady mean-flow part was taken from a predecessor RANS simulation using the DLR TAU code with unstructured CENTAUR meshes with hexahedral elements and $n+=O(1)$ resolution at the walls. For the subsequent scale resolving simulation of aeroacoustics, octree-grids with the mean-flow interpolated from the RANS grid are used. The geometry is resolved with different resolution levels with highest resolution in the jet and close to the surface. The far-field resolution is sufficient to maintain acoustic propagation up to Sr=3. With the current methods, also cells with elongated aspect ratio can be used for a better resolution at the surface. For the aircraft, a normalized resolution based on the jet diameter yields $\Delta x=0.02688$ and $R\Delta\varphi=0.0111$ at the nozzle exit. For the wind tunnel set up the corresponding parameters are $\Delta x=R\Delta\varphi=0.0075$.

Wall modelling is applied at all walls as the octree-cartesian grids do not allow to properly capture the viscous sublayers at the wall. In the NLDE framework, the wall model is reformulated for the fluctuating part only by means of a no-slip condition with modified near wall eddy viscosity informed by the mean-flow RANS solution. As such, the wall model accounts for non-equilibrium effects as prescribed by RANS. In the current work, a zonal LES is accomplished by limiting the scale resolving simulation just to the jet. The onset of turbulence at the surface is suppressed by switching off the near-wall eddy viscosity in the wall-model. Jet turbulence is triggered by applying stochastic forcing at the jet nozzle exit. An implicit subgrid scale model is applied to prevent energy pileup at higher resolved wavenumbers using a high-order upwind scheme as proposed by Kuwahara with some mild levels of upwinding applied inside the jet, akin to the approach discussed by Shur et al. Outside the jet only spatial filtering is applied. The large surface spacing allowed in the wall model enables the use of a fourth order explicit Runge-Kutta for time integration, which due to its inherent small dissipation together with the spectral properties of the numerical scheme supports sound propagation with minor dissipation over the entire computational grid, refer to **Fig. 1**.

Simulations are carried out for the wind tunnel model (**Fig. 2**) and a representative aircraft as being studied as platform 1 cases in DJINN (**Fig. 1**). The RANS mean-flow simulation of the aircraft assumes free flight conditions and the wind tunnel simulations includes the entire wind tunnel with installed model including the nozzle and collector. The domain of the zonal LES therefore can be restricted to include only half of the aircraft and part of the wind tunnel model as all flow effects on larger scales are fully accounted for by the background flow fields.

Typically, octree cartesian grids require more computational grid points than necessary as, e.g., compared to a structured multi-block grid. However, the topology is very suitable for massive parallel simulation on state-of-the-art high-performance architectures and short turnaround times can be achieved thus. For the present simulations 4207 processors have been used on the DLR CARA cluster for the aircraft and 5167 processors for the wind tunnel model. Acoustic propagation to the far-field is accomplished using an STL-based FW-H surface that encloses the jet and the high-lift wing. Details of the simulations will be reported at the workshop.

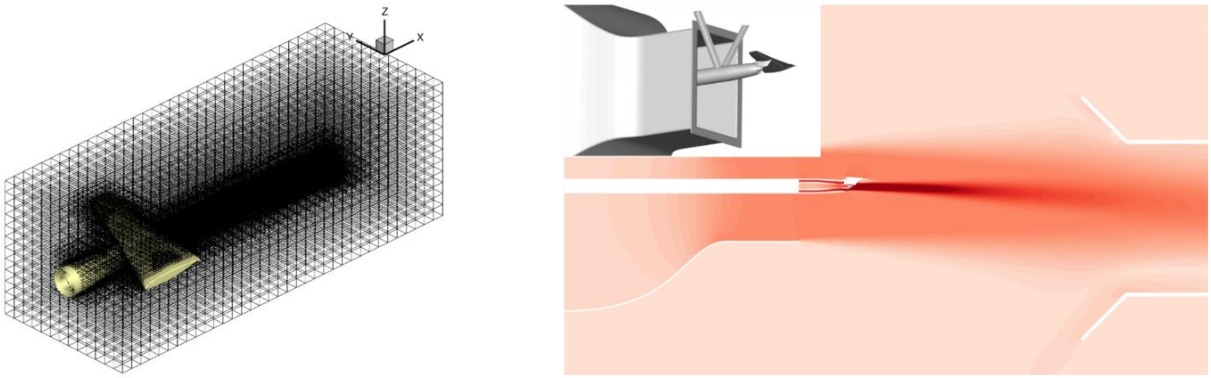

Fig. 2 PIANO-IBM St=3 wind tunnel model, 20658 blocks, 251M points, 3 levels (left); RANS simulation (right)