Aeroacoustics of New Aircraft Engine/Fuselage Integration Concepts

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The ever increasing use of small propeller-driven Unmanned Aerial Vehicles (UAVs) for commercial, scientific or recreational applications in close proximity to urban areas, as well as the emergent aviation market of propeller-driven Personal Aerial Vehicles (PAVs) for on-demand aviation services, has recently renewed the interest in fully understanding, predicting and reducing the noise generated and radiated by this type of aircrafts during an arbitrary unsteady maneuver. The noise generated by the propellers themselves is widely recognized as the major limitation of UAVs/PAVs operation in populated areas, and its accurate prediction represents a critical issue for the development of low-noise procedures, such as the identification of low-noise optimal trajectories aimed to reduce the on-the-ground acoustic impact. These procedures usually make use of methodologies that combine an aero-mechanical model, a near-field noise model and a far-field noise propagation model for the evaluation of the on-the-ground acoustic impact. In general, the identification of low-noise trajectories might correspond to unsteady maneuvers which require to update the near-field acoustic source model accordingly to the change of the flight conditions. In order to avoid computationally expensive aeroacoustic simulations, this is typically achieved by extracting the near-field model (provided in terms of acoustic hemisphere map rigidly connected to the aircraft) from a Noise Hemisphere Database (NHD) generated through off-line aeroacoustic simulations of rectilinear steady-state flights associated with a number of points within a given domain of flight parameters, suitable to ensure the instantaneous noise emitted equivalence between the maneuver and the steady-state flight [1]. In addition, the extraction of the noise hemispheres from the NHD during the unsteady maneuvers requires the evaluation of a certain number of flight dynamic parameters from a UAVs/PAVs aero-mechanical model. Since UAVs/PAVs deal with high unsteady flight conditions, the former aero-mechanical models have to be able to take into account non-linear and unsteady flow effects with a satisfactory level of accuracy. To this aim, in the past decade several efforts have been made to formulate techniques that predict aerodynamic responses using Computational Fluid Dynamics (CFD) [2].

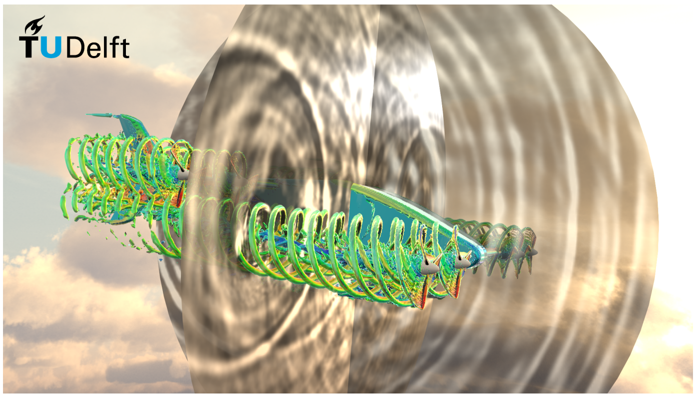

Figure 1: Dilatation field and turbulent structures around a Airbus Vahana-like PAV from LBM-VLES simulation.

In the light of the above, the overall objective of this research project is to show how high-fidelity Lattice-Boltzmann Very Large Eddy Simulations (LBM-VLES) can be efficiently used to fully characterize the aero-mechanical and aeroacoustic behavior of UAVs/PAVs for the on-the-ground noise footprint prediction and this constitutes the original contribution of the present research. More specifically, the goal of the present research project is three-fold and deals with the development, by means transient and compressible LBM-based simulation, of: (i) an accurate and reliable computational aeroacoustic approach to evaluate primary sources of noise on propeller-driven UAV/PAV platforms, with a particular emphasis on Blade-Vortex Interaction (BVI) and Turbulent Boundary Layer Trailing-Edge (TBL-TE) noise; (ii) a Reduced-Order Model (ROM) for the evaluation of the unsteady and non-linear aerodynamics for the aero-meachanical modeling of UAV/PAV platforms; (iii) a framework which integrates the above mentioned UAV/PAV aero-mechanical model with a noise hemisphere database and a far-field noise propagation model for noise footprint prediction and trajectory optimization purposes. The necessity to accurately capture the near-field noise propagation (from the source region up to the hemisphere surface rigidly connected to the aircraft, for the NHD generation) and to accurately predict the flow unsteadiness and non-linearities (for a reliable ROM aerodynamic database generation) are requirements that can take respectively advantage of the intrinsic low-dissipation/dispersion properties and of turbulence modeling properties of the LBM-VLES scheme compared to conventional CFD approaches, while keeping the computational cost affordable against a satisfactory level of accuracy.

References

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[2] Ghoreyshi, M., Jirsek, A., and Cummings, R. M., "Reduced Order Unsteady Aerodynamic Modeling for Stability and Control Analysis Using Computational Fluid Dynamics". Progress in Aerospace Sciences, 71, 167–217, (2014).