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Influence of boundary layer tripping on the flow and sound field produced by a turbulent jet

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Jet noise has remained the dominant source of aircraft noise during take-off since jetliners were introduced over half a century ago [4]. A better understanding of the underlying mechanisms that generate jet noise is therefore needed in order to develop quieter aero-engines, and thereby minimize noise pollution around airports.

In this work, we will investigate how the state of the boundary layer (laminar vs turbulent) inside the nozzle affects the flow and sound field produced by a turbulent jet. Historically, this influence has only been possible to study experimentally, owing to the large computational cost associated with Large Eddy Simulations (LES) of turbulent boundary layers. With recent advancements in high performance computing, however, this topic is now possible to study numerically as well.

In recent years, several studies have demonstrated that additional noise is produced when the boundary layer exiting the nozzle is in a laminar state [1, 2]. In order to obtain accurate LES simulations of high Reynolds number jets, it is therefore important to ensure that the boundary layer is in a turbulent state. Often, a tripping device placed close to the nozzle exit is used for this purpose. For jet noise, several different approaches have been used to trip the boundary layer. These include, but are not limited to, the use of roughness elements along the wall [5] and injection of isotropic turbulence [2]. A good tripping device produces realistic turbulence levels at the outlet of the nozzle, without negatively affecting the far-field acoustic signature of the jet.

The goal of this work is to apply boundary layer tripping to a recent simulation of a subsonic jet, see Fig. 1. The simulations will be performed with the compressible flow solver available in the spectral/hp element framework Nektar++ (www.nektar.info) [3, 6]. The compressible flow solver in Nektar++ uses the high-order discontinuous Galerkin (DG) method to solve the Navier-Stokes equations on unstructured grids. The account for unresolved turbulent scales, an implicit LES (iLES) approach is used. In this approach, the favourable dissipation properties of the DG discretization are used to remove marginally resolved wavenumbers from the solution. The jet under consideration operates at an acoustic Mach number of $M = 0.6$, and diameter-based Reynolds number of $Re = 5.5 \cdot 10^5$. For validation, extensive experimental data obtained in the DOAK laboratory, located at the University of Southampton, is available [7].

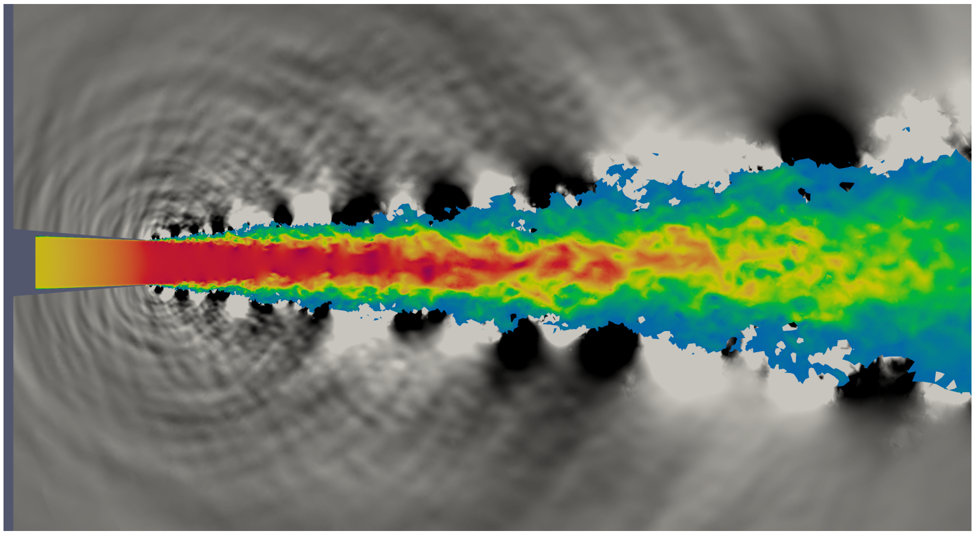

Figure 1: Illustration of the turbulent jet studied in this work. The turbulent flow is illustrated by Mach number contours, and the acoustic field by normalized pressure fluctuations.

References

[1] C. Bogey, O. Marsden, and C. Bailly. "Influence of initial turbulence level on the flow and sound fields of a subsonic jet at a diameter-based Reynolds number of 10^5". In: *Journal of Fluid Mechanics* 701 (June 2012), pp. 352–385. DOI: 10.1017/jfm.2012.162.

[2] G. A. Brès et al. "Importance of the nozzle-exit boundary-layer state in subsonic turbulent jets". In: *Journal of Fluid Mechanics* 851 (Sept. 2018), pp. 83–124. DOI: 10.1017/jfm.2018.476.

[3] C. Cantwell et al. "Nektar++: An open-source spectral/hp element framework". In: *Computer Physics Communications* 192 (July 2015), pp. 205–219. DOI: 10.1016/j.cpc.2015.02.008.

[4] E. Envia. "Noise emissions from commercial aircraft". In: *Green Aviation: Reduction of Environmental Impact Through Aircraft Technology and Alternative Fuels*. Ed. by E. S. Nelson and D. R. Reddy. 1st ed. Leiden, The Netherlands: CRC Press, 2017. DOI: 10.1201/b20287.

[5] F. Gand and M. Huet. "On the generation of turbulent inflow for hybrid RANS/LES jet flow simulations". In: *Computers and Fluids* 216 (Feb. 2021). DOI: 10.1016/j.compfluid.2020.104816.

[6] D. Moxey et al. "Nektar++: Enhancing the capability and application of high-fidelity spectral/hp element methods". In: *Computer Physics Communications* 249 (Apr. 2020). DOI: 10.1016/j.cpc.2019.107110.

[7] A. Proença, J. Lawrence, and R. Self. "Experimental Investigation into the Turbulence Flow Field of In-Flight Round Jets". In: *AIAA Journal* 58.8 (Aug. 2020), pp. 1–11. DOI: 10.2514/1.J059035.