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# Assessment of Grey-Area Mitigation Techniques and their effects on Jet Aerodynamics and AeroAcoustics

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## 1. Abstract

The standard method employed by the Computational AeroAcoustics (CAA) community involves splitting hydrodynamics and acoustics using two different solvers. The acoustic solver requires as inputs some hydrodynamic variable values that are obtained from solving the Navier-Stokes equations numerically. Consequently, acoustics will not be computed correctly if turbulence or hydrodynamics are not accurately resolved. In this research, we put focus on two main factors that impact the accuracy of the numerical solution utilized by the acoustic solver. These factors include, among all the ones that compose a numerical simulation, the order of numerical discretization of the convective operator and the turbulence model.

Regarding the first issue, as higher-accuracy numerical solutions are preferred by the acoustic solver, high-order schemes are in great demand. Shur et al. [1, 2] and Bogey [3] have simulated subsonic round jets using high-order schemes on structured meshes. However, using such meshes can be challenging when simulating more complex geometries, which are common in industrial problems. A possible alternative is the use of 2nd order low-dissipative schemes, in exchange for requiring finer meshes. Tyacke et al. [4], Fuchs et al. [5], and more recently, Duben et al. [6] have utilized 2nd order schemes in the simulation of transonic turbulent jets. Finally, another alternative is to use 2nd order schemes with extended stencils, i.e., high-accuracy schemes. Duben and Kozubskaya [7] and Duben et al. [6] have employed such schemes in the simulation of transonic turbulent jets.

The second issue concerns turbulence modelling. Specifically, we will be focusing on the family of hybrid RANS-LES models due to their excellent balance between accuracy and computational cost. And more precisely, we restrict this study only to non-zonal DES models. One of the current lines of investigation within non-zonal DES is mitigating the grey-area problem in shear-layer flows, which causes non-physical oscillations that render the results invalid. The Grey-Area Mitigation (GAM) techniques commonly use a special subgrid length scale sensitive to the local parameters of the flow, such as $\Delta_{SLA}$ [8], $\tilde{\Delta}_{\omega}$ [9], or $\Delta_{lsq}$ [10], in conjunction with an LES model sensitive to two-dimensional flow patterns, such as $\sigma$, WALE [11], or S3QR [12].

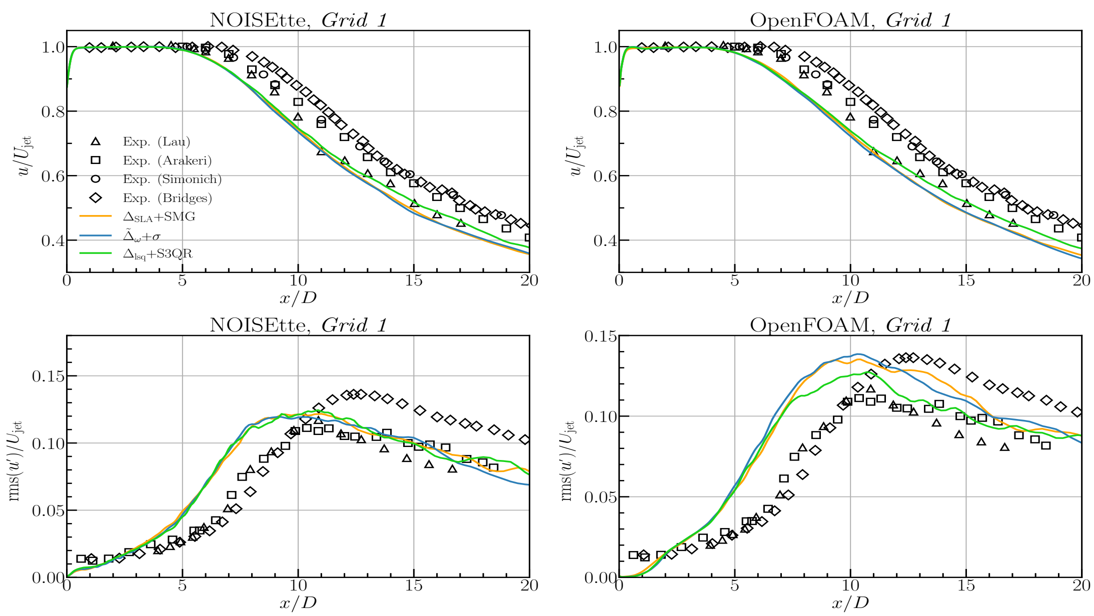


Figure 1: Centerline distributions of the streamwise velocity (top) and its pulsations (bottom) obtained using NOISEtte (left) and OpenFOAM (right) on a set of refining meshes (from left to right). Coarsest considered mesh.

This study investigates an immersed jet emerging from a conical nozzle with a Mach number of $M = 0.9$ and a Reynolds number based on the diameter of $Re_D = 1.1 \cdot 10^6$. To assess the impact of numerical scheme accuracy, two different codes were utilized: NOISEtte [13], which employs high-accuracy schemes with extended stencils, and OpenFOAM, an open-source simulation software that uses low-order schemes. Additionally, the energy budget of the different terms in the Navier-Stokes equations will be computed in order to further highlight the differences between the used schemes. Regarding turbulence modelling, three different Grey-Area Mitigation (GAM) techniques were used to study the effect of the RANS-to-LES transition. These GAM strategies involved using combinations of $\Delta_{SLA}$ with the Smagorinsky model, $\tilde{\Delta}_{\omega}$ with the $\sigma$ model, and $\Delta_{lsq}$ with the S3QR model. The present work also examines the effect of mesh on hydrodynamic and acoustic results, using three different hexahedral refining meshes ranging from 1.5 to 8.8 Million Control Volumes. Some details of the used meshes are included in Table 1. The hydrodynamic results in the centerline are shown in Figure 1, while Figure 2 displays the acoustic results in the coarsest considered mesh.

Table 1: Meshes parameters

| Parameter | G1 | G2 | G3 |
|---|---|---|---|
| $N_n$ | 1.52M | 4.13M | 8.87M |
| $N_\varphi$ | 64 | 80 | 160 |
| $\Delta_x/D$ at the nozzle exit | 0.011 | 0.008 | 0.008 |
| $\min(\Delta_r/D)$ in the shear layer | 0.003 | 0.0025 | 0.0025 |
| $r\Delta_\varphi/D$ in the shear layer | 0.05 | 0.04 | 0.02 |

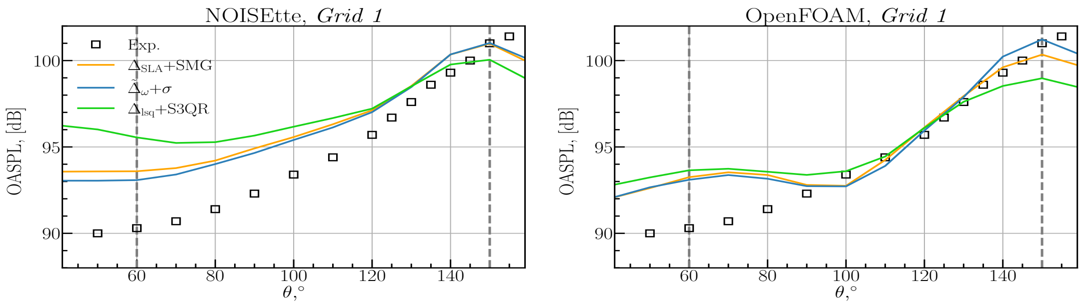


Figure 2: Noise directivity obtained using different approaches. Coarsest considered mesh.

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