

JET NOISE PREDICTION USING A FULLY UNSTRUCTURED LARGE EDDY SIMULATION SOLVER

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1. INTRODUCTION

Jet noise has been subject of intensive research for sixty years, since it is the major contribution to aircraft noise at take off. Recent work to reduce jet noise sound emission investigates various noise reduction devices such as dual stream nozzles, chevrons, microjets injection, and lobed mixers. Most advanced state-of-art tools are based on high-order, low-dispersive and low-dissipative schemes designed for structured hexahedral grids. However, numerical methods based on fully unstructured grids are known to be better adapted to deal with complex geometries as those found in noise reduction devices. In a previous work [1], a comparison of this methodology with a high-order structured dedicated solver on jet configurations without nozzle has been performed. This comparison demonstrated the promising capabilities of a fully unstructured methodology. The present work deals with simple jet configurations including a nozzle geometry. This is a necessary step towards the simulation of geometrically complex jet noise reduction devices.

2. JET CONFIGURATION

The jet configuration considered is a cold 0.9 Mach jet. The nozzle considered is the SMC000 nozzle as shown in Figure 1. The diameter of the nozzle is $D=5.08\text{cm}$.



Figure 1. SMC nozzle: 0.9 jet Q-criterion isosurface.

3. NUMERICAL PROCEDURE

The grid is fully unstructured using only tetrahedral elements. Maximum cell sizes in the acoustic source area, namely the mixing layer and the transition region (up to $20D$ from the nozzle exit), allow capturing frequencies at least up to a Strouhal number (Str) of 1.5. A finer meshing is done in the nozzle boundary layer in order to allow a natural transition to turbulence of the mixing layer at the nozzle exit. In that zone, waves are resolved up to $\text{Str}=5$. The grid contains 7 million points and 43 million cells.

All inlet and outlet boundary conditions are defined using non-reflecting Navier-Stokes boundary conditions [2]. At the nozzle inlet, total pressure and temperature are prescribed while a very small co-flow is prescribed at the

inlet outside the nozzle. At the outlet, only a far-field pressure is prescribed.

The computations are initialized using mean flow fields provided by a RANS simulation [3] using the $k-\epsilon$ model. The numerical scheme used is a two-step Taylor-Galerkin scheme 3rd order in time and space. The WALE subgrid scale model [4] is used. The CFL is fixed to 0.7.

Acoustic sources data are collected on surfaces at about $1.5D$ from the jet in order to avoid dispersion and dissipation effects and limit the grid size. Acoustic prediction is then performed using the permeable surface formulation of the Ffowcs-Williams and Hawkins analogy implemented in the MCAAP code [5].

4. RESULTS

4.1 Turbulent flow statistics

The computations have been run for about $300D/U$. This is enough to converge statistics data. The results (named SMC in figures) are compared to results obtained experimentally [6]. They are also compared to numerical results obtained by the simulations of Bogey and Bailly [7], performed with low-dispersive and low-dissipative schemes on a structured grid of comparable size without the nozzle geometry (named Bogey et al.). Numerical results obtained in a previous work [1] on a fully unstructured grid of comparable size but without nozzle geometry (named W/O Nozzle) are also presented. The two simulations without nozzle use a vortex ring excitation to mimic the effect of the nozzle. The “W/O Nozzle” results have been shifted by $5D$ to account for a delayed transition to turbulence.

Figure 2 shows the evolution of the centerline mean axial velocity. The velocity decay is in a very good agreement with experiments. Only the SMC computations predict the correct potential core length without forcing.

Figure 3 presents the evolution of axial turbulent intensities both along the jet centerline and lip line. Once again, results named “W/O Nozzle” have been shifted. Along the centerline, the turbulent intensity peaks and the levels in the transition region are in good agreement with experiments [6] and Bogey and Bailly computations [7]. The axial turbulent intensity along the lip line increases rapidly, showing that the jet mixing layer is already turbulent at the nozzle exit even if no excitation have been introduced in the SMC computations. The peak is reached at about $2D$ higher than in experiments [8]. It might be due to vortex

pairing. However, this peak is lower than the peak obtained by Bogey and Bailly. This peak could also be due to instabilities in the vicinity of the lips. It does not appear in “W/O Nozzle” results as no vortex pairing has been detected. The mixing layer development should be investigated further. Overall, the turbulent flow results are very satisfactory.

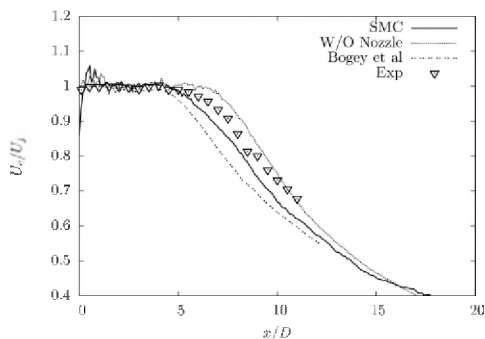


Figure 2. Mean centerline velocity decay.

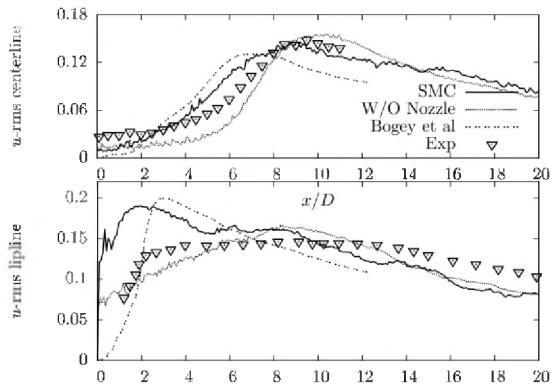


Figure 3. Axial turbulence intensities. Top: centerline. Bottom: lipline.

4.2 Acoustic results

Acoustic source data have been recorded during only $40D/U$ with a time step of $0.008D/U$. Therefore, low frequencies are not completely resolved but high frequencies are only limited by the mesh size cutoff. The acoustic data computed at 30° and 90° from the jet axis, $100D$ from the origin are shown on Figure 4. The agreement with experimental data [9] is very good. A dominant mode around a Strouhal number of 1.5 could be observed at 90° . It is probably due to vortex pairing occurring around $x=2D$ in the mixing layer.

5. DISCUSSION AND CONCLUSIONS

In the present study, the possibility to study jet noise using Large Eddy Simulation methodology on a fully unstructured tetrahedral mesh has been investigated. Both aerodynamic (the turbulent structure) and aeroacoustic results obtained on cold jets with and without nozzle geometry show good agreement with experiments. It is worth noting that, at this point of the survey, with the nozzle geometry, no excitation method is needed to obtain a turbulent mixing layer at the nozzle exit. Further

investigations will look at the vortex pairing still present in the simulation. They will also assess the dependence of the flow field on the mesh and the inlet conditions. The coherence of jet noise sources will be checked.

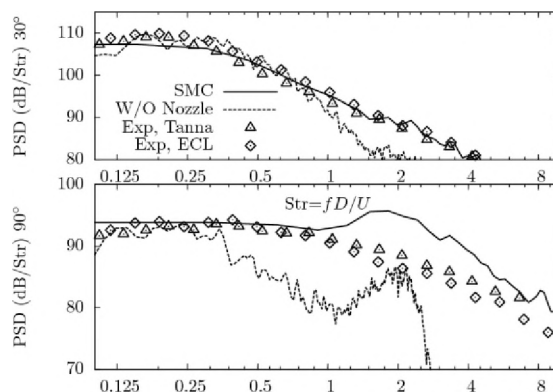


Figure 4. Spectra of acoustic pressure at $100D$.

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