PhD Title : Numerical study of the effects of a secondary flow on screech noise generated by supersonic jets

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Description

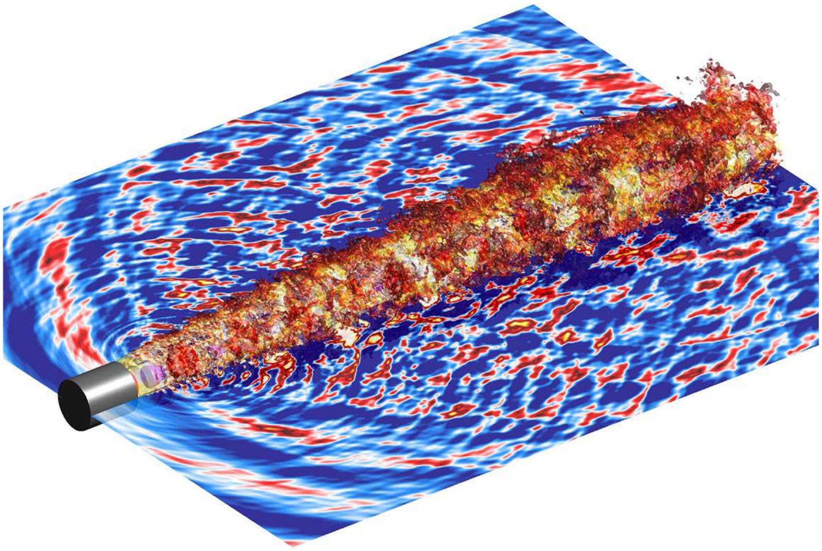
The effects of a secondary flow (often referred to as coflow) on the noise components generated by turbulent jets have been investigated in several experimental studies of the literature. For a supersonic jet, in particular, surrounding the jet by a secondary flow can suppress Mach wave radiation [1] by rendering all turbulent motions intrinsically subsonic. For a shock-containing supersonic jet, it was also found to significantly affect the screech tones emerging at specific frequencies due to the establishment of aeroacoustic feedback loops. It has been reported that the secondary flow leads to a reduction in amplitude of the screech tones [2] and can also cause a mode switching, i.e. a shift in the dominant screech mode, or a change in the tone frequencies.

The effects of a secondary flow on screech tones can be explained by the modifications of the components involved in the screech feedback loops, namely the downstream-propagating jet instability-waves/coherent-structures, the shock-cell structure, the upstream-propagating acoustic waves resulting from the instability-wave /shock-cell interactions and the receptivity at the nozzle lip. In most studies, the changes in the screech tone properties are attributed to the fact that a secondary flow can stretch the axial development of the shock cells, altering the spacing and strength of the shocks, and can modify the jet spreading rate and turbulence levels. A secondary flow is also likely to disrupt the feedback loops by diverting the propagation path or damping the upstream-propagating acoustic waves, leading to reduced or suppressed screech.

Since less than a decade, it has been known that the upstream-propagating acoustic waves closing the screech feedback loops are not free-stream sound waves propagating outside the flow, but waves guided in the jets. These guided jet waves (GJW) are confined within the core of jets, can propagate upstream or downstream while maintaining a constant amplitude (neutral waves), and have specific dispersion relations [3]. Over the past years, they have been a hot topic in the aeroacoustics community and the subject of numerous studies, which have shown that they play a crucial role in most resonance phenomena that can occur in shocked jets or jets interacting with a wall [4].

Based on the above, the objective of the PhD will be to document and explain the effects of a secondary flow on screech noise generated by supersonic jets by combining large-eddy simulations (LES) of jets and modellings of the GJW involved in the feedback loops using linear stability and sound propagation computations.

Jets considered in experiments of the literature will be simulated by high-fidelity LES. The LES will be performed by solving the unsteady compressible Navier-Stokes equations using in-house codes based on high-order schemes [5] on cylindrical meshes containing on the order of 500 million points, in order to directly obtain both the aerodynamic and acoustic fields. This approach has been successfully applied to subsonic and supersonic, free [6], screeching [7] and wall-impacting [8-9] jets at the LMFA Acoustics Team for many years (see the list of publications at https://acoustique.ec-lyon.fr/publication_uk.php). As an illustration, the density field and the pressure fluctuations obtained inside and outside a screeching jet in reference [7] are represented in the figure below. Strong screech waves are observed to propagate in the upstream directions.



The objectives of the thesis will be first to reproduce the turbulent and acoustic fields generated by supersonic screeching or non-screeching jets, with or without a secondary flow, and then to describe the effects of the secondary flow on the jet flow and sound fields, focusing on the key elements of the feedback loops for screeching jets. In the latter case, specific attention will be paid to the GJW, which will be characterized in the jets as was previously done for single-stream jets [10]. The GJW properties will be compared with those obtained using linear stability analysis but also numerical simulations of sound waves in the jet mean field [11]. The different results should then allow us to understand the causes of screech attenuation when a secondary flow is used, and, on a broader level, the physical mechanisms behind resonant phenomena in high-speed jets.

References

[1] Papamoschou, D., 1997, Mach wave elimination in supersonic jets, AIAA J., 35(10), 1604-1011.

[2] Debiasi, M. & Papamoschou, D., 2001, Noise from imperfectly expanded supersonic coaxial jets, AIAA J., 39(3), 388-395.

[3] Tam, C.K.W. & Hu, F.Q., 1989, On the three families of instability waves of high-speed jets, J. Fluid. Mech., 201, 447-483.

[4] Edgington-Mitchell, D., 2019 Aeroacoustic resonance and self-excitation in screeching and impinging supersonic jets - a review, Intl J. Aeroacoust., 18 (2-3), 118–188.

[5] **Bogey, C.** & Bailly, C., 2004, A family of low dispersive and low dissipative explicit schemes for flow and noise computations, J. Comput. Phys., 194(1), 194-214.

[6] **Bogey, C.,** Marsden, O. & Bailly, C., 2011, Large-Eddy Simulation of the flow and acoustic fields of a Reynolds number 105 subsonic jet with tripped exit boundary layers, Phys. Fluids, 23, 035104, 1-20.

[7] Gojon, R., **Bogey, C.** & Mihaescu, M. 2018 Oscillation modes in screeching jets. AIAA J. 56 (7), 2918–2924.

[8] **Bogey, C.** & Gojon, R., 2017, Feedback loop and upwind-propagating waves in ideally expanded supersonic impinging round jets, J. Fluid Mech., 823, 562—591.

[9] Varé, M. & **Bogey, C**., 2022, Generation of acoustic tones in round jets at a Mach number of 0.9 impinging on a plate with and without a hole, J. Fluid Mech., 936, A16, 1-32

[10] **Bogey, C.,** 2021, Acoustic tones in the near-nozzle region of jets : characteristics and [8] variations between Mach numbers 0.5 and 2, J. Fluid Mech., 921, A3 1-41.

[11] **Bogey, C.,** 2025, Guided-jet waves generated by an acoustic source in a jet at a Mach number of 0.95, J. Fluid Mech., 1024, R1, 1-13.