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MODELLING OVER-EXPANDED JET SCREECH BY ILES

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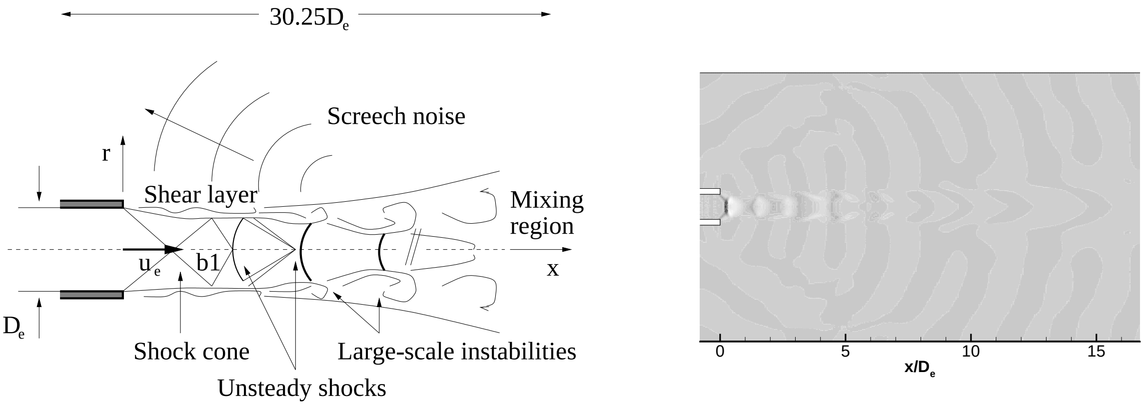
High-speed fighter aircraft feature low-bypass engines where the dominant noise source is the aerodynamic jet noise. As the jet is operated incorrectly expanded, it can feature an intense tonal noise, commonly referred to as a screech tone. The origin of screech stems from operating the jet incorrectly expanded, whereupon a system of shock cells interacts with convected instabilities in the jet outer shear-layer, generating noise [1].

The selection of convectively amplifying shear-layer instabilities by upstream feed-back locks the noise generation process in a feed-back loop, which determines the tonal characteristic of screech. From a computational viewpoint, screech therefore involves mainly a narrow band of the kinetic energy spectrum in the jet shear layer. This makes this problem treatable by a numerical approach that resolves directly the relevant scales of motion associated to screech and models the effects of any under-resolved smaller-scale dynamics on the resolved motion.

Such approach has been followed in the form of an Implicit Large Eddy Simulation. In this paper, this approach is applied to an over-expanded cold air jet from a convergent-divergent nozzle of design Mach number 2.0. The model jet exit diameter $D_e = 49.89$ mm and the nozzle is operated at a total to ambient pressure ratio $p_s/p_\infty = 3.601$, corresponding to a fully expanded isentropic Mach number $M_j = 1.49$. The jet discharges in ambient quiescent air at temperature $T_\infty = 288.15$ K. These conditions are designed to match experiments [2] in which screech was observed.

Figure 1(a) gives a diagrammatic description of the main flow features characterising the over-expanded jet, close to the nozzle exit plane. Compressions and expansions alternate along the jet axis, forming a shock-cell plume. The location of these waves is affected by the jet outer shear-layer that contains them through a local wave refraction effect. The shear-layer motion makes the shocks unsteady. The shock interaction with the inflected velocity profile of the shear-layer, which rolls-up into downstream propagating toroidal vortices, creates a condition for part of the shock front to be exposed to the subsonic flow



(a) Flow features of an over-expanded jet.

(b) Numerical schlieren showing the radiating pressure.

Figure 1: Implicit Large Eddy Simulation of an over-expanded jet screech.

outside the shear-layer. This process causes the release of a propagating pressure wave that is perceived as screech noise in the acoustic far-field [3]. This radiation also provides feed-back for phase-locking the screech instability at the nozzle lip.

The finite-amplitude aerodynamic pressure perturbations that characterise the jet near-field can be directly computed by a time-dependent computational fluid dynamic in-house scheme. A second-order space and time accurate method is used, where the inviscid fluxes are estimated from the second-order implementation of the approximate Riemann solver of Roe [4], with the min-mod flux limiter to provide selective upwinding in regions of large state variable gradients. Time advancement is provided by a four-step Runge-Kutta time-marching scheme, with a constant time step, implemented in the low-memory storage form. The flow governing equations are the Navier-Stokes equations in cylindrical coordinates, which have been normalised by the nozzle exit plane flow state. Second-order central differences are used for estimating the viscous fluxes.

Preliminary results in Figure 1(b) indicate that, for this flow instability involving a narrow-band dominant tone and selected scales of motion, an Implicit Large Eddy Simulation approach is able to reproduce salient time-dependent features observed in experiment.

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