Direct acoustic computations of cold and heated jets

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Résumé :

Le rayonnement acoustique de jets circulaires subsoniques est étudié à l'aide de simulations numériques directes de l'écoulement. Les équations de Navier-Stokes compressibles sont résolues en s'appuyant sur une formulation aux caractéristiques et des schémas aux différences finies de haute précision. L'influence de la température du jet sur le développement de l'écoulement et sur le rayonnement sonore associé est examinée.

Abstract :

Round jets having a Mach number of 0.9 are computed by direct numerical simulations using a characteristic-type formulation and high-order compact finite differences. Two simulations are carried out where the ratio of inflow to ambient temperature is equal to 1 (isothermal jet) and to 2 (anisothermal one) respectively. The influence of the jet temperature on the main features of the flow and its associated sound field is investigated.

Mots clefs : Aeroacoustics - Direct Numerical Simulation (DNS) - Compressible free shear flows

1 Introduction

Identifying the mechanisms responsible for the production of sound by unbounded turbulence is an extremely difficult task due to our poor understanding of the underlying physics. Thanks to recent progress of numerical simulations, the direct computation of the noise radiated by turbulent jets is possible, by Direct Numerical Simulations (DNS) or Large Eddy Simulations (LES) techniques. Such numerical databases involving the spatio-temporal evolution of each variable are very useful to extract relevant information regarding the physical mechanisms of sound production [1, 2, 3]. We note that only few direct computations [4, 5] deal with the temperature effect on jet noise, despite the importance of this parameter for real jet engines.

Our aim is to constitute DNS databases to investigate the sound radiation from isothermal and non-isothermal jets. The next section presents briefly the flow configuration and the numerical techniques used in the computational code. Then we present preliminary results of three-dimensional simulations of cold and hot jets.

2 Flow configuration and numerical methods

The full compressible Navier-Stokes (NS) equations are solved in a rectangular box $(50r_0, 46r_0, 46r_0)$, with r_0 the initial radius of the jet. A non-conservative, characteristic-type formulation [6, 7] is used, involving in particular the acoustic, entropic and vorticity modes. Time integration uses a fourth order Runge Kutta scheme, and spatial derivatives are evaluated using high order compact finite differences. The fifth-order Compact Upwind scheme with High Dissipation (CUHD) developed by Adams & Shariff [8] was chosen and used to compute the first derivatives included in the acoustic, entropic and vorticity modes. The viscous and heat conduction terms, involving in particular second derivatives via a Laplacian formulation, are solved with compact centred schemes [9]. Non-reflecting boundary conditions associated with sponge zones at the outflow [6, 7] are applied to allow a good representation of the infinite extent of the physical domain. Previous direct computations of the sound radiated from two-dimensional mixing layer flow showed the ability of the current NS solver to provide reliable dynamic and acoustic results [10].

Two jets having a Mach number of 0.9 are simulated[1] where the ratio of inflow to ambient temperature is specified as 1 (cold jet) and 2 (hot jet) respectively. Here the equations are discretised on a non-uniform grid with 27 million grid points approximately. The axial velocity profile is given by a hyperbolic tangent profile, and small random disturbances are added in the shear layer zone to initiate the transition process.

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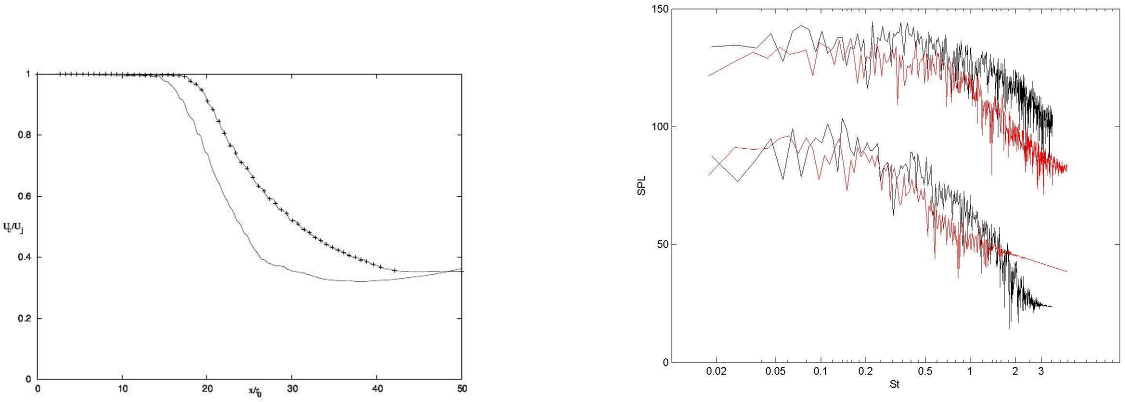
[1] Present calculations were carried out on the NEC-SX8 supercomputer at the Institut du Développement et des Ressources en Informatique Scientifique (IDRIS), to which we are thankful.



a) b)

FIG. 1 – a) Longitudinal evolution of the normalised mean centerline velocity U_c/U_j of hot jet (solid line) and cold jet $(+)$. b) Sound pressure spectra of cold (black line) and hot (red line) jets as a function of the Strouhal number $St = fD/U_j$ at the observation points located at $x = 18.5r_0$, $y = 45r_0$, $z = 0$ at the bottom and $x = 38r_0$, $y = 34r_0$, $z = 0$ at the top.

3 Results

Preliminary results from three-dimensional simulations of the isothermal and non-isothermal cases are presented here. The enstrophy field (not shown here) shows the initial flow development related to growing instability waves in the shear layer. Then the mixing zones grow, up to the end of the potential core (region with uniform velocity U_j). Downstream, a three-dimensional motion appears and the flow tends towards developed turbulence. We observe in figure 1-a that the potential core (region with uniform velocity U_j) ends for about $x = 18r_0$ in the cold jet and for a slightly smaller distance $x = 15r_0$ in the hot jet. These core lengths are quite large due to the low Reynolds number value of present DNS, according to previous results [1, 11]. The value of the mean centerline velocity decays linearly downstream from the end of the potential core, as expected.
Figure 1-b shows the pressure spectra obtained from both heated and unheated jets, at observation angles close to 30^o and 90^o from the jet axis. We observe the typical shape of acoustic spectra for moderate Reynolds number jets, with a peak for a Strouhal number around $St = 0.2$. We note that the sound levels are higher downstream of the end of the potential core. Finally the figure shows that the acoustic radiation of the cold jet is higher than the acoustic radiation of the hot jet for both observation points.

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