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INFLUENCE OF THE INITIAL STRUCTURE OF A TURBULENT JET ON ITS ACOUSTIC EMISSION

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ABSTRACT
Modifying the structure of a turbulent jet leads to change the emitted acoustic noise. These phenomena are discussed in the case of a subsonic turbulent axisymetric jet with given flow rate and initial velocity profile. The characteristic quantities of the turbulent flow are computed using a k-ε formulation and a method with control volumes. The calculation of the emitted acoustic power uses the Ribner's model validated from Lush and Juvé experiments. Radiated noise from parallel, convergent or divergent jets with an uniform axial velocity profile, and from parallel jets with non uniform velocity profile have been computed. The influence of the initial turbulence for a simple jet is discussed.

1 - INTRODUCTION
Following Ribner, quadrupolar acoustic radiation from a volume of turbulent jet may be modelled using statistical properties of the turbulence. Now turbulent quantities may be obtained from a k- ε model. In the last years some studies have been done using such methods for simple jets for which experimental results may be found in the literature and results were good enough to try using these methods as a predictability tool for any turbulent jet [1]. So, we intend to evaluate the influence of initial structure (angle of jet, velocity profile and turbulent intensity) of a turbulent jet on the radiated acoustic waves.

2 - ACOUSTIC MODELLING OF THE TURBULENT JET
Reynolds equations for an incompressible flow may be written:

$$\frac{\partial \overline{\mathrm{U_i}}}{\partial \mathrm{t}} + \overline{\mathrm{U_j}}\frac{\partial \overline{\mathrm{U_i}}}{\partial \mathrm{x_j}} = -\frac{1}{\rho}\frac{\partial \mathrm{P}}{\partial \mathrm{x_i}} + \nu \Delta \overline{\mathrm{U_i}} - \frac{\partial \overline{\mathrm{u'_i u'_j}}}{\partial \mathrm{x_j}} \qquad \frac{\partial \overline{\mathrm{U_i}}}{\partial \mathrm{x_i}} = 0 \quad \text{and} \quad \frac{\partial \mathrm{u'_i}}{\partial \mathrm{x_i}} = 0$$

with $\overline{\mathrm{U_i}}$ mean velocity flow, P mean pressure, $\overline{\mathrm{u'_i u'_j}}$ turbulent Reynolds stresses, ν the kinematic viscosity and ρ the density.

A classical k-ε model is used, with turbulent kinetic energy $\mathrm{k} = \frac{\overline{\mathrm{u'_i u'_i}}}{2}$, turbulent dissipation rate $\varepsilon = \nu \overline{\frac{\partial \mathrm{u'_i}}{\partial \mathrm{x_j}}\frac{\partial \mathrm{u'_i}}{\partial \mathrm{x_j}}}$, turbulence production $|P = \overline{\mathrm{u'_i u'_j}}\frac{\partial \overline{\mathrm{U_i}}}{\partial \mathrm{x_j}}$ and $\nu_\mathrm{t} = \mathrm{C}_\mu \mathrm{k}^2/\varepsilon$ eddy viscosity:

$$\frac{\partial \mathrm{k}}{\partial \mathrm{t}} + \overline{\mathrm{U_j}}\frac{\partial \mathrm{k}}{\partial \mathrm{x_j}} = \frac{\partial}{\partial \mathrm{x_j}}\left(\frac{\nu_\mathrm{t}}{\sigma_\mathrm{k}}\frac{\partial \mathrm{k}}{\partial\ \mathrm{x_j}}\right) + |\ \mathrm{P} - \varepsilon$$

$$\frac{\partial \varepsilon}{\partial \mathrm{t}} + \overline{\mathrm{U_j}}\frac{\partial \varepsilon}{\partial\ \mathrm{x_j}} = \frac{\partial}{\partial\ \mathrm{x_j}}\left(\frac{\nu_\mathrm{t}}{\sigma_\varepsilon}\frac{\partial\ \varepsilon}{\partial \mathrm{x_j}}\right) + \frac{\varepsilon}{\mathrm{k}}(\ \mathrm{C}_{\varepsilon 1}\,|\mathrm{P} - \mathrm{C}_{\varepsilon 2}\varepsilon\,)$$

Constants are the standard ones: C_μ= 0.09, σ_κ=1, σ_ε= 1.3, $\mathrm{C}_{\varepsilon 1}$=1.44, $\mathrm{C}_{\varepsilon 2}$=1.92.
Computations made by Fluent, gave local mean velocity, turbulent energy k and dissipation ε.

We used Ribner's model [2], convenient for jet flows with small Mach numbers, and modified by Bailly & al. [3] for calculation of the product of mean velocities U'U in two points.
Acoustic intensity I at the point x in the far field from an unit volume source at the point y may then be written as the sum of the two terms for self and shear noise:

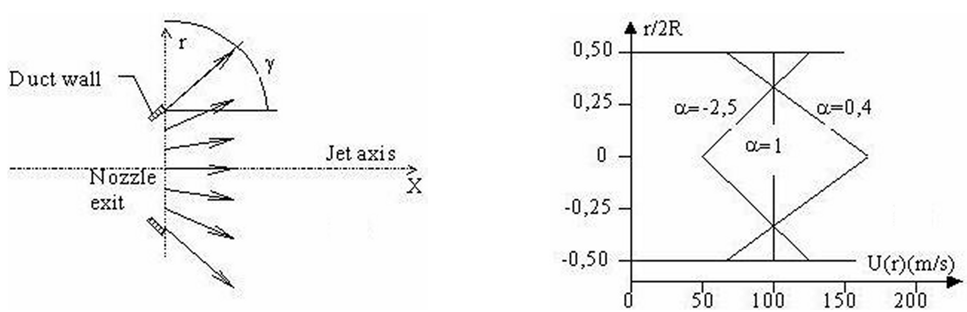
$$\mathrm{I_{self}}\,(\vec{\mathrm{x}}\,,\theta\,|\vec{\mathrm{y}}\,) = \frac{3\sqrt{2}}{4\pi^2\,\mathrm{x}^2}\,\frac{\rho_0}{\mathrm{c}_0^5}\mathrm{L}_1^3\overline{\mathrm{u}_\mathrm{t}^2}^2\,\omega_\mathrm{t}^4\frac{1}{(1-\mathrm{M_c}\cos\theta)^5}$$

$$\mathrm{I_{shear}}\,(\vec{\mathrm{x}}\,,\theta\,|\vec{\mathrm{y}}\,) = \frac{3}{8\pi^3\mathrm{x}^2}\,\frac{\rho_0}{\mathrm{c}_0^5}\,\mathrm{L}_1^5\overline{\mathrm{u}_\mathrm{t}^2}\,\left(\frac{\partial \mathrm{U}_1}{\partial \mathrm{y}_2}\right)^2\omega_\mathrm{t}^4\,\frac{\cos^2\theta+\cos^4\theta}{2\,(1-\mathrm{M_c}\cos\theta)^5}$$

$\mathrm{M_c}$ is the Mach number with convection velocity Uc equal to 0,67 time the axial exit velocity. Acoustic power W of jet is calculated integrating in the whole space on a sphere.
Characteristic length of turbulence was taken as $\mathrm{L} = \mathrm{K_L}\mathrm{k}^{3/2}/\varepsilon$. Constant $\mathrm{K_L}$, defined from the fact that self noise and shear noise acoustic intensities are nearly equal [2] on the jet axis was retained equal to 0.66, mean of local values in the acoustic sources domain,. The proportionality factor between characteristic turbulent pulsation ω_t and $2\pi\varepsilon/\mathrm{k}$ was obtained adjusting global acoustic intensity with experimental data [5] for θ=90° in a simple jet, and a Mach number from 0.2 to 0.6,. The same factor will be used for all the studied cases.
The method was tested for a simple jet [5] and for coaxial jets [4]. A quite good agreement was observed between computed and experimental acoustic intensities.

3 - INFLUENCE OF THE INITIAL STRUCTURE OF THE TURBULENT JET ON THE ACOUSTIC EMISSION

All the jets (divergent, convergent and parallel) have the same volumic flow rate. On figure 1, initial conditions at the nozzle exit are displayed: angle γ (figure 1a) for convergent and divergent jets and velocity profiles for parallel jets (figure 1b):



(a) **(b)**

Figure 1: Geometry exit flow.

$\mathrm{U_q}$ being volumic flow rate velocity, velocity profile for parallel jets has been taken as:

$$\mathrm{U}\,(\mathrm{r}) = \frac{3\mathrm{U_q}}{2\alpha+1}\left[(\,\alpha-1)\,\frac{\mathrm{r}}{\mathrm{R}}+1\,\right] \qquad \text{with} \quad \alpha = \frac{\mathrm{U_{axis}}}{\mathrm{U_{wall}}}$$

With uniform parallel jet as reference, acoustic gain is defined as G=10 log $\mathrm{W_{ref}}$/W.
For convergent/divergent jets, G is displayed as a function of the angle γ (figure 2).
Convergent jets ($\gamma < 0$) are noisier than the reference jet (G<0). Indeed, in a convergent jet, velocity in the central part is increased, more turbulent kinetic energy is produced with maximum values around the nose of the potential core, and not in the near wake of the nozzle walls. For $\gamma = -40°$, these values are nearly twice those of the simple jet and for X>10D to 12D, the same shape for isovalues of k is observed with equally a factor 2.
Divergent jets are less noisy than the simple one (for γ<52°): G is positive, grows with γ up to 18 db when γ=45°; in this case, the mean velocity is very low near the axis for x<4D, then the velocity profile becomes nearly uniform but is wider than the simple jet, turbulent kinetic energy is very much smaller (roughly 50% for γ=40°). For γ>45°, a recirculating flow appears inside the jet, near the exit, explaining the quickly decreasing of G.
For parallel jets, G is given on table 1 for different values of α.

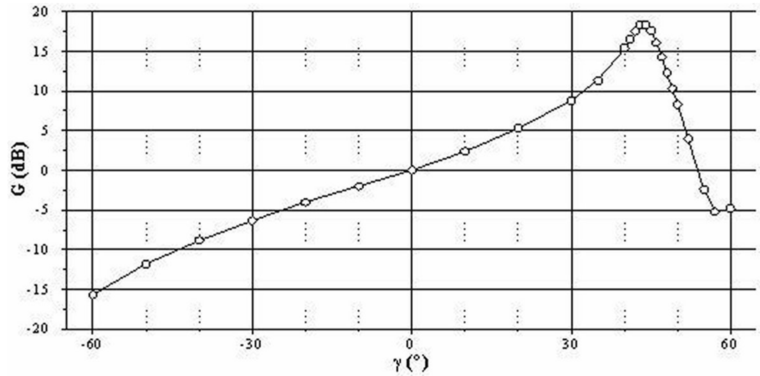


Figure 2: Acoustic gain for convergent and divergent jets.

α	0,2	0,4	0,6	0,8	1	1,25	1,67	2,5	5	7,5	10
Uaxis (m/s)	214,	166,7	136,4	115,4	100	85,7	69,2	50	27,3	18,7	14,3
G (dB)	- 9,8	- 4,2	-1,3	- 0,1	0,0	- 0,3	- 1,0	- 2,3	- 4,1	- 4,8	- 5,1

Table 1: Acoustic gain for parallel jets with non uniform exit profiles.

For α<1, the initial velocity profile is nearly conical, the jet is noisier than the simple jet (G<0), specially when α is small (very sharp profile), as it can be expected: the velocity on the axis is higher than U_0 and the profile stays steeper far downstream. Potential core is shorter and kinetic turbulent energy very high in the vicinity of the end of this core. For α=0.2, the more intense acoustic sources lies between 6D and 8D (0 to 2D for the simple jet).
For α>1, axis velocity is smaller than U(R), G is again negative, that may seem surprising because the mean flow, not far from the exit, looks like a divergent jet flow. In the two cases, the maximum velocity is observed in the wake of the walls, but here U(R) is higher (U(R)>140 m/s for α=10) and velocity profiles downstream are less flat.
For a simple jet, the influence of the quantity of initial turbulent energy on the gain G was evaluated: initial turbulent intensity I_t from 0 to 20% is considered; characteristic turbulent length L, necessary to define the entry dissipation rate ε, varies widely from R/10 to 2R (R nozzle radius) (high L gives very small ε). Figure 3 shows that acoustic radiation increases when turbulent intensity becomes higher than 5%; for I_t>5%, increasing L decreases acoustic radiation as it might be expected, but the influence of L is moderate.

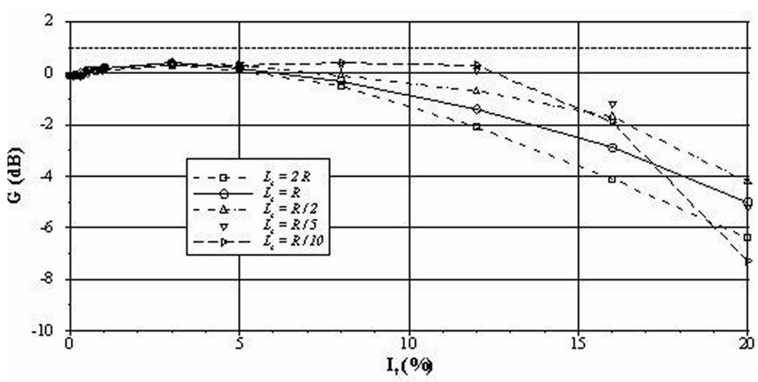


Figure 3: Acoustic gain for a round jet as a function of turbulent intensity I_t.

4 - CONCLUSION

Comparing radiated noise from subsonic convergent or divergent jets displayed that, at constant flowrate, the divergent jets are very less noisy than the simple jet. In the case of parallel jets with same flowrate, the initial velocity profile has a strong influence. At last, initial turbulence is also of importance for the radiated noise.

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