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A METHOD FOR PREDICTING THE TRAILING EDGE NOISE CONTRIBUTING TO THE SOUND EMISSION OF HEAT PUMPS FANS

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ABSTRACT
The aim of reducing the acoustic radiation of air conditioning outdoor units leads to study the contribution of their cooling fans to the noise emission. The broadband part of the noise emitted by the axial fans installed on such systems is generally the most important part of the total radiated noise. In this paper, we focus our attention on the " self-noise " of an isolated blade profile caused by the turbulence of the boundary layer, assuming no stall occurs. We present a method to predict the noise emitted by a 2D isolated profile, knowing its geometric characteristics, the incidence and the speed of the incoming flow. Calculations have been performed on a NACA012 profile, for several trailing edge sharpness, flow speeds and angles of attack. The results show good agreement with literature's measurement data.

1 - INTRODUCTION
Related to the turbulence of the flows, the broadband part of the noise emitted by a low-speed fan may have several origins. First, the interaction of the rotor blades with the upstream turbulence can induce noise. Another type of noise results from the interaction of blade wakes with obstacles downstream. Eventually, the turbulence of the boundary layers or stall zones on the blades is also responsible for an emission, called "self noise" or "trailing edge noise". In this paper, we focus ourselves on this very kind of emission, assuming no stall occurs.
The study of the noise emitted by an isolated blade is difficult for several reasons: difficult access to the turbulence parameters near the trailing edge, statistic approach necessary, large variety of phenomena.
We present a method to compute the noise emitted by a 2D isolated profile, knowing its geometric characteristics, the angle of attack and the speed of the incoming flow. It consists of performing 2D CFD calculations to obtain statistic information on the flow near the trailing edge. This is then related to the spectral characteristics of the surface pressure fluctuations using analytical theories developed by Corcos and Benarrous. These characteristics are used to deduce the spectrum of the noise emitted by the profile, thanks to Howe's acoustic theory.

2 - THEORETICAL BACKGROUND

2.1 - Model of the noise emitted by an ideal 2D profile under a flow: Howe's theory
Howe ([1]) has proposed a theory for predicting the generation of sound by a semi-infinite rigid plate. We assume this theory is valid for a 2D profile with a sharp trailing edge. The spectrum of the far-field sound emitted can be related to the interspectrum of the surface pressure fluctuations $\pi(k_1, k_2, \omega)$ by the relation:

$$S_K(\omega) = \frac{2\bar{V}L}{\pi c R^2} \frac{\sin\alpha \sin^2\left(\frac{\bar{\theta}}{2}\right)}{2} \frac{\int_{-\infty}^{\infty} \pi_K\left(k_1, \frac{\omega \cos\alpha}{c}, \omega\right) dk_1}{c} \tag{1}$$

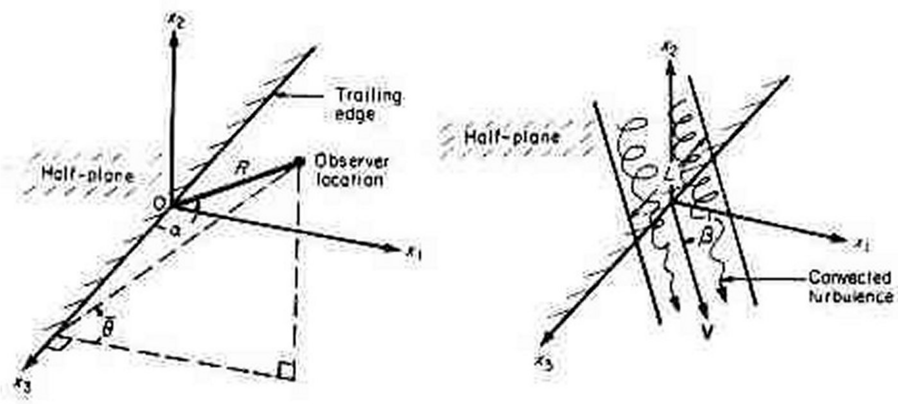

Figure 1: Coordinates system.

$F(\omega) = \dfrac{\omega \frac{W}{V}}{V}$ takes into account the fact that the Kutta-Jukowsky condition is respected in a certain frequency range.

2.2 - Modelling the interspectrum of the parietal pressure fluctuations: Corcos theory
Most of the time the boundary layer is turbulent on the trailing edge of the profile. Then the interspectrum $\pi_K(k_1, k_2, \omega)$ which must be evaluated near the trailing edge is not depending of what happened upstream, but only of the local state of the boundary layer.
So we assume:

$$\pi_K(k_1, k_2, \omega) = \Phi_p(\omega) \, A(k_1, U_C, \omega) \, B(k_2, U_C, \omega) \, C(k_1, U_C, \omega) \tag{2}$$

$\Phi_p(\omega)$ is the energy distribution of the pressure fluctuations at the trailing edge; A and B are the so-called "Corcos functions" ([2]) and can be written:

$$A = \frac{a}{\pi}\frac{U_C}{\omega}\frac{1}{a^2 + \left(\dfrac{k_1 U_C}{\omega} - 1\right)^2} \tag{3}$$

and

$$B = \frac{b}{\pi}\frac{U_C}{\omega}\frac{1}{b^2 + \left(\dfrac{k_1 U_C}{\omega} - 1\right)^2} \tag{4}$$

$$C = \begin{cases} a_0 \left(\dfrac{k_1 U_C}{\omega}\right)^2 & \text{, if } \dfrac{k_1 U_C}{\omega} \leq 1 \\ a_0 & \text{, if not} \end{cases} \tag{5}$$

a, b and a_0 are constants and U_c=0.7 V (V: convection speed of vortices).

2.3 - Modelling the parietal pressure fluctuations frequency spectrum: Benarrous theory
To determine the expression of the distribution $\Phi_p(\omega)$, the semi-empirical theory proposed by Benarrous ([3]) gives expressions for the convection speed the pressure fluctuations spectrum:

$$V(\omega) = U_0 \left(0.6 + 0.4 e^{-\frac{2.2\omega\delta_1}{U_0}}\right) \tag{6}$$

and

$$\Phi_p(\omega) = \frac{q^2 \delta_1}{2U_0} \frac{10^{-3}\left(\dfrac{\omega\delta_1}{V}\right)}{V} F_C(\omega) \tag{7}$$

δ_1 is the thickness of the boundary layer, q the kinetic energy: $q^2 = \frac{1}{2}\rho_0 U_0^2$ and $F_c(\omega)$ is constructed to take into account the cutting frequency of the turbulence spectrum.

3 - DESCRIPTION OF THE METHOD

According to equations (1-7), the sound power spectrum can be written:

$$S_K(\omega) \propto \frac{U_0 V^2 \delta_1}{\omega} \frac{1}{b^2 + \left(\frac{0.7V}{c_0} - 1\right)^2} \frac{10^{-3}\left(\frac{\omega\delta_1}{V}\right)}{V} \tag{8}$$

Equation (8) depends only on parameter δ_1, and must be updated in amplitude to be used.
The method is the following: literature's measurements on an isolated 2D profile are compared to results obtained with the above expression, the parameter δ_1 being obtained by a numerical simulation on a profile with the same geometric characteristics and incident flow.

3.1 - Measurement datas

Brooks and Hodgson ([4]) have done acoustic measurements on two-dimensional airfoils embedded in a uniform low-mach number flow. Parameters include angle of attack, flow velocity, and the trailing edge bluntness.

3.2 - Numerical simulation

Simulation has been performed using N3S which is a finite-element-based-code developed by the R&D division of EDF. The turbulence, assumed stationary, is modelled by means of a classical k- ε model. The boundary layer is represented by a two-layers-boundary-law. To be accurate enough near the boundary, the mesh has been constructed in order to satisfy y^+<25, what leads to more than 20 000 nodes on the boundary. $^+$ is determined by calculating the displacement thickness of the boundary layer at a fixed distance of the trailing edge.

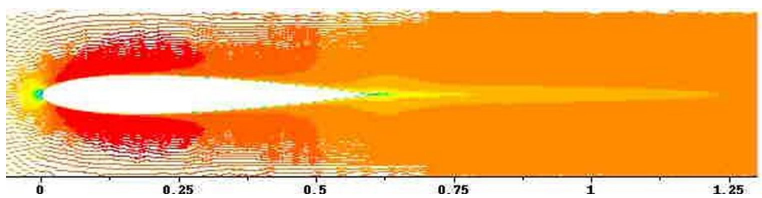

Figure 2: Example of numerical result; speed of an incoming flow on a profile.

4 - RESULTS AND DISCUSSION

For two different values of incoming flow speeds, the following figures give the spectrums of the measured and computed cases. The angle of attack is 0° and the airfoil chord is 60.96 cm.
The results show good agreement between the measured values and the computed ones.
The broadband effect induced by a smooth trailing edge is then modelled by a gaussian curve:

$$LDB_{\mathrm{sup}} = 10\log\left(\frac{S_{\mathrm{sup}}}{p_{ref}^2}\right) = A\exp\left[-\left(\frac{f - f_b}{\sigma}\right)^2\right] \tag{9}$$

Where a, f_b and σ must be updated thanks to measurements.
The results obtained with equation (9) for two trailing edge sharpness and incoming flow speeds are shown (figures 5 and 6).
The influence of the smooth trailing edge is well represented by our theory.

5 - CONCLUSION

The results presented in this paper show that a coupling between analytical acoustic, aerodynamic, theories and CFD calculation can lead to an accurate prediction method of the " self-noise " of an isolated airfoil. Such work must be continued to study and validate the more realistic case of a 3D rotating blade combining 3D numerical simulations on an isolated airfoil with kinetic analysis to take into account the rotation effects.

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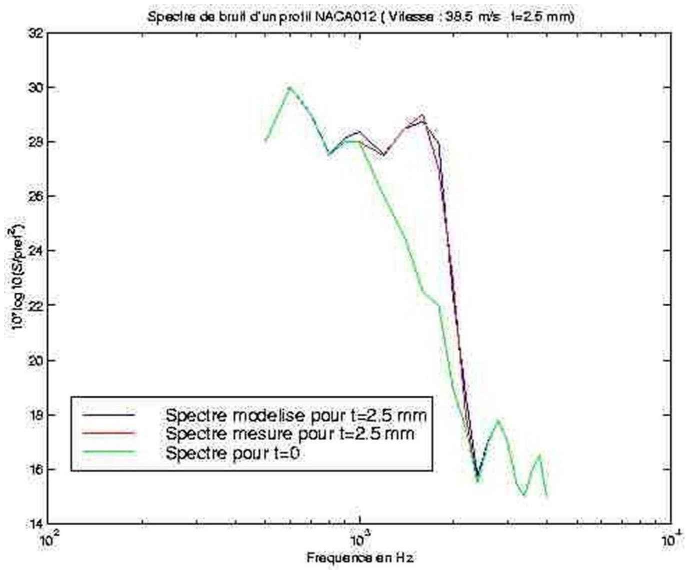

Figure 3: Comparison measures/computing (incoming flow speed: 38.6 m/s).

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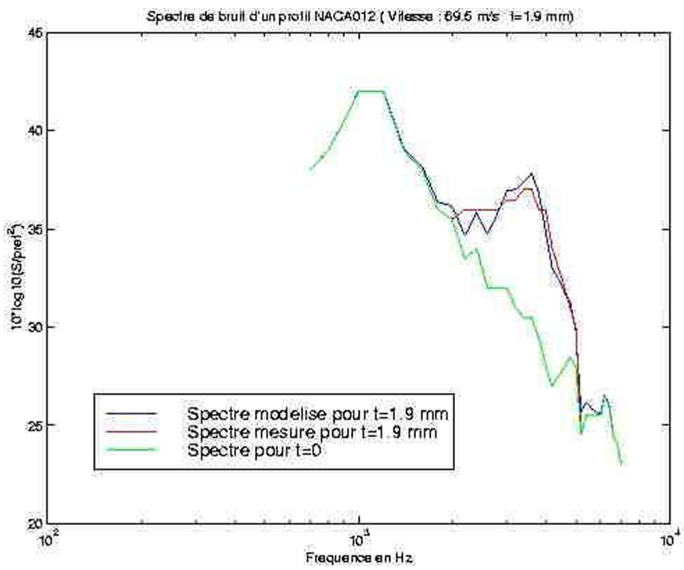

Figure 4: Comparison measures/computing (incoming flow speed: 54.1 m/s).

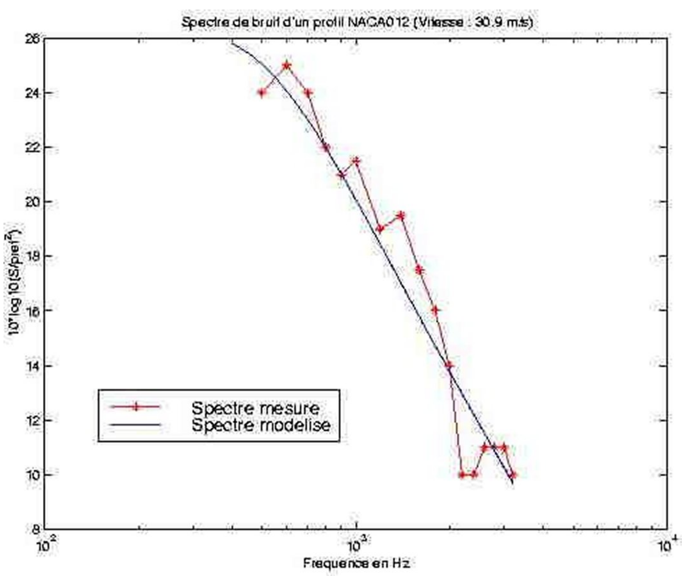

Figure 5: Comparison measures/computing (incoming flowspeed: 38.5 m/s, TE sharpness: 2.5 mm).

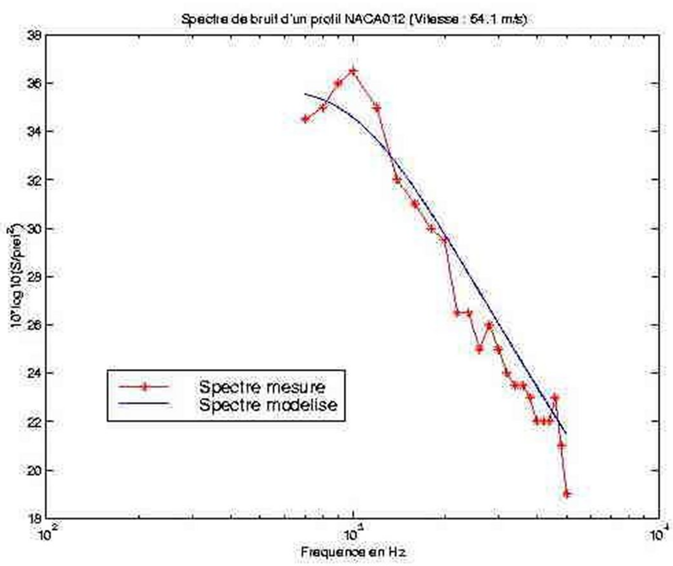

Figure 6: Comparison measures/computing (incoming flow speed: 69.5 m/s, TE sharpness: 1.9 mm).