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Antenna geometry effect on the reconstruction of the unsteady rotating forces of axial fan blade

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ABSTRACT

The aim of this paper is to investigate the influence of the geometrical arrangement of acoustic pressure measurement sensors on the reconstruction of the unsteady rotating forces acting on the fluid by the fan's blade. A development based on the tonal noise generated by an axial fan and validated with a directivity experience is used to derive a discretized form of the direct problem and to simulate acoustic pressures at known spatial positions in the radiated field. The inverse problem is usually ill-posed and requires optimization technique to stabilize the solution for small perturbations in the measured acoustic input data. The reconstruction shows that the inverse problem conditioning depends on the aeroacoustic source and the far-field sensor number and geometrical distribution as well as on the studied frequency. Tikhonov regularization can provide an appropriate regularization parameter leading to a satisfactory reconstruction of imposed unsteady rotating forces even in the presence of measurement noise. Simulations are conducted for three geometrical arrangements of microphones: line, arc of a circle and square.

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1. Introduction

Due to the increasing demand of improved passenger comfort and safety and to the increasing use of communication systems, interior acoustic comfort of future vehicles is expected to be one of the main decision making factors in an extremely competitive market. Tonal noise of axial engine cooling fans is one of several noise sources inside a vehicle. Therefore, there is a need for manufacturers of engine cooling units to design improved low noise axial fans.

The study of the dominant tonal noise in small axial fan was conducted by many authors. The first analytic model used for fan noise prediction was written by Gutin [1] in 1936. Lowson [2] studied the sound generated from singularities in motion and applied it to the aerodynamic forces. Ffowcs Williams and Hawking [3] extended the Lighthill theory [4] to take into account the presence of rigid corps in the fluid acting on the fan.

In order to well understand the source behavior and for the fan fault diagnosis, different source reconstruction techniques has been developed. After discretization of the direct problem, a matrix relating the aerodynamic forces to the acoustic pressures emitted by the fan is then written. The inverse model consists on inversing this matrix.

For source reconstruction, Li and Zhou [5] presented a technique to reconstruct the pressure distribution on the blade surface from the radiated sound field. Their method is based on inversing the Farassat integral with the assumption of steady aerodynamic force on the fan surface. Luo and Li [6] used the Fredholm integral equation of the first kind for their inverse method. Anthony et al. [7] proposed theoretical and experimental results for source reconstruction of axial fan based on dipole source distribution.

In the first section of this paper, the adopted direct model is presented. The inverse model is detailed in the following section and a regularization technique is proposed to overcome a poor conditioning of the inverse problem. Then, numerical simulations are conducted to assess the influence of the geometrical arrangement of downstream far-field acoustic microphones. Finally, simulation results are presented and discussed.

2. Direct model for fan's blade tonal noise prediction

The direct model used to compute the acoustic pressure emitted by an axial fan due to a singular aerodynamic force concentrated at source point (aerodynamic center of the blade), at the free space observed point (Fig. 1), was detailed and validated in

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Nomenclature

B	number of blades
D	drag force
F_i	component of the unsteady rotating force $\vec{F}$
J	cost function
J_q	Bessel function of the qth order
K_h	condition number
M	number of measurement point in the discretized radiation space
N	dimension of the thrust force vector
R_1	hub radius
R_2	blade tip radius
SNR	signal to noise ratio
T	thrust force
c_0	speed of sound
i	imaginary number ($\sqrt{-1}$)
m	microphones number
n	frequency index for the thrust force
q	circumferential index (harmonics)
q_{max}	maximum circumferential index q
q_{min}	minimum circumferential index q
r	source-observer distance
r_i	component of the source-observer vector
r_o	radius of the observed point
r_s	radius of the aerodynamic center of the blade (Source point)
s	frequency index for the acoustic pressure
t_d	time lag between two successive blades
P_s	sth fourier coefficient of the acoustic pressure
$\{P_s\}$	computed acoustic pressure vector at sth frequency
$\{\hat{P}_s\}$	far-field acoustic pressure measurement vector at sth frequency
$\{e\}$	error vector
$[H]$	transfer function matrix
$\vec{F}$	unsteady rotating force vector
$\vec{T}$	source vector
$\vec{r}$	source-observer vector
α	blade pitch
β	regularization parameter
ω	angular frequency
σ_{max}	maximal singular value of $[H]$
σ_{min}	minimal singular value of $[H]$
τ	time relative to the source
r_o, θ_o, φ_o	spherical coordinates in the radiation space
r_s, φ_s	polar coordinates of the source point
H	Hermitian transpose
$+$	pseudo-inverse

Abid et al. [8]. The sth Fourier coefficient of this acoustic pressure is given by:

$$P_s = \frac{is\omega^2}{8\pi^2 c_0}\int_0^{\frac{2\pi}{\omega}} \frac{r_i F_i}{r^2} e^{is\omega\left(\tau+\frac{r}{c_0}\right)} d\tau \tag{1}$$

With τ is the time relative to the source, F_i the component of the unsteady rotating force $\vec{F}$ acting by the fan blade on the fluid and r_i the component of the source-observer vector $\vec{r}$ defined as follow:

$$\vec{r} = \begin{pmatrix} r_o \sin\theta_o \cos\varphi_o - r_s \cos\varphi_s \\ r_o \sin\theta_o \sin\varphi_o - r_s \sin\varphi_s \\ r_o \cos\theta_o \end{pmatrix} \tag{2}$$

With $\varphi_s = \omega\tau$ and r_s is the radius of aerodynamic center of the blade given as follow [2,9]:

$$r_s = \frac{2}{3}\frac{\left(R_2^3 - R_1^3\right)}{\left(R_2^2 - R_1^2\right)} \tag{3}$$

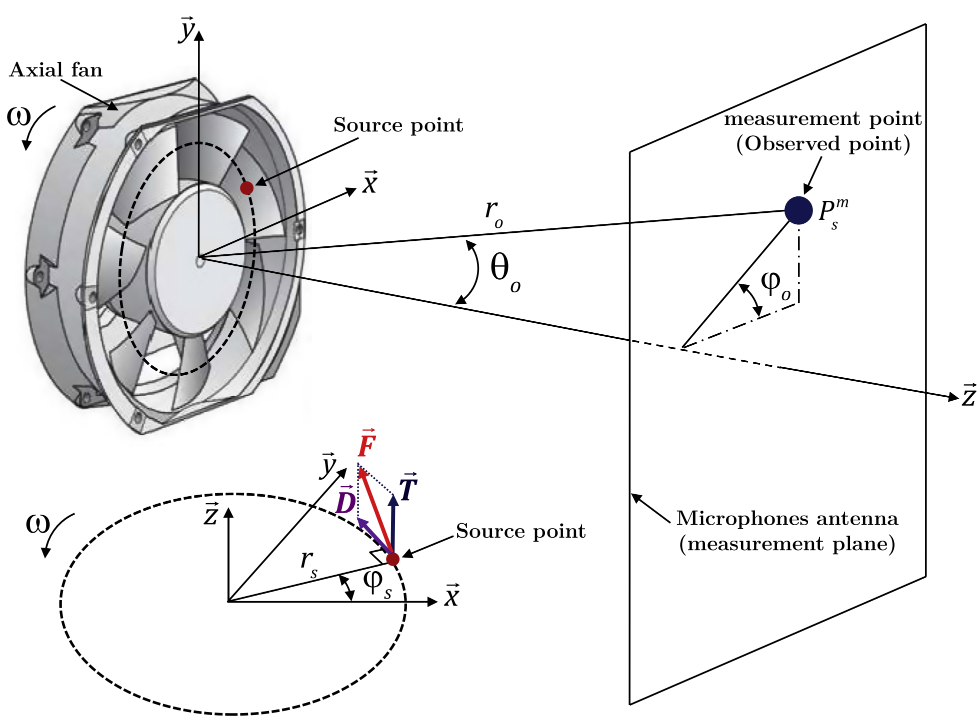

Fig. 1. Coordinate system and variables for the studied fan.

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