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Installation effects on the tonal noise generated by axial flow fans

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ABSTRACT

The paper presents the results of experiments on a low-speed axial-flow fan flush mounted on flat panels typically employed in tests on automotive cooling fans. The experiments have been conducted in a hemi-anechoic chamber and were aimed at evaluating the installation effects of the whole test configuration, including chamber floor and size and shape of the mounting panel. The largest panels cause important SPL variations in a narrow, low frequency range. Their effect on the propagation function has been verified by means of parametric BEM computations. A regular wavy trend associated with reflections from the floor is also present. In both cases, the tonal noise is more strongly affected than the broadband one.

The analysis is performed by means of an existing spectral decomposition technique and a new one, which allows to consider different noise generating mechanisms and also to separate the emitted tonal and broadband noise from the associated propagation effects. In order to better identify the features of the noise at the blade passing frequency (BPF) harmonics, the phase of the acoustic pressure is also analysed.

Measurements are taken during speed ramps, which allow to obtain both constant-Strouhal number SPL data and constant-speed data. The former data set is employed in the new technique, while the latter may be employed in the standard spectral decomposition techniques.

Based on both the similarity theory and the analysis of the Green's function of the problem, a theoretical description of the structure of the received SPL spectrum is given. Then, the possibility of discriminating between tonal and broadband noise generating mechanisms is analysed and a theoretical base for the new spectral decomposition technique is provided.

1. Introduction

Tests on low-speed axial-flow fans are often performed in hemi-anechoic chambers, possibly resulting in a departure from the expected free-field conditions, but also in modifications in the flow-field. This is a general problem regarding the effects of the mounting configuration [1–6]. In the present work, a typical configuration [7] for tests on low-speed axial fans for automotive applications is considered: the fan is supported by a flat, stiff panel and a microphone is located on-axis upstream of the rotor. The whole assembly is positioned in the test chamber, at a height from the floor and the fan outlet flow is re-ingested after mixing with the air within the chamber. Such test conditions require adopting a Turbulence Control Screen (TCS), see for instance [8,9], which destroys the incoming turbulent structures, thus eliminating the associated tonal

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Nomenclature

a_0	speed of sound
A	blade area, amplitude of a generic wave
C	constants in Eqs. (5), (6) and (8), functions of the harmonic order
d	distance between source and receiver
D	diameter
$\mathbf{e}_3$	versor of the axial coordinate
$E[-]$	expected value operator
f	frequency
F	source spectral distribution function
$\mathbf{F}$	surface distribution of the dipole strength
$\mathfrak{F}$	non-dimensional function in Eq. (1)
G	propagation function
g	Green's function
h	auxiliary function in Eq. (10)
h_R	height of the rotational axis from the ground
H	auxiliary function used in Eq. (14)
He	Helmholtz number
j	imaginary unit
k	harmonic order of the BPF
K	constant in Eqs. (7) and (8)
Ma	Mach number at the rotor tip
m	summation index in Eq. (16)
n	harmonic order of the rotational speed
$\mathbf{n}$	unit vector normal to the blade surface
N_g	number of uncorrelated noise generating mechanism
OASPL	overall SPL, ref. 20 μPa
p	acoustic pressure
$p_{bl}(\mathbf{y},t)$	blade surface static pressure
p_0	ambient static pressure
p_{out}	static pressure at the fan discharge
p_{ref}	reference acoustic pressure, 20 μPa
P	amplitude of tonal noise peaks in $S_{pp}(\omega)$
Q	volume flow rate
r	distance between rotor centre and receiver
R	$=D/2$, radius
Re	Reynolds number
Re[-]	real part
S_{aa}	one-sided auto power spectral density of a
S_{ab}	one-sided cross power spectral density of a and b
SPL	sound pressure level spectrum, ref. 20 μPa
St	Strouhal number based on the rotational frequency
t	time
T	time interval
$\mathbf{x}$	receiver position vector
x_1, x_2, x_3	cartesian components of $\mathbf{x}$
$\mathbf{y}, \mathbf{y}', \mathbf{y}''$	source position vector
y_1, y_2, y_3	cartesian components of $\mathbf{y}$
z	rotor blade number
α	Mach number exponent in Eq. (3)
β	Reynolds number exponent in Eq. (3)
γ	coherence function
Γ	level of the function G
$\delta(-)$	Dirac Delta function
ΔA	area of a correlated source
Δf	frequency resolution, frequency repetition
Δn	harmonic order resolution
ΔSt	Strouhal number resolution
$\Delta \Omega$	rotational speed resolution
ϑ	azimuthal coordinate
Θ	inclination angle
λ	wavelength
Π	level of the function F (for tonal noise)
ρ	air density, radial coordinate
φ	$=8Q/\pi\Omega D_{tip}^3$, flow coefficient
ϕ	phase angle
Φ	level of the function F (for broadband noise)
Ω	rotational speed

Subscripts

bb	related to broadband noise
bl	related to the blade surface
dir	related to the direct radiation path
ext	related to the annular panel external edge
hub	related to rotor hub
max,1, max,2	related to the Γ_{comp} maxima about the dip
out	related to discharge conditions
refl	related to the reflected radiation path
t	related to tonal noise
tip	related to blade tip
VK	related to von Kármán vortices
0	related to the ambient conditions

Superscripts

*	complex conjugate
~	Fourier transform
–	average value
=	weighted-average value
bb	related to broadband noise
t	related to tonal noise

noise generating mechanism [10–12] with no significant modifications in performance [13,14]. In the present case, the TCS is constituted of a further annular panel which supports a hemispheric hood made of fabric. From the acoustic point of view, the fabric should have a limited transmission loss but the panel may cause a significant alteration in the received noise. Though the studied configurations were different, similar effects have already been reported [15,16]. They may be explained considering that diffraction from the panel edges and a stiff wall boundary condition on its surface affect the expected free-field conditions. A common solution to this problem is lining the panel with a layer of sound absorbing material, see for instance Sturm and Carolus, [9], but, unfortunately, this results in practical complications when measurements have to be taken on different fans. The chamber floor constitutes a reflecting plane, [1], which further affects the radiated noise.