Computation of Broadband Noise Radiated by a Ducted Fan

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Broadband fan noise has become the major component of sound radiated by high-bypass-ratio turbofans, because of the past progress in reducing the tones. The main difficulties in predicting it arise from the facts that there are several competing noise generation mechanisms, and that the input data are generally poorly known. The method proposed here is aimed at avoiding these drawbacks, and at being easy to implement. It is based on dipole radiation from a ducted rotor. It assumes that the blade loading spectrum is flat, according to previous tests in a SNECMA facility. The sound pressure is computed using the Ffowcs Williams and Hawkings model in which the Green's function in free space is replaced by the Green's function in a cylindrical hard-walled duct. Free-field radiation is derived using the Tyler and Sofrin model. It has been checked that the acoustic power balance between the induct and free-field sound fields is excellent if the mean flow is neglected inside the duct. Directivity patterns, sound power spectra, and the variation of the overall sound power level versus the rotation speed are in good agreement with FANPAC upstream acoustic measurements which were analysed in a previous IJAV article. The effect of the radial turbulence length scale along the blade span is also predicted.

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Notations

$A_{m\mu}$ — Acoustic pressure amplitude
a — Speed of sound
B — Number of rotor blades
b — Rotor blade span
C — Blade load constant
D, θ, ϕ — Spherical coordinates for free-field radiation
d, ψ, y_1 — Cylindrical coordinates of a source $\vec{\mathbf{y}}$ on the rotor
$F, \hat{F}$ — Blade load, and its azimuthal Fourier transform
f — Frequency
G — Green's function
I — Sound intensity
$\Im$ — Integral on a point source
J_m — Bessel function of first kind and of order m
K, k_t, k_z — Total, transverse, and axial wave-numbers
L — Duct length
l — Radial turbulence length scale
m, μ — Spinning mode (m azimuthal, μ radial)
M_{ax} — Axial Mach number in the annular duct in front of the rotor
M_{tip} — Tip rotational Mach number
M_z — Mach number of the uniform flow in the duct
N — Rotor angular rotation speed (either in rpm or in Hz)
n — Number of point sources along the blade span in non-compact calculations
p, P — Sound pressure in the duct and in the far field, respectively
q — Exponent of decrease of the blade pressure fluctuations at high frequency
R — Duct radius
r, φ, x_1 — Cylindrical coordinates of a point $\vec{\mathbf{x}}$ in the duct
S — Blade surface area
t, τ — Reception time, emission time
U_{rot} — Rotation speed of a point source on a blade
W — Sound power
δ — Dirac function
ρ_0 — Mean fluid density
σ — Fan hub-to-tip ratio
$\chi_{m\mu}$ — μ-th root of $J'_m = 0$
Ω — Rotor angular rotation speed ($\Omega = 2\pi N$)
ω — Angular frequency ($\omega = 2\pi f = aK$)

Subscripts

c — Angular reference location of the blade chord (for swept blades)
d — Design parameters
D, T — Drag, thrust
f — Fourier transform of the reception time, t
max — Maximum value
s — Blade loading frequency
1 — Axial coordinate (along the z-axis)

Abbreviations

OAPWL — Overall sound power level
OASPL — Overall sound pressure level
PWL — Sound power level
SPL — Sound pressure level

1. INTRODUCTION

Broadband fan noise has become increasingly important in aircraft turbofans because tones have been reduced during the past few decades.[1] Its prediction is thus needed to allow further reduction of the noise radiation by aircraft in the future. Some semi-empirical methods based on full scale tests are available, such as the one from NASA Lewis for computing tones, multiple pure tones and broadband components radiated either forwards or rearwards.[2] A similar method due to