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Prediction and reduction of internal blade-passing frequency noise of the centrifugal fan in a refrigerator

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ABSTRACT

The internal blade-passing frequency (BPF) noise of a centrifugal fan in a household refrigerator is computed using a hybrid method. The unsteady flow field of the centrifugal fan in a duct is predicted by solving the incompressible Reynolds-averaged Navier–Stokes equations with conventional computational fluid dynamics techniques. The principal sources of noise are then extracted from the predicted flow field through the acoustic analogy. Finally, the internal BPF noise is predicted using the modeled sources in combination with the boundary element method. A parametric study using this hybrid technique shows that the BPF noise levels predicted for various non-dimensional cutoff distances closely follow the experimental data. Based on this result, a low-noise design for the centrifugal fan is proposed. A BPF noise reduction of approximately 3 dB is achieved in comparison with the original model, which is in good agreement with the prediction using the hybrid techniques.

Prévision et diminution du bruit associé á la fréquence des passages des aubes du ventilateur axial d'un réfrigérateur

Mots clés : Réfrigérateur domestique ; Expérimentation ; Mesure ; Bruit ; Ventilateur ; Modélisation

1. Introduction

Fans in refrigerators are used for several purposes: to cool the compressor, to circulate cold air from the evaporator to the freezer and the cool chamber, and to make cakes of ice for the external ice dispenser (Lee et al., 2008a,b). Together with the compressor, the fan is a source of noise that contributes the most to the refrigerator's overall noise level. In large refrigerators, circulating fans must rotate faster to generate larger flowrates. Such high-speed rotation causes fan noise to be of

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Nomenclature

Roman symbols

A	A-weighted level
B	the number of blades
c	speed of sound, m/s
CMM	cubic meters per minute, m^3/min
f	force per unit volume, N/m^3
P	hydrodynamic pressure, Pa
p	acoustic pressure, Pa
R	radius of centrifugal fan, m
RPM	rotation per minute, rotation/min
SPL	sound pressure level Re. 2×10^{-5} Pa, dB
t	time, s
u, v, w	fluid velocity in x, y, and z directions
V	cell volume, m^3
$\mathbf{x}$	position vector of observation location
$\mathbf{y}$	position vector of source location

Greek symbols

Δr	distance between the volute tongue and the tip of fan blade, m
ρ	density, kg/m^3
τ	source time, s
υ_{eff}	effective viscous term

Subscript

υ	viscous term
0	mean quantity

greater concern than other sources of noise in a refrigerator. Systematic design tools, which are used to estimate the noise from fans, are essential in creating low-noise designs.

Many studies using experimental and/or numerical methods have been carried out on fan noise and have contributed to a better understanding of the mechanisms of fan noise generation. These mechanisms can be characterized according to whether the fan is a centrifugal or axial type. For centrifugal fans, Neise (1975, 1976, 1982) provided a detailed review of noise-reduction methods that use measurement techniques; he showed that the main source of aerodynamic tonal noise is the interaction between non-uniform impeller flow and the fixed-volute tongue. Velarde-Suárez et al. (2006) carried out an experimental study on the source of tonal noise from centrifugal fans. They showed that the strong source of noise at the blade-passing frequency (BPF) is the interaction between the fluctuating flow that leaves the impeller and the volute tongue, and that the source region is concentrated in the vicinity of the volute tongue. Based on this finding, Velarde-Suárez et al. (2008) performed experiments on the reduction of aerodynamic tonal noise of centrifugal fans by modifying the volute tongue.

Numerical approaches have been used to understand the unsteady flow fields and mechanisms of noise generation by fans. Moon et al. (2003) solved two-dimensional (2-D) Navier–Stokes equations using a finite volume method coupled with Curle's model to predict the dipolar tonal noise of a centrifugal fan. Maaloum et al. (2004) used Reynolds-averaged Navier–Stokes (RANS) equations in conjunction with Ffowcs-Williams and Hawkings' far-field model to predict dipolar tonal noise from an axial fan. Khelladi et al. (2008) used similar approaches to assess the relative

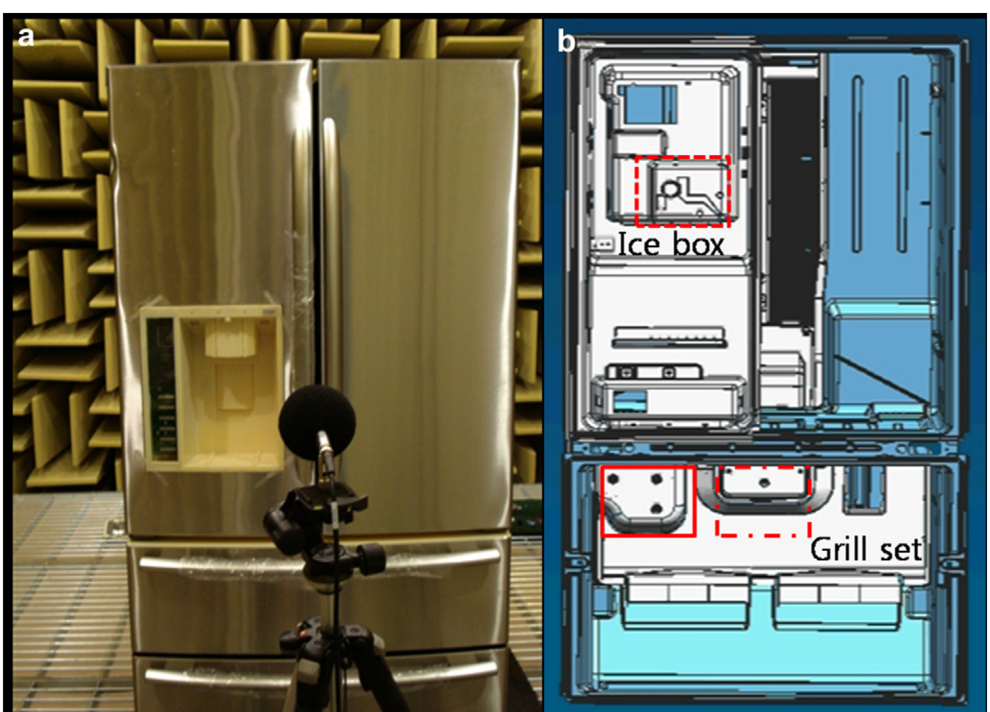

Fig. 1 – Experimental setup for the measurement of total noise level of the refrigerator and its internal structure: (a) the targeted refrigerator, and (b) CAD representation of the internal structure of the refrigerator.