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Experimental investigation of the noise emission of axial fans under distorted inflow conditions

Florian J. Zenger *, Andreas Renz, Marcus Becher, Stefan Becker

Friedrich-Alexander University Erlangen-Nürnberg, Institute of Process Machinery and Systems Engineering, Cauerstr. 4, 91058 Erlangen, Germany

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ABSTRACT

An experimental investigation on the noise emission of axial fans under distorted inflow conditions was conducted. Three fans with forward-skewed fan blades and three fans with backward-skewed fan blades and a common operating point were designed with a 2D element blade method. Two approaches were adopted to modify the inflow conditions: first, the inflow turbulence intensity was increased by two different rectangular grids and second, the inflow velocity profile was changed to an asymmetric characteristic by two grids with a distinct bar stacking.

An increase in the inflow turbulence intensity affects both tonal and broadband noise, whereas a non-uniform velocity profile at the inlet influences mainly tonal components. The magnitude of this effect is not the same for all fans but is dependent on the blade skew. The impact is greater for the forward-skewed fans than for the backward-skewed and thus directly linked to the fan blade geometry.

1. Introduction

Aeroacoustic noise radiation has become a key parameter to be taken into account during the design and development of low-speed axial fans. Two important parameters that directly affect the noise emission of axial fans are the blade design strategy and the inflow conditions.

1.1. Influence of blade skew on noise emission of axial fans

Blade skew is an effective measure to reduce the tonal noise of axial fans [1]. As a consequence of the nonuniform inflow conditions, axial fans emit tonal noise at the blade passing frequency (BPF) and its higher harmonics. This is due to variations of the relative inflow velocity to the blade, which lead to periodic changes in the angle of attack and fluctuating blade forces (periodic loading) [1–3]. Skewed fan blades reduce this source mechanism as each section of the fan blade interacts with the inflow at a different instant and thereby reduces the maximum force [1].

Depending on the blade skew (forward or backward), the turbulent boundary layer thickness is reduced (forward-skewed fan blades) or increased (backward-skewed fan blades) [1,4]. If a backward sweep is applied, the boundary layer fluid will move further outwards and therefore travel a longer path along the blade before reaching the trailing edge – the

* Corresponding author. Fax: +49 9131 8529462.
E-mail address: ze@ipat.uni-erlangen.de (F.J. Zenger).

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Nomenclature

A	measurement surface
A_0	reference surface
c	flow velocity
c'	velocity fluctuations
c_L	lift coefficient
c_{ref}	reference velocity
d	duct diameter
D	rotor diameter
D_{hub}	hub diameter
$\tilde{e}$	specific shaft work
F_u	tangential force
I	integral time scale
k_0	grid design resistance grading
l	airfoil chord length
L_P	sound pressure level
L_W	sound power level
M_{mesh}	mesh size
n	rotational speed
N	number of samples
r	radius
R	normalized autocorrelation coefficient
s	tip gap
t	blade spacing
t_{bar}	grid bar width
t_s	grid stacking distance
T	torque
u	circumferential velocity
$\dot{V}$	volume flow rate
w_∞	local mean flow velocity
z_b	number of blades
α	angle of attack
α_s	solidity
β_∞	local mean flow angle
Δp	pressure difference
Δp_{ts}	total-to-static pressure difference
Δp_t	total pressure difference
ϵ	drag to lift ratio
η_{ts}	fans efficiency
λ	sweep angle
λ_g	grid design velocity factor
Λ_x	integral length scale in the x-direction
ν	dihedral angle
ρ	fluid density
τ	time lag
φ_g	grid rotational angel
Φ	flow rate coefficient
ψ_{ts}	pressure coefficient

opposite applies to a forward sweep. As a consequence, the boundary layer thickness of backward-skewed fans is expected to be greater. Broadband noise is influenced by, among others, pressure fluctuations on the blade surface due to the turbulent boundary layer. This mechanism is considered to be more dominant for backward-skewed fans. However, no great impact is expected from this mechanism [4].

1.2. Influence of inflow distortions on noise emission of axial fans

In addition to the fan design, the inflow conditions have a major effect on the tonal and broadband noise emission of axial fans. Two different approaches to alter the inflow conditions are the modification of the inflow turbulence intensity and the modification of the velocity profile at the inlet (or a combination of the two). Both approaches affect tonal noise generation. As an increased inflow turbulence intensity and a velocity profile at the inlet both induce nonuniformity of the inflow, tonal components at the blade passing frequency (BPF) and its harmonics are elevated. The reason for this behavior is higher periodic fluctuating blade forces [5]. If the integral length scale of the inflow is greater than the blade chord length, which is especially the case if elongated turbulent structures in the casing boundary layer interact with the blade tips, tonal noise at the BPF and its harmonics can be created [6]. Sturm and Carolus [7] showed that large structures at the intake can also be a source of tonal components at the BPF. Christophe et al. stated that a 90° turn of the mean flow direction in front of the inlet can increase tonal components [8].

In terms of broadband noise, only an increased inflow turbulence intensity is expected to have an impact. If the integral length scale is smaller than the blade chord length, a local area with pressure fluctuations develops at the leading edge of the fan blades, resulting in broadband noise [9]. Schneider [10] showed that broadband noise can be profoundly influenced by increased inflow turbulence.

When considering the influence of either the fan blade design or inflow distortions on the aeroacoustic noise emission of axial fans, it is obvious from the studies cited above that those mechanisms are well understood. However, the combination of these two mechanisms needs to be further investigated as there is little knowledge so far on how the two mechanisms interact. According to Wright and Simmons [4], a backward swept blade is considered to reduce the noise due to the interaction of the turbulent inflow with the fan blade leading edge more efficiently than with forward swept blades. However, no physically founded explanations have been given for this phenomenon. Hence this study was aimed at experimentally investigating the effect of inflow distortions on the aeroacoustic noise emission of unskewed and forward/backward-skewed fans.

In Section 2, the design procedure and parameters of the three different fans are described. The experimental setup for sound- and flow-field measurements is outlined in Section 3 and Section 4 presents the experimental results and a discussion. Section 5 summarizes the results obtained and points out the benefits of the new insight.