Redesign of an electric motor cooling fan for reduction of fan noise and absorbed power

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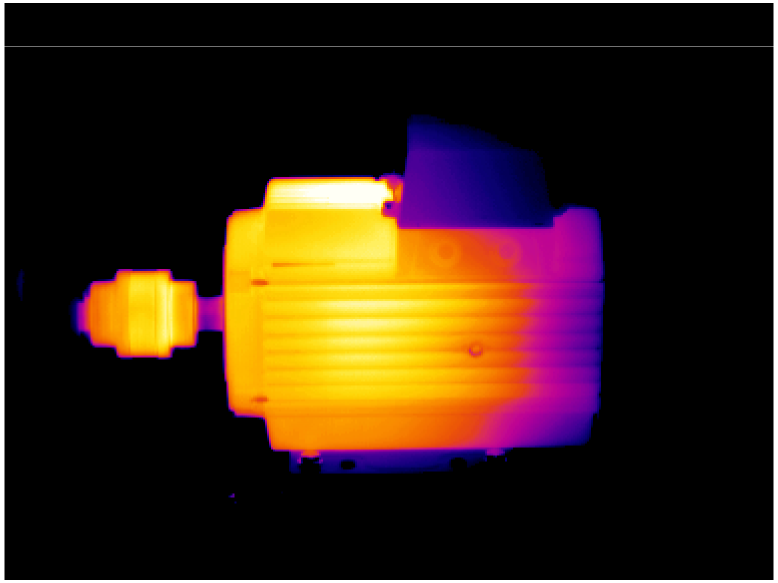
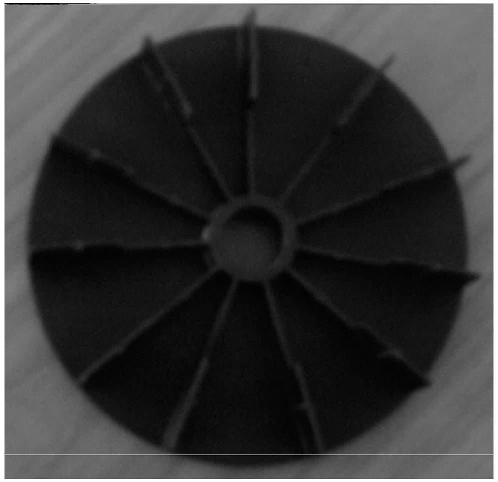
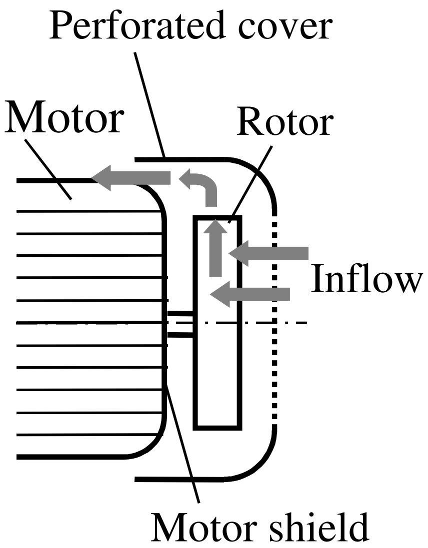
Outline

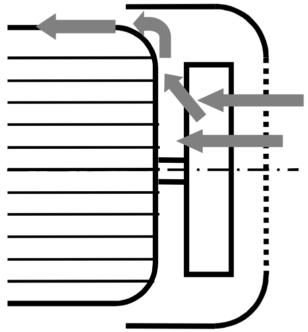
- Objectives: radial $\rightarrow$ axial motor cooling fan
- Survey on the existing radial fan
- Axial fan design
- Prototyping and testing
- Summary



1. Introduction and objectives







Radial datum rotor

Axial rotor as result of redesign
(Rotor environment unchanged)

Simple geometry
Unidirectional operation
BUT
Flow separation
Increased aerodynamic loss
Pronounced noise

More complex geometry
Bidirectional operation
BUT

Moderate absorbed power
Moderate noise

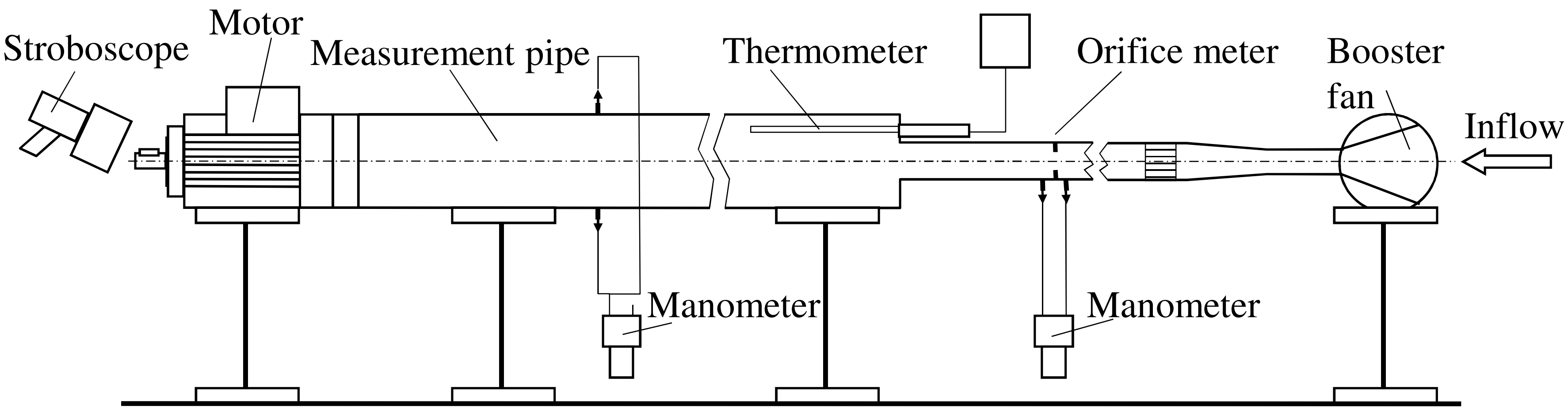
RADIAL FANS

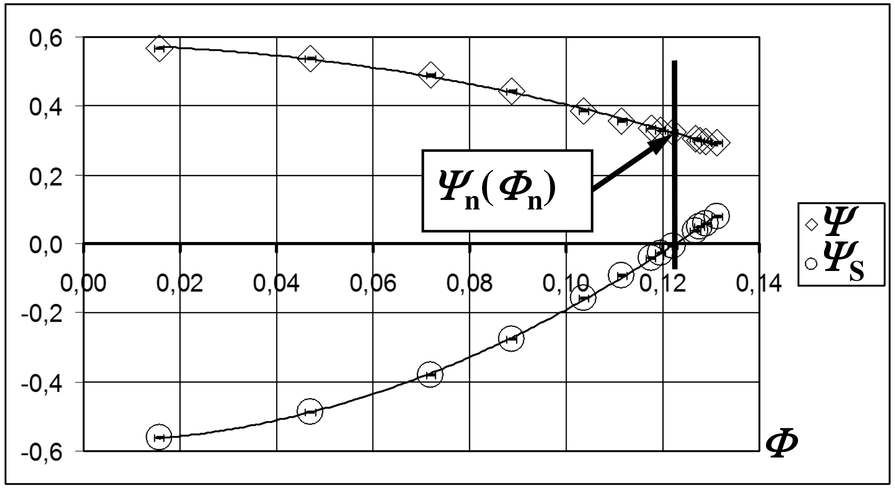
- Only very few publications on radial flow blade rows with extremely high incidence (as for truly radially shaped straight blades) (Noda et al., 2005; Johnson et al., 2007)
- No combination of aerodynamic and acoustic aspects
- No literature on characteristic and efficiency curves

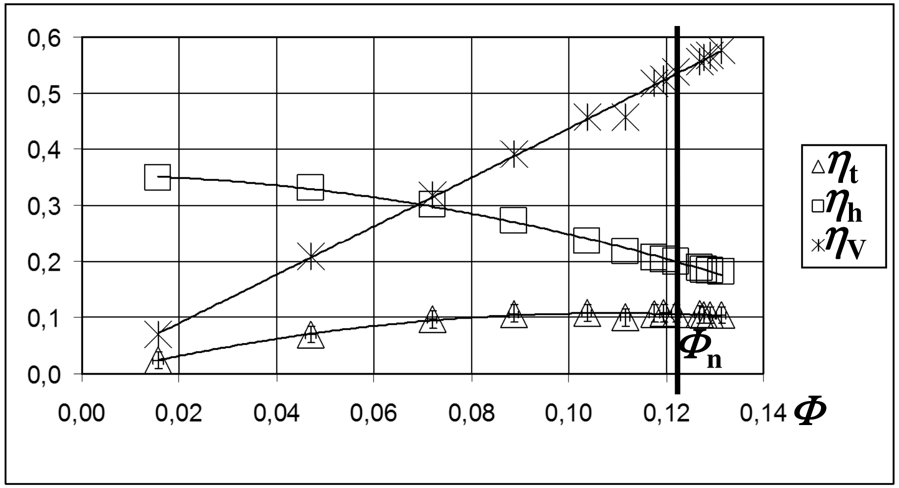
AXIAL FANS

- Automotive cooling fans, operating in a confined environment (e.g. Gifford et al., 2009; Moreau et al., 2009) ⇔ presence of perforated cover; motor shield located extremely close downstream
- Combined aerodynamic and acoustic aspects of „radial" tip clearance (e.g. Corsini et al., 2009) ⇔ no „radial" clearance (shrouded rotor) but „axial" clearance

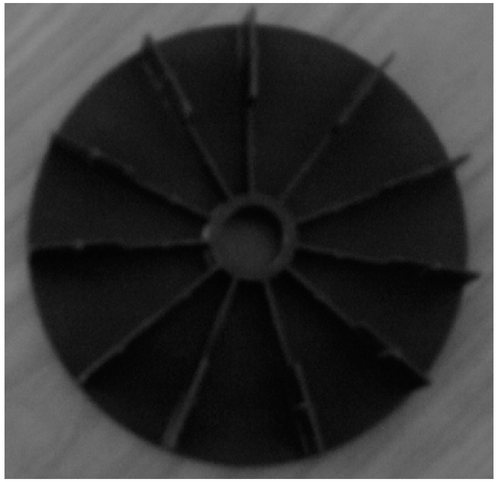
2. Survey on the existing radial fan

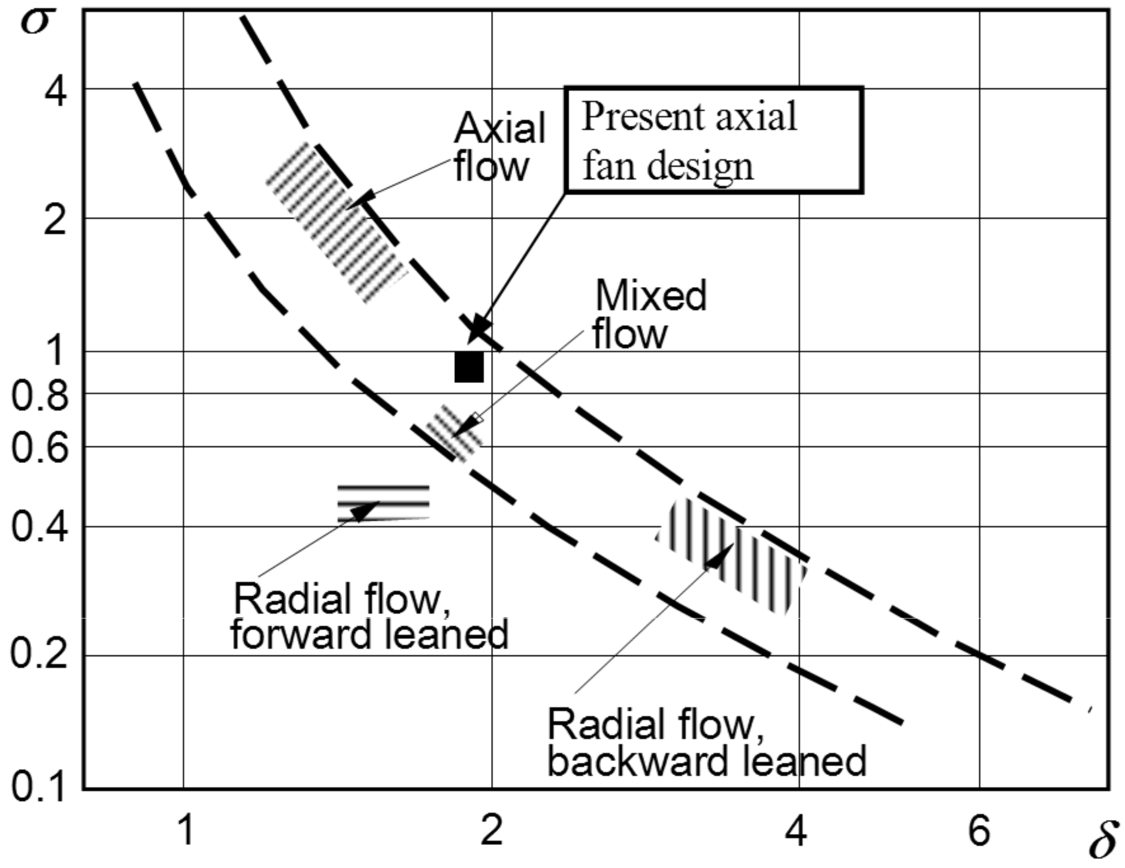






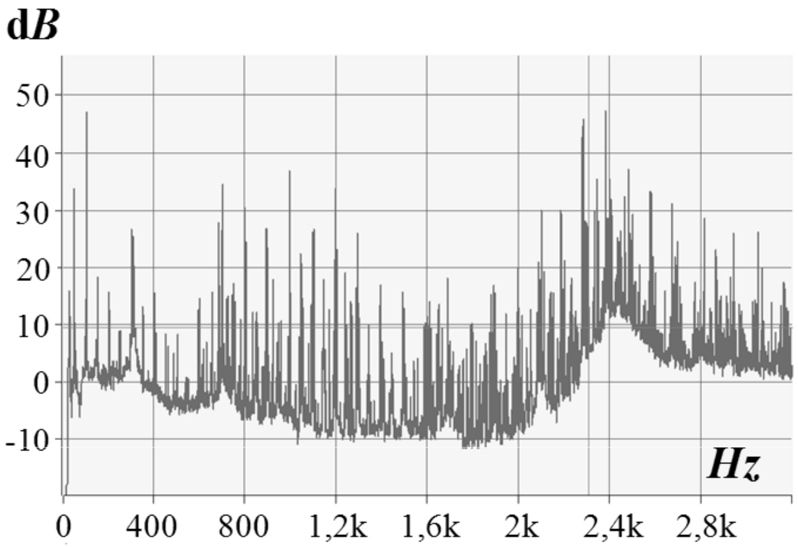
N	11
Re	$1.51 \cdot 10^{5}$
Ma	$5.29 \cdot 10^{-2}$
Φ_n	0.123
Ψ_n	0.322



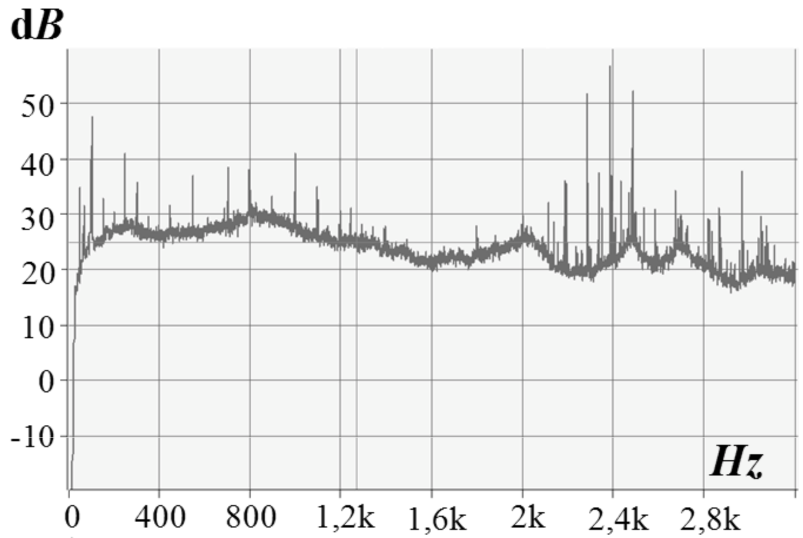


Cordier diagram

Acoustic investigation



Motor alone



Motor with rotor and cover

Measured sound pressure level spectra

3. Axial fan design

Aerodynamics

Controlled vortex design: spanwise increasing blade load

•Higher axial velocity at higher radii ⇒ cooling ribs

•Better utilization of blade sections at higher radii ⇒ high specific performance

•Near-hub blockage ⇔ unloading the near-hub blade sections

Strong radial outward flow ⇒ modelling conical stream tubes through the rotor

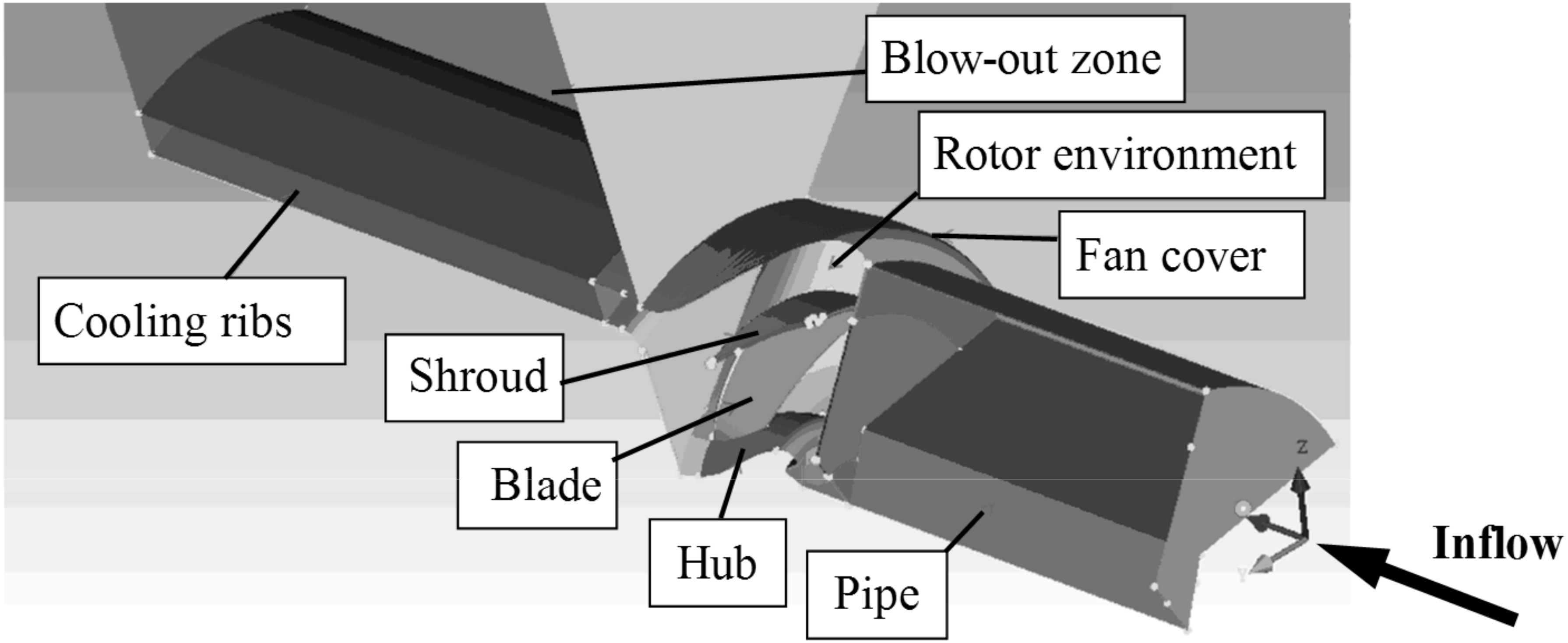
Motor shield close downstream ⇒ increased deviation ⇒ compensated

Acoustics

High specific performance ⇒ moderation of rotor circumferential speed ⇒ possibility for moderation of noise

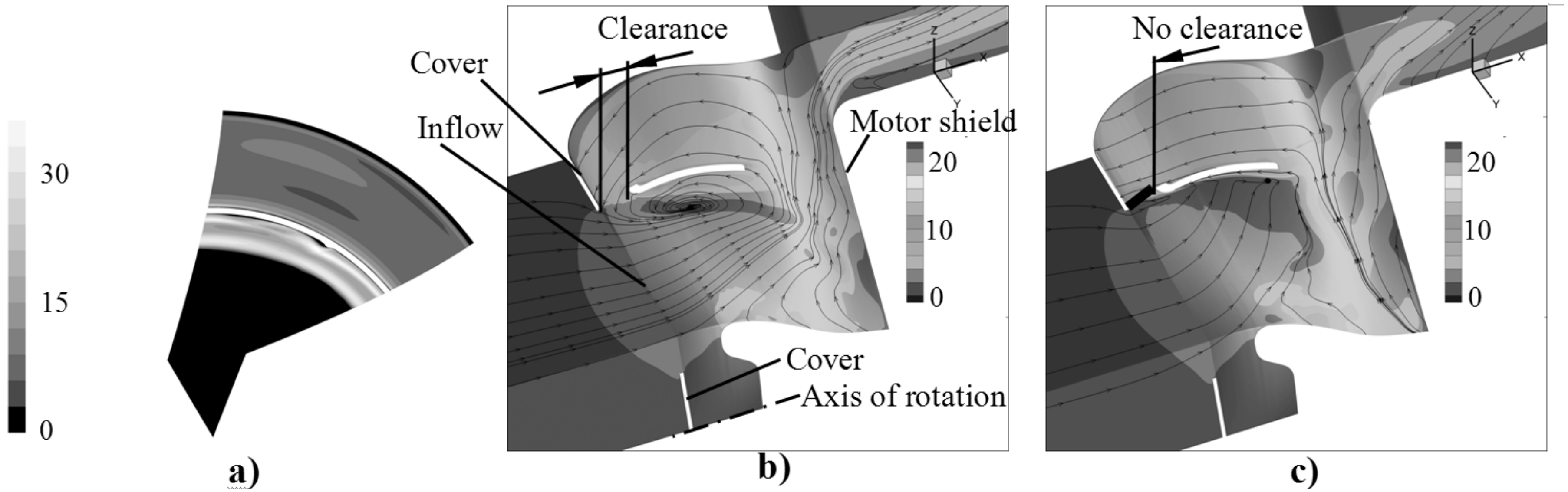
Sickle-shaped (forward-skewed) blades (⇔ interaction and BL noise)

Leakage flow

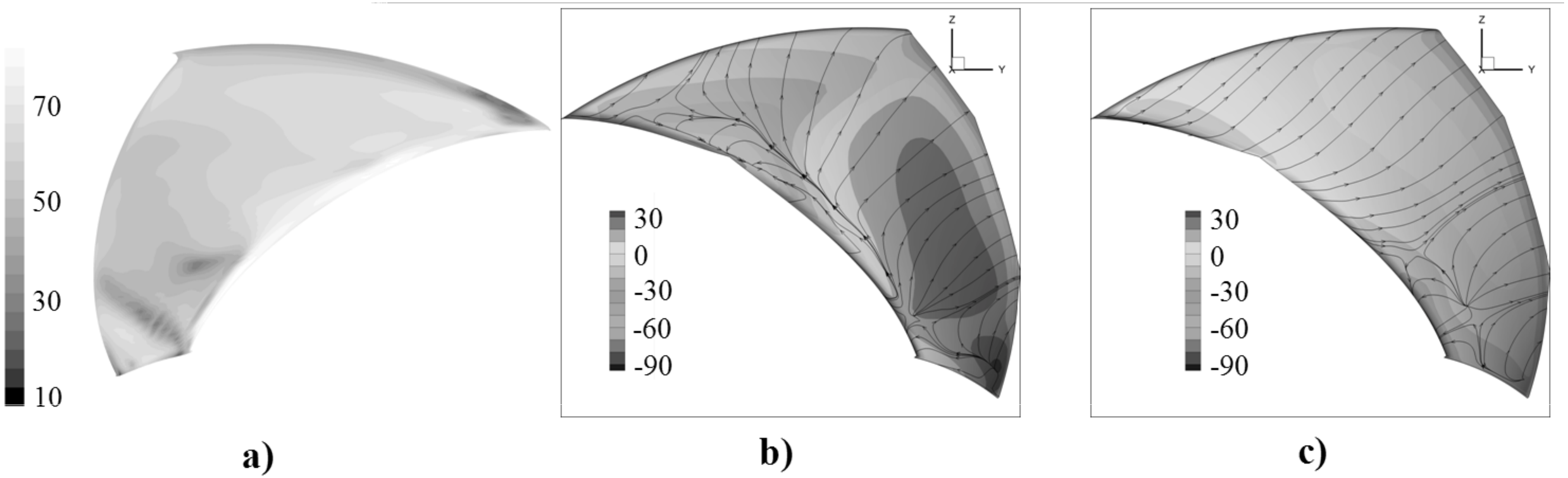


Computational domain

Computational Fluid Dynamics (CFD)
Computational Aero-Acoustics (CAA) (Cros and Carbonneau, 2009)

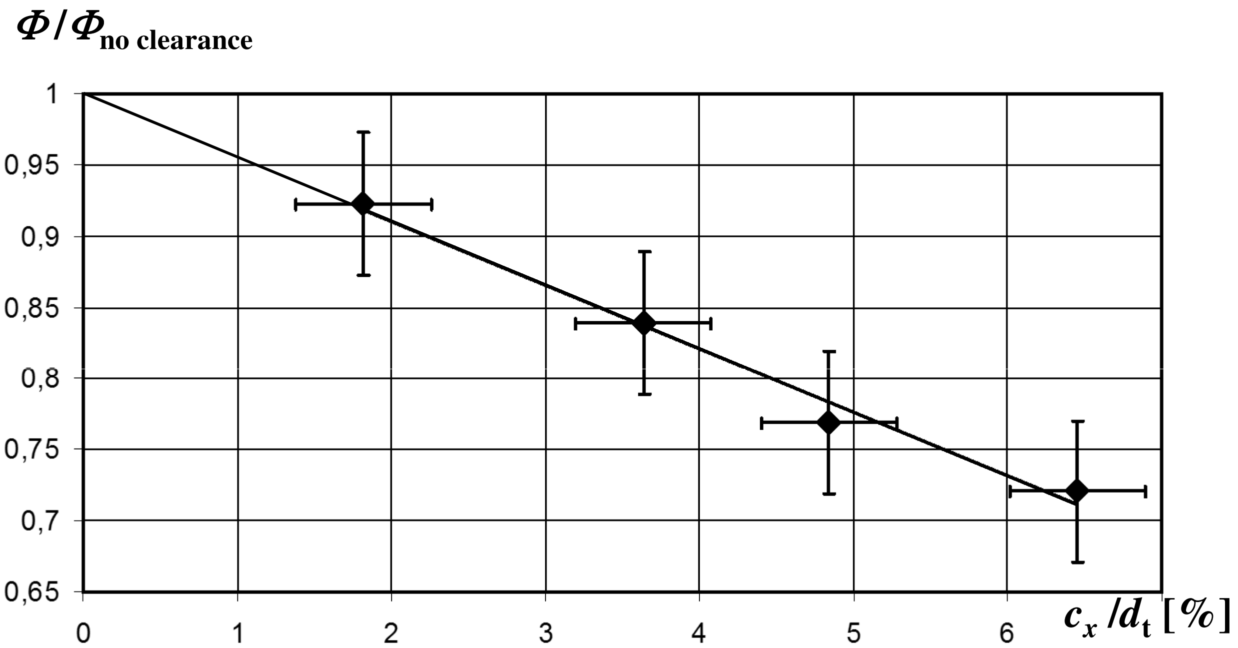


CAA and CFD results. a): c_x = 5.2 % d_t. Acoustic power level [dB] at the plane normal to the rotor axis just downstream of shroud inlet. b), c): Streamlines and velocity magnitude [m/s] in a meridional section. b): c_x = 5.2 % d_t. c): No clearance.

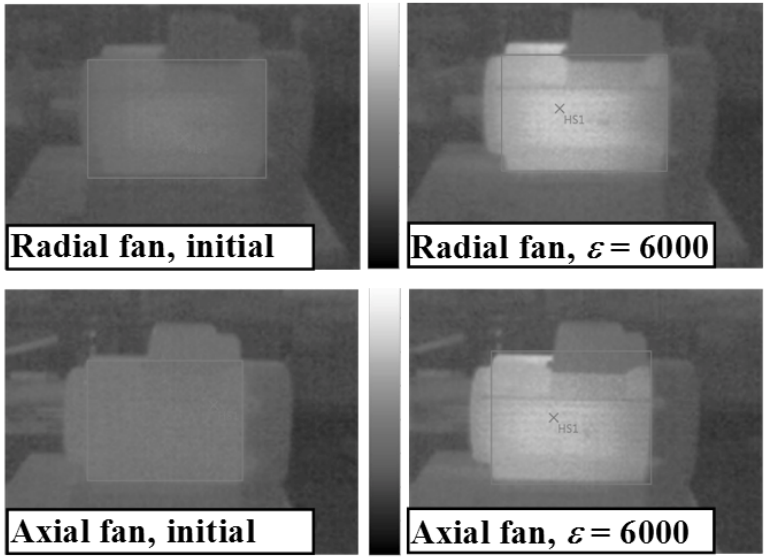


CAA and CFD results related to the blade surface. a): c_x = 5.2 % d_t. Acoustic power level [d*B*] on the suction side. b), c): Limiting streamlines and static pressure [*Pa*, relative to atmospheric] on the pressure side. b): c_x = 5.2 % d_t. c): No clearance.

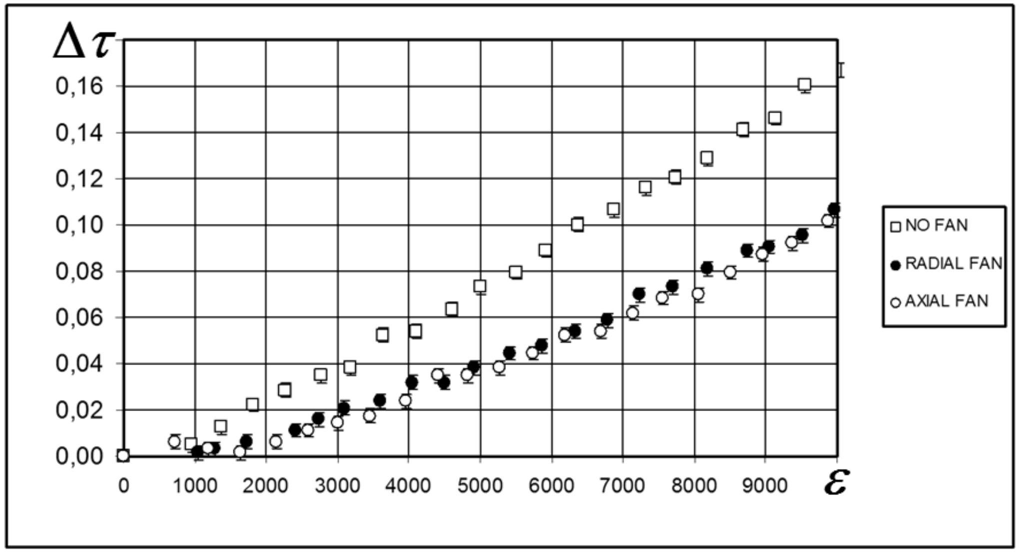
4. Prototyping and testing



4.1. Dependence of flow rate on axial clearance size: measurements



a)



b)

4.2. Thermodynamic studies

a) Examples for thermocamera records, b) Warm-up history

4.3. Acoustic studies

3 measuring points, 0.5 m distance, on-axis, ±90° off-axis
Axial fan: 7.3 dB(A) reduction of the A-weighted SPL

4.4. Absorbed shaft power

Axial fan: 30 % reduction

7. Summary

Radial fan

Characteristic and efficiency curves for a radial cooling fan with truly radially shaped straight blades

Redesign ⇒ Axial fan

- **Purposeful application of controlled vortex concept in axial fan design: less cooling demand at lower radii, more cooling demand near the circumference (cooling ribs)**
- **Leakage flow in the axial clearance: deterioration of flow conditions along the entire span – to be considered in design**
- **Flow rate delivered toward the cooling ribs: decreases nearly linearly with axial clearance size**
- **Leakage flow in the axial clearance: a major noise source**

Axial (vs. radial) fan

- **Unchanged cooling capacity**
- **≈7 dB(A) reduction of A-weighted sound pressure level**
- **≈30 % reduction of absorbed shaft power**