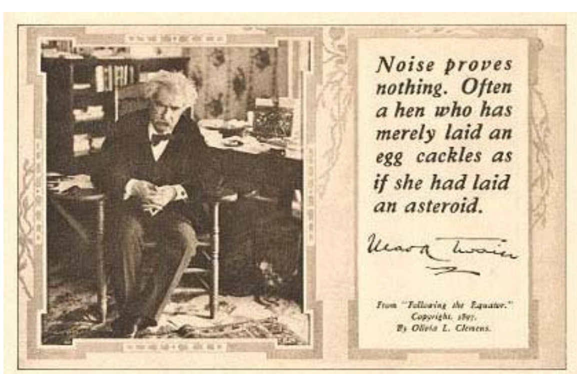
18 – 20 April 2012
Senlis, France

Noise Proves Nothing
- Sources of Fan Noise and Their Prediction -

Th. Carolus

Institut für Fluid- und Thermodynamik
Universität Siegen
Germany

UNIVERSITÄT SIEGEN

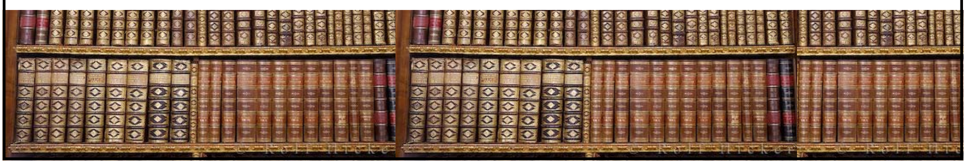


UNIVERSITÄT SIEGEN

NOISE PROVES NOTHING ....

- Rated machine power does not necessarily correlate with sound power
  (sound power << hydraulic power)

- Generalization of empirical findings on noise mechanisms and noise reduction methods is often difficult
  → overwhelming number of publications, conferences, ...



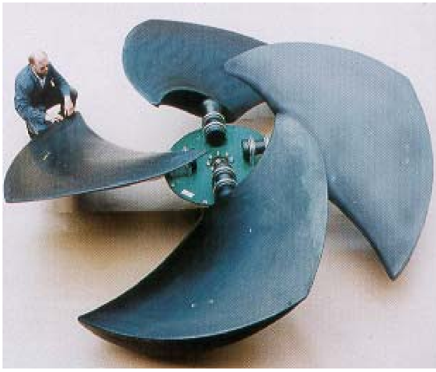
... nevertheless,

AEROACOUSTICS

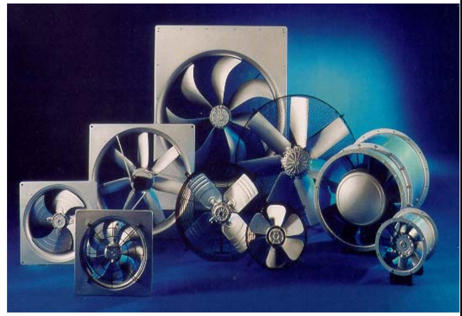
is a priority item in many fields of engineering

- Aero space
- Renewable energy systems
- Automotive
- Heating, ventilating, air conditioning (HVAC)
- Household appliances
- .....

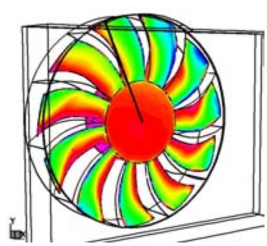
UNIVERSITÄT SIEGEN



HVAC for buildings (Howden)

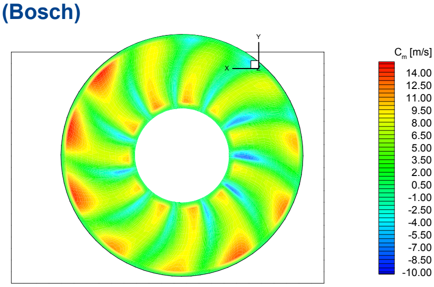


Multi purpose (Ziehl Abegg)



Radiator Cooling (Bosch)

HVAC (Bosch)



H. Reese 2001

S. Oerlemans et al. 2007,Starzmann et al. 2011

Objectives

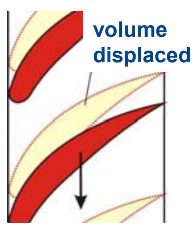
- **Understanding of basic noise mechanisms in fans**
- **Overview of engineering type noise prediction methods**
- **Selected experimental methods for noise measurement and source detection**

UNIVERSITÄT SIEGEN

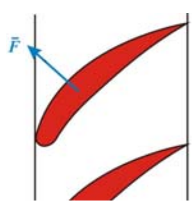
Contents

2. Overview: Basic fan noise mechanisms

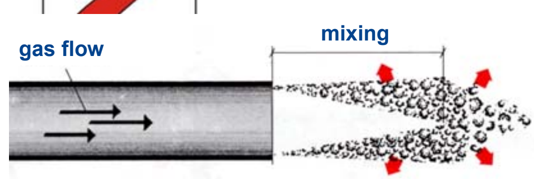
- Fluid displacement (Monopole sound)



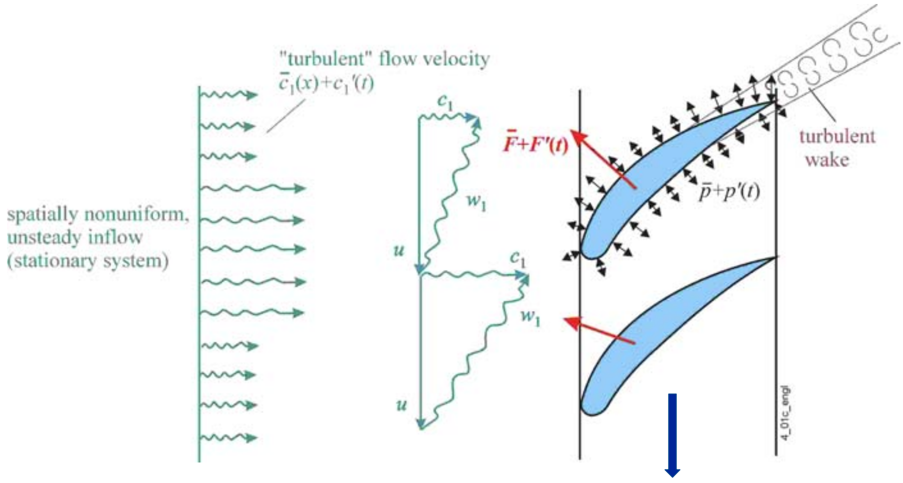
- Forces on surfaces (Dipole sound)



- Turbulence in fluid (Quadrupole sound)

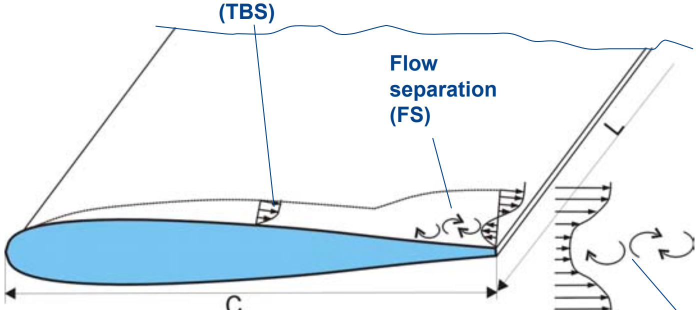


Forces on blade cascade



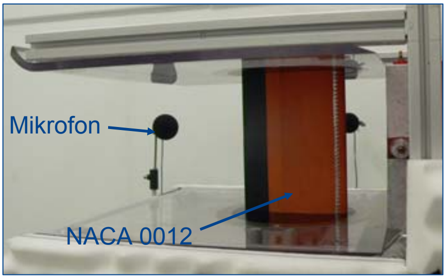
spatially nonuniform inflow ⇒ tonal noise („Unsteady loading noise“)
unsteady inflow ⇒ broad band noise

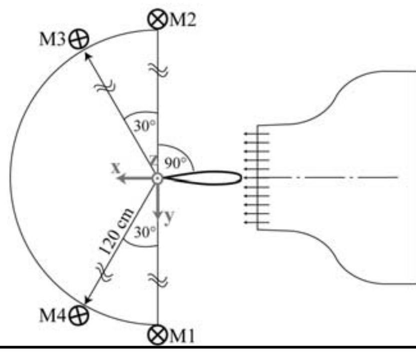
A detail: Airfoil self-noise



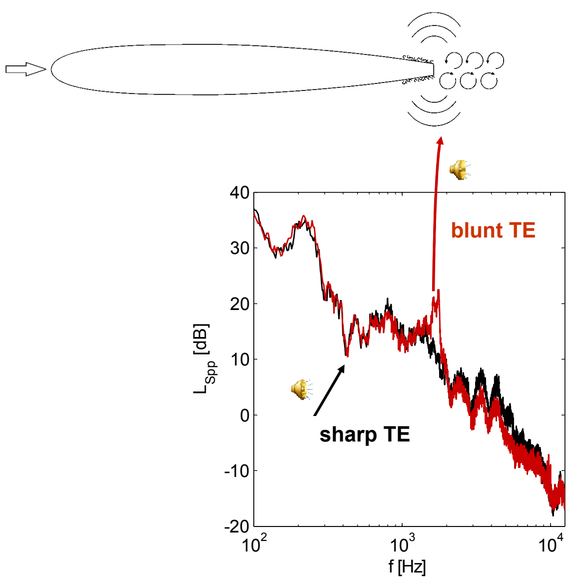
⇒ mostly broad band noise

Wind tunnel test of isolated airfoil

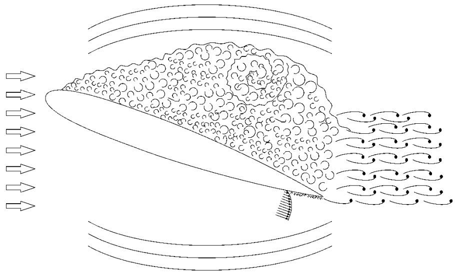


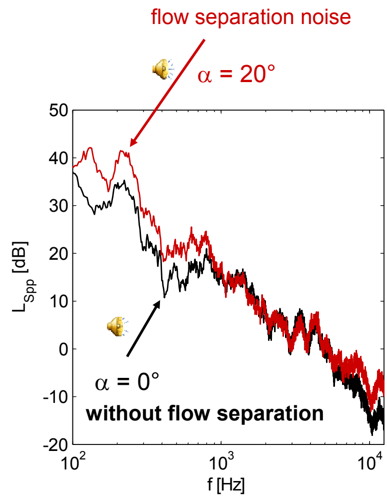


Bluntness of trailing edge

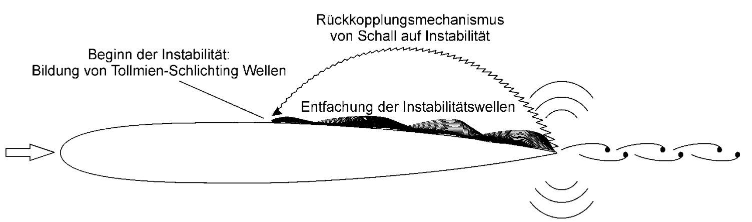


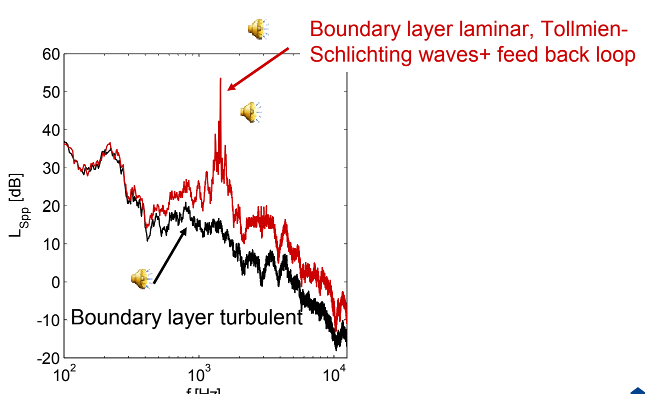
Flow separation noise



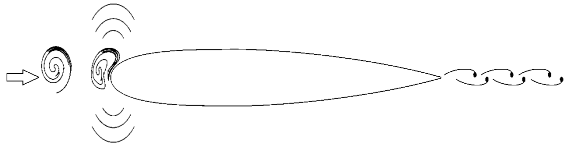


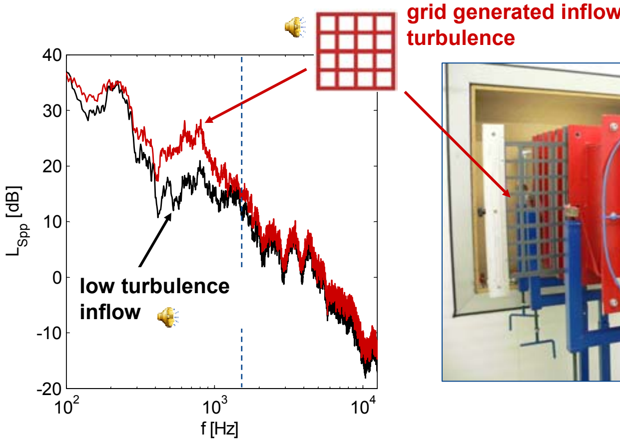
Low Reynoldsnumber whistling





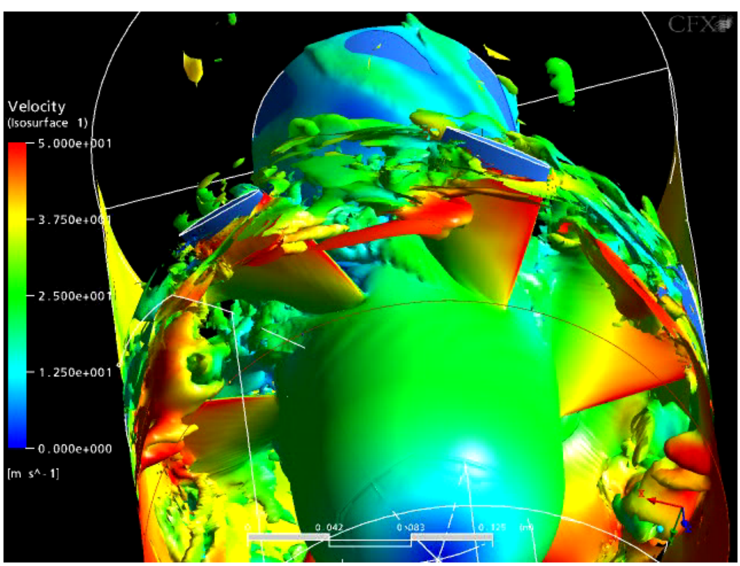
Turbulent inflow noise





UNIVERSITÄT SIEGEN

Secondary sources, e.g. tip clearence flow



UNIVERSITÄT SIEGEN

Classification of fan noise prediction methods

CLASS I
Basic maschine parameters
- type
- diameter
- speed
- flow rate
- pressure rise

CLASS II
- Separate consideration of various noise generation mechanisms
- Simplified fan geometry, flow field (e.g. blade ⇒ flat plate)
- Simplified flow analysis

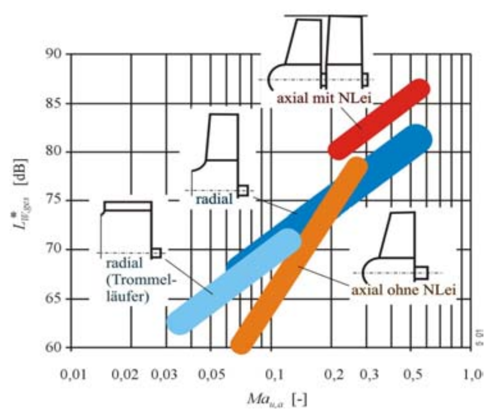
CLASS III
- Common consideration of various noise generation mechanisms
- Detailed fan geometry
- High fidelity flow field data (e.g. from unsteady CFD)

Class I → Simple algebraic function (correlation)

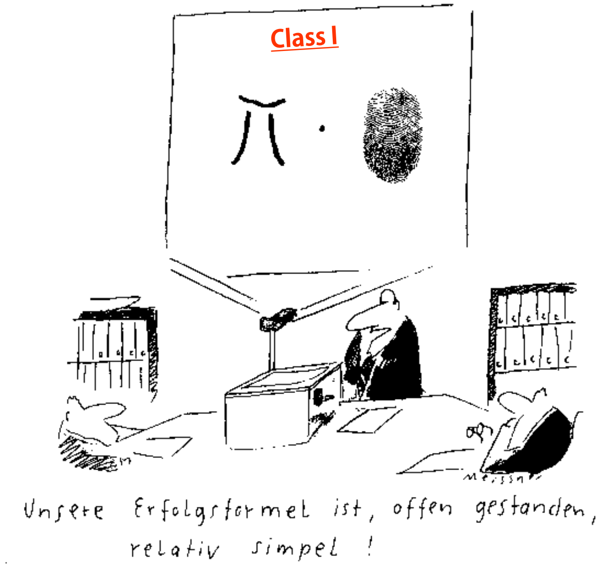
Class II, Class III → Acoustic models

Simple algebraic function (correlation) → (SPECTRAL) SOUND POWER ← Acoustic models

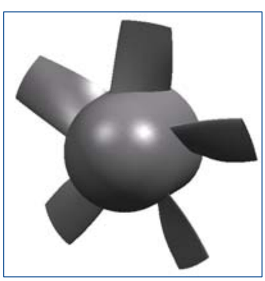
$$L^*_{W,ges} \equiv L_{W,ges} - 10\lg\left[\frac{\dot V}{\dot V_0}\frac{\Delta p_t}{\Delta p_0}\left(\frac{1}{\eta}-1\right)\right] = L_{Wspez,R} + 10\ m \cdot \lg\left(\frac{u_a}{c_0}\right) \quad \text{dB}$$

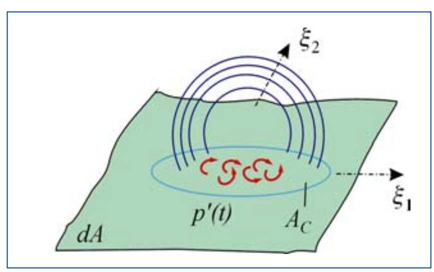


⇒ Specific sound power level for various types of fans



A class II – noise prediction method (I)





Pressure fluctuations on a flat plate and their spatial correlation area

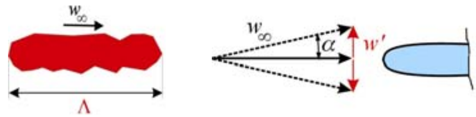
⇒ acoustic sound power radiated

Sharland 1964: $$P_{acoustic} = \frac{\pi}{3} \cdot \frac{f^2}{\rho c_0^3} \iint_A \left[\overline{\Delta p'^2}(\xi_1,\xi_2) \cdot A_c(\xi_1,\xi_2) \right] d\xi_1 d\xi_2$$

(simplified Ffowcs Wiliams and Hawkings equation)

Example: Turbulent ingestion (TI)

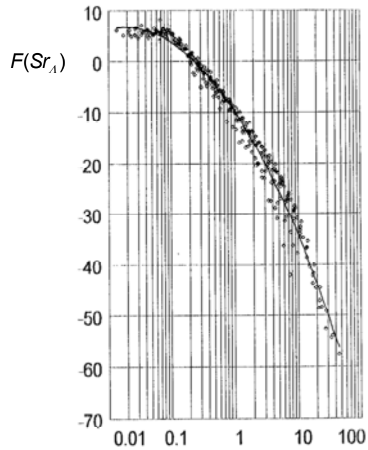
Velocity fluctuations of turbulent inflow:
Curve fit to dimensionless experimental results from various turbulence generators



$$\frac{d\overline{w'^2}}{df} = w_\infty \cdot Tu^2 \cdot \Lambda \cdot 10^{\frac{1}{10}F(Sr_\Lambda)}$$

⇒ **Lift force fluctuations in terms of modeled turbulent velocity fluctuations**

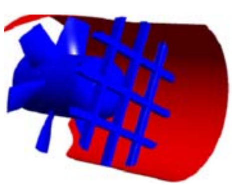
$$\frac{dP_{TI}}{df}(f) \approx const \cdot B \cdot \frac{\rho}{c_0^3} w_\infty^4 \cdot \frac{d\overline{w'^2}}{df} \cdot C \cdot L$$

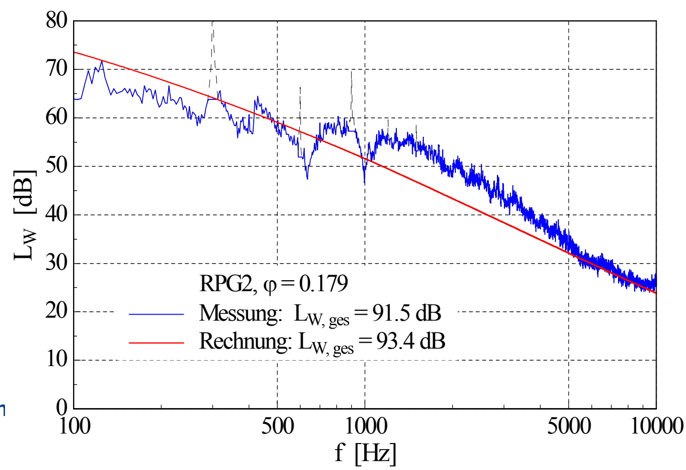


$$Sr_\Lambda = \frac{f\Lambda}{w_\infty}$$

UNIVERSITÄT SIEGEN

Typical result



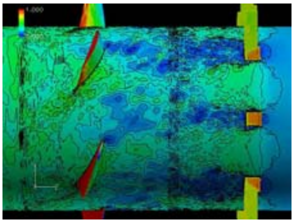


- **Prediction „smooth**
- **Only broad band**
- **Very fast method**

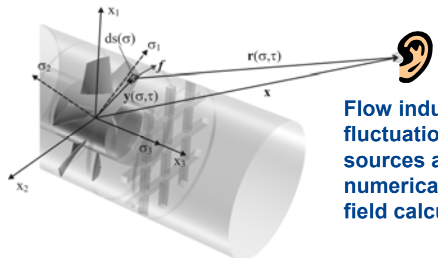
Schneider, M.: Der Einfluss der Zuströmbedingungen auf das breitbandige Geräusch eines Axialventilators. Fortschritt-Berichte VDI Reihe 7: Strömungstechnik (Dr.-Ing. Diss. Univ. Siegen). Vol. Nr. 478. Düsseldorf: VDI Verlag GmbH, 2006. - ISBN 3-18-347807-2

UNIVERSITÄT SIEGEN

A Class III – noise prediction method



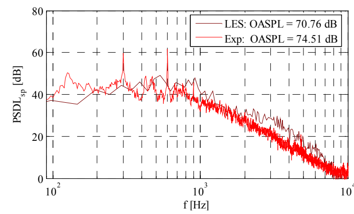
Detailed unsteady flow field data



Flow induced fluctuation forces as sources analytical or numerical acoustic field calculation

Reese, H.: Anwendung von instationären numerischen Simulationsmethoden zur Berechnung aeroakustischer Schallquellen bei Ventilatoren.
(Dr.-Ing. Dissertation Universität Siegen), Fortschritt-Berichte VDI Reihe 7, Nr. 489, VDI Verlag, Düsseldorf, 2007

Reese, H., Kato, C., Carolus, T.: Large eddy simulation of acoustical sources in a low pressure axial-flow fan encountering highly turbulent inflow. ASME J. of Fluids Engineering, March 2007, Vol. 129, pp. 263-272



Sound power spectrum

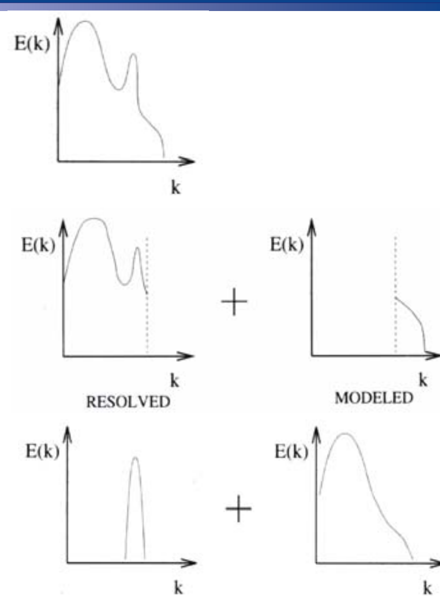
UNIVERSITÄT SIEGEN

Unsteady CFD-Methods

Direct Numerical Simulation (DNS):
- Basic equations are solved without any additional models
- Solution contains the acoustic field
- High numerical costs ~ Re^3

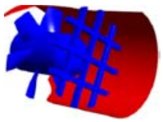
Large Eddy Simulation (LES):
- Filtering of the basic equations
- Large scales are solved directly
- The numerical costs are still high ~ $Re^{1.4}$.

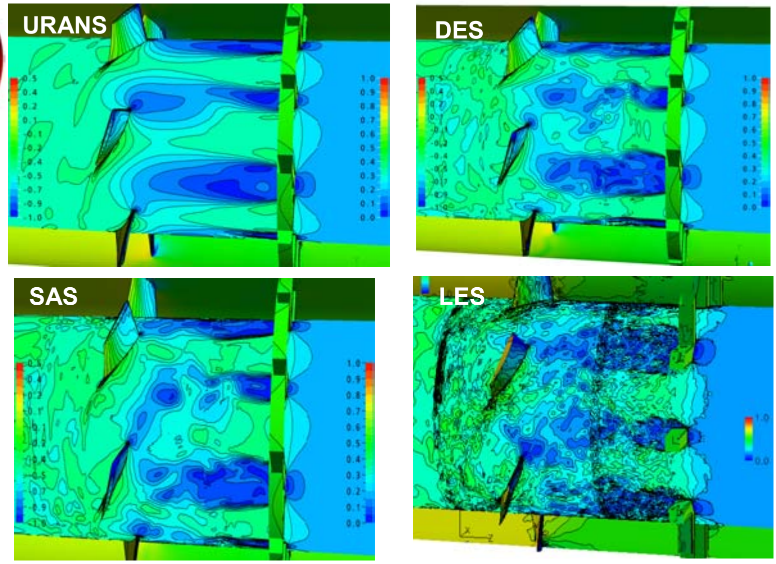
Unsteady Reynolds Averaged Navier-Stokes Simulation (URANS):
- Ensemble averaging of the basic equations
- Turbulence completely modeled
- The numerical costs are independent of Re

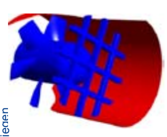


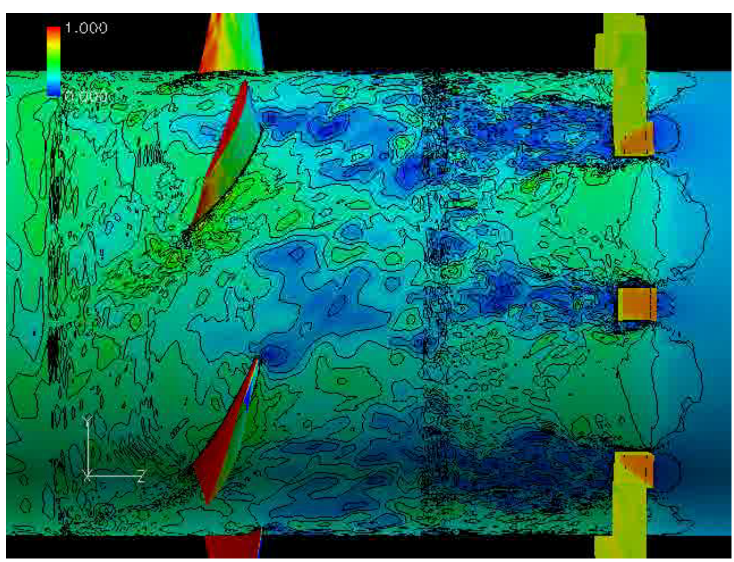
UNIVERSITÄT SIEGEN

Snap shot of the absolute velocity (v/u_{TIP}) at 50% blade height

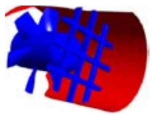




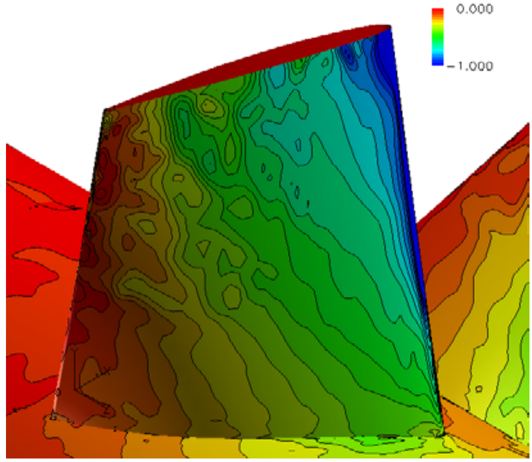




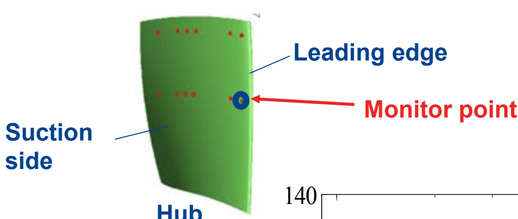
Quelle: Reese, Kato 2004

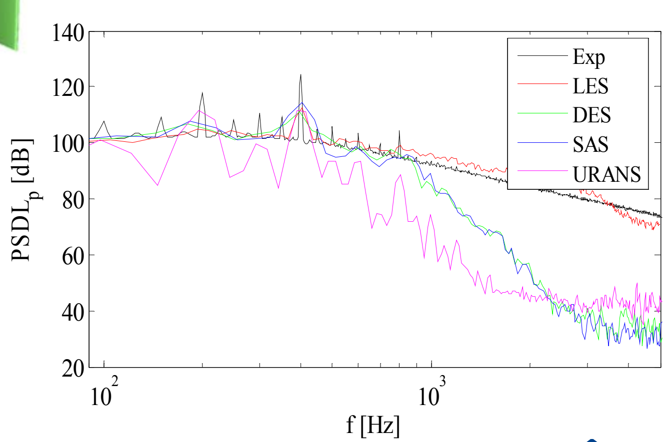


Pressure on Blade suction side ($p / 0.5\rho u_{Tip}^2$)

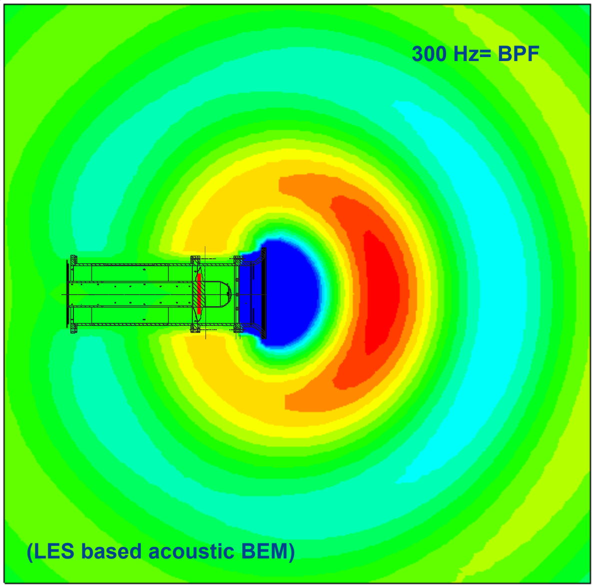


(LES)





Numerical Noise Prediction with BEM

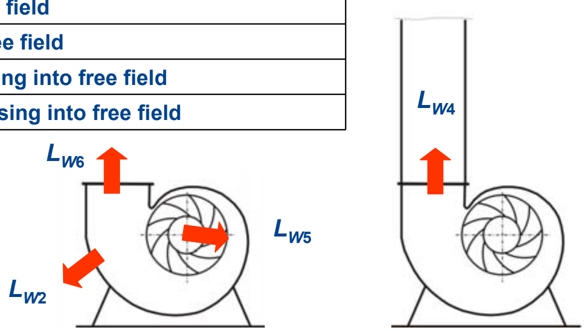


Reese/LMS Sysnoise

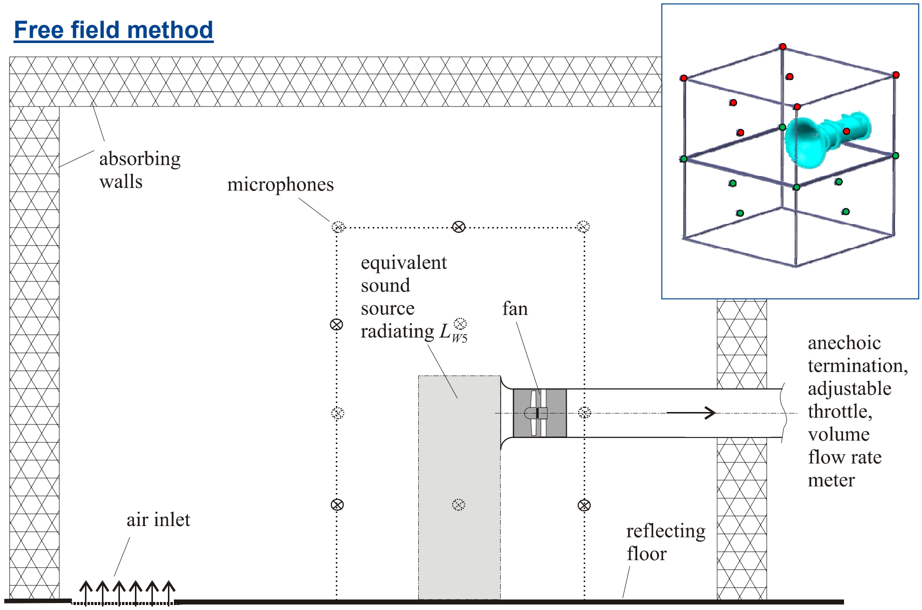
4. Experimental Methods

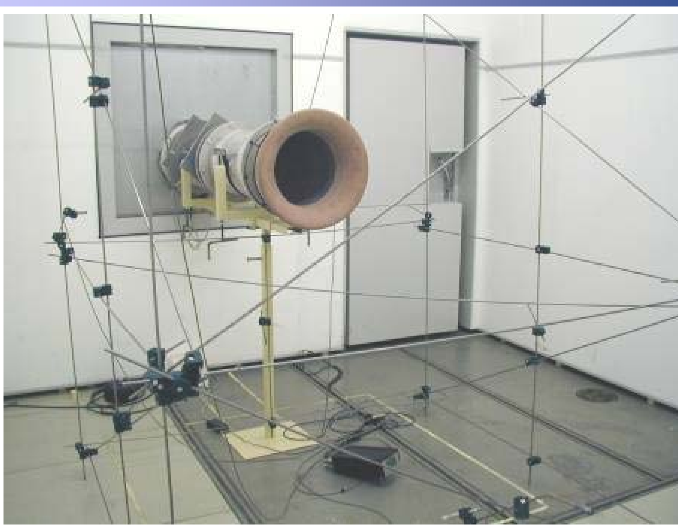
Definitions of sound power levels for fans (DIN 45635 T38 [3])

	Characterizes sound power radiated from ....
L_{W1}	... inlet, outlet and casing into free field
L_{W2}	... casing into free field
L_{W3}	... inlet into attached duct
L_{W4}	... outlet into attached duct
L_{W5}	... inlet into free field
L_{W6}	... outlet into free field
L_{W7}	... inlet and casing into free field
L_{W8}	... outlet and casing into free field



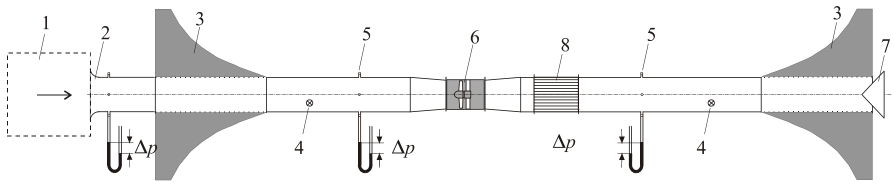
Free field method





Small semi-anechoic chamber at IFT with f_{min}= 125 Hz
Absorbing walls: Sandwich of Melamine foam/patches of sheet metal attenuators;
Design: Fraunhofer Institut für Bauphysik, Stuttgart and Faist Anlagenbau, Germany

- Free field method ✓
- Reverberant field method
- Duct method according to DIN EN ISO 5136



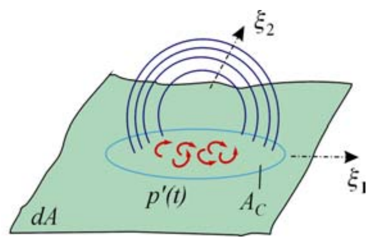
Duct test rig for determination of L_{W3} and L_{W4}
(1) undisturbed inflow domain
(2) volume flow rate meter
(3) anechoic termination
(4) microphone
(5) static pressure tap
(6) fan
(7) adjustable throttle
(8) honey comb

Duct test rig at IFT, diameter 0.3 m

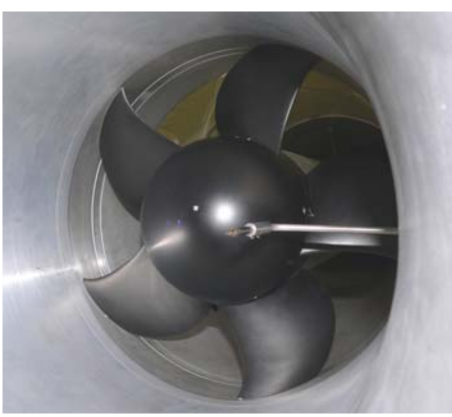
4.2 Measurement of sound relevant flow quantities

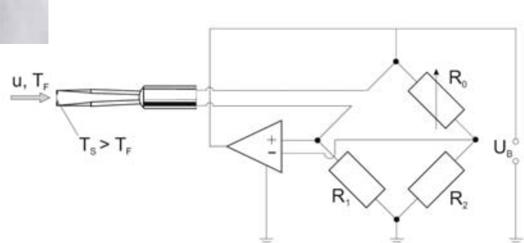
Guiding acoustic model (Sharland 1964):

$$P_{acoustic} = \frac{\pi}{3} \cdot \frac{f^2}{\rho c_0^{\;3}} \iint_A \left[\overline{\Delta p'^2}(\xi_1, \xi_2) \cdot A_c(\xi_1, \xi_2) \right] d\xi_1 d\xi_2$$

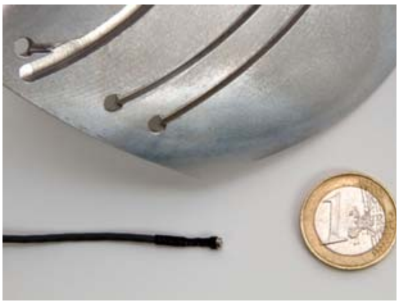


Flow field analysis with how wire anemometry





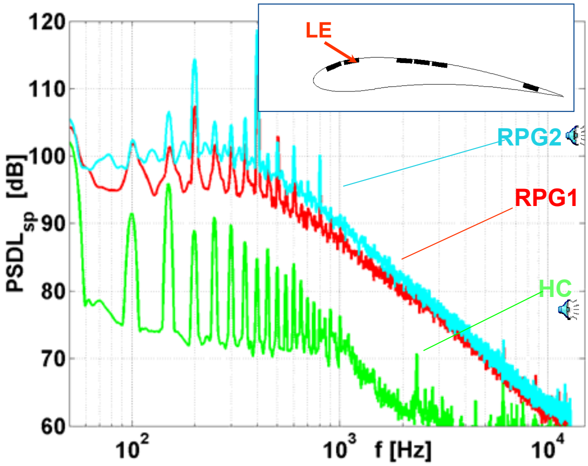
Surface mounted pressure transducers

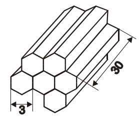


T. Zhu, 2011

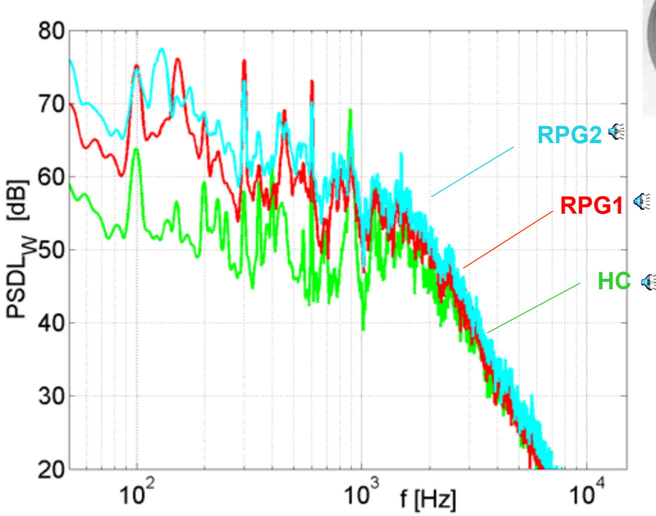
5. Case studies
5.1 Grid generated inflow turbulence

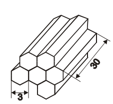
Surface pressure fluctuations



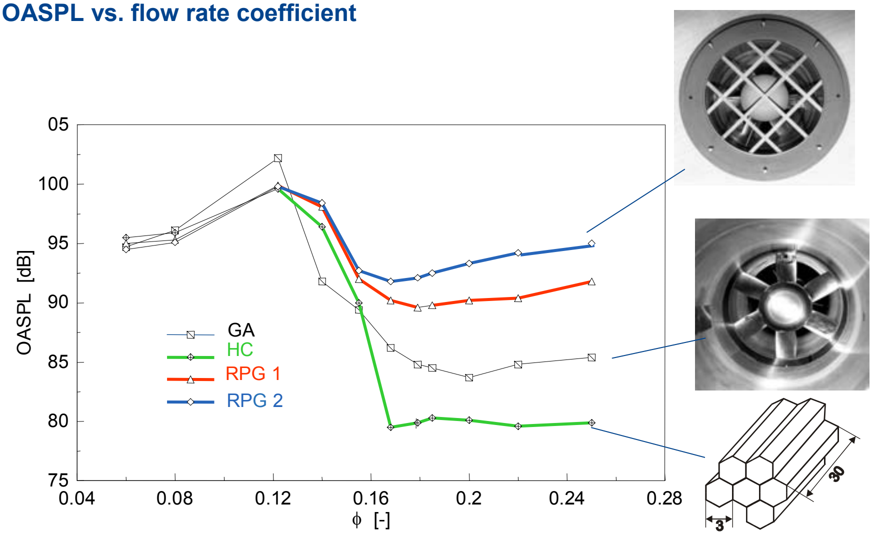


Free field sound power



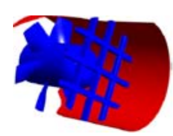


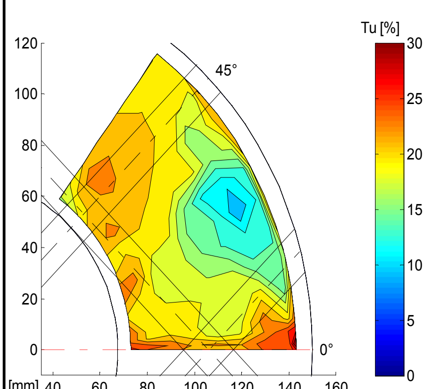
OASPL vs. flow rate coefficient



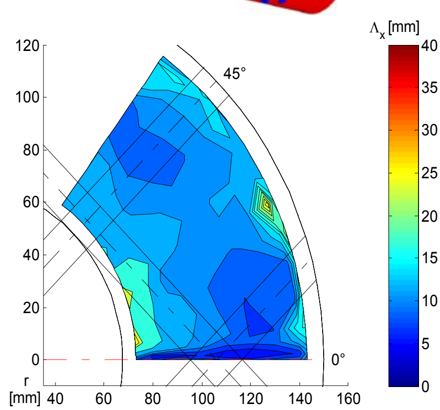
Schneider, M., Carolus, T.: Turbulent Ingestion Noise from Axial Fans - Statistic Parameters of the Inflow and Noise Prediction. Proc. of the 12th Int. Congress on Sound and Vibration. Lissabon, 2005

Details of ingested flow





Turbulent intensity

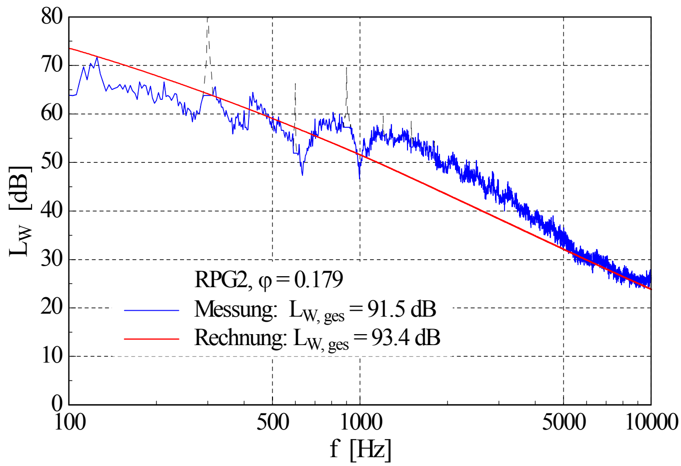


Axial correlation length Λ_x

in rotor leading edge plane

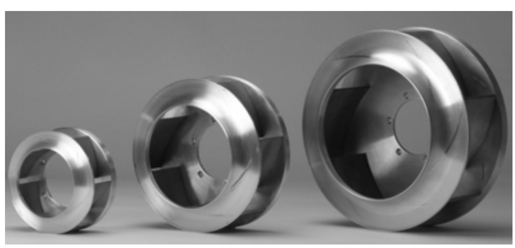
Schneider 2006

Typical application

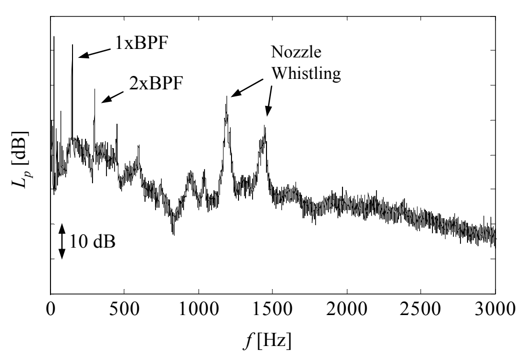


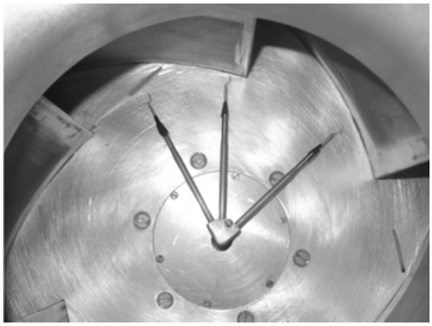
Schneider 2006

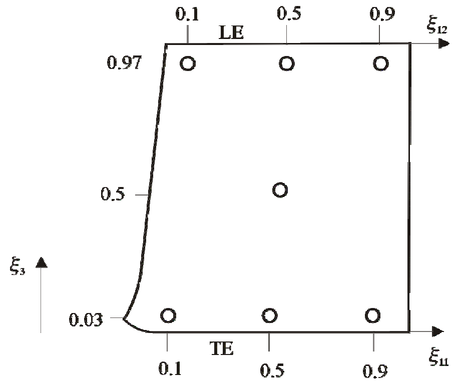
5.2 Sound sources in a radial fan



LM050 (50%) *LM075* (75%) *LM100* (100%)

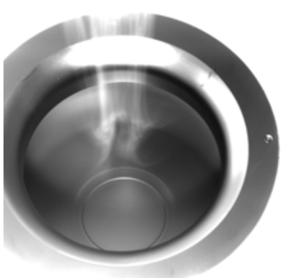


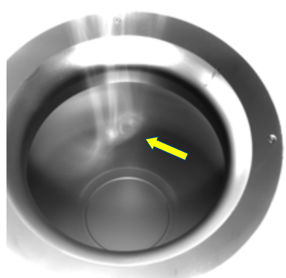


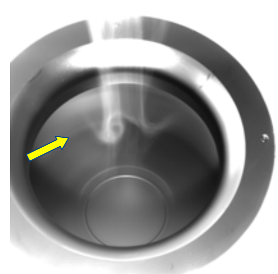


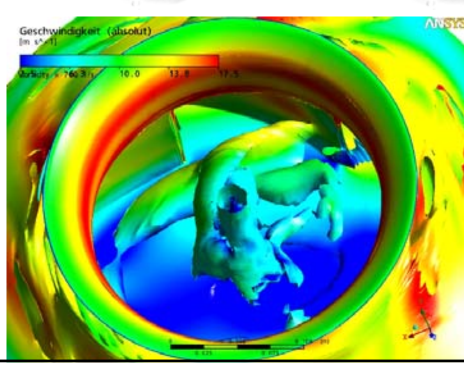
UNIVERSITÄT SIEGEN

Self induced vortex: Smoke visualization and unsteady CFD



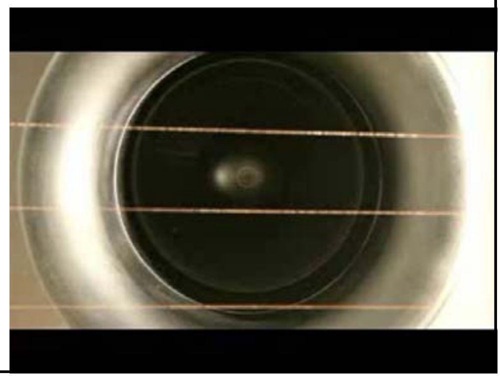


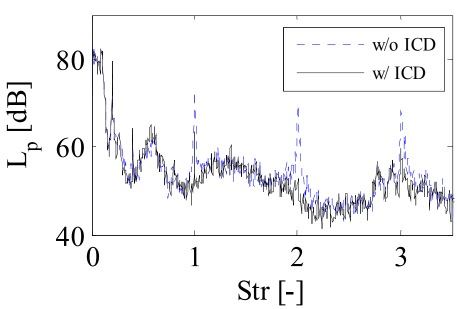


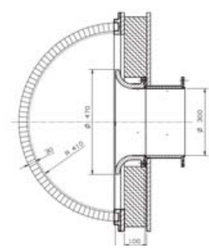


Wolfram, D., Carolus, T.: Experimental and numerical investigation of the unsteady flow field and tone generation in an isolated centrifugal fan impeller. J. of Sound and Vibration 329 (2010) 4380-4397

UNIVERSITÄT SIEGEN







Inflow Control Device

Schneider 2006, Sturm 2012

- Aeroacoustic noise sources in low Ma number fans are flow induced forces
- Several principle mechanisms can be identified, such as spatial non-uniform inflow, turbulent ingestion, blade self noise, tip clearance flow, etc.
- Noise prediction methods range form simple correlations (class I) to complex computational aeroacoustics (CAA) methods (class III)
- Confirmation of the classical rule: High fidelity acoustic prediction requires excellent source data, e.g. the unsteady flow field in realistic fan assemblies
- Experimental flow field data: Unsteady velocities and pressures; serve either as empirical data in semi-empirical (class II) models or for validation (class III models)
- Three examples of fan noise projects illustrate methodologies
- Understanding of mechanisms is first step of noise reduction measures!