FLT WORKING GROUP FANS

BENEFITS AND RESULTS OF PRE-COMPETITIVE COMMUNITY RESEARCH

Erik REICHERT

ebm-papst Mulfingen GmbH & Co. KG,
Bachmühle 2, 74673 Mulfingen, Germany

SUMMARY

The German Research Association for Air and Drying Technology (FLT) is a platform for pre-competitive industrial community research. This paper provides an overview of FLT's ongoing activities as well as a review of the projects carried out over the last 12 years by the Fan Working Group. One aim is to summarize the research topics and to show some of their interesting results. Another is to show the possibilities to initiate new research projects at German universities.

INTRODUCTION

For more than five decades, the Research Association for Air and Drying Technology (FLT) has been offering its members a platform for pre-competitive industrial community research. Industry experts and scientists from over 20 German research institutes work closely together in project-accompanying workgroups. Within these working groups, the FLT members determine and develop the technical topics, objectives and contents of the projects. By doing so, the industrial participants benefit from the efficient knowledge transfer with the research centers as well as from the free use of all research results. The close collaboration with the universities also offers the companies further perspectives, such as contact with highly and well-trained engineering science graduates, as well as the opportunity to initiate bilateral research projects.

The intention is to provide an overview of the projects carried out over the last 12 years by the Fan Working Group, to summarize the main research topics and to list the research institutes. Furthermore, some selected research results are presented and discussed. In addition, possibilities to initiate new research projects are assessed.

GENERAL OVERVIEW

At the moment, the FLT consists of two active working groups *Fans* and *Air Conditioning - Technical Building Equipment*, see Figure 1. The fan projects initiated by the 12 industrial members of the Fan Working Group - mainly fan manufacturers - are aimed at improving the efficiency and acoustics of axial and radial fans used both in industrial applications and in room ventilation and air conditioning.

Figure 1: Industrial members of the FLT-Working Groups "Fans" and "Air Conditioning"

The main research topics of the Fan Working Group are shown in Figure 2. A thematic focus is on the investigation of methods and concepts for aerodynamic optimization of efficiency and air performance of fans. Other key challenges are the increasing knowledge of aeroacoustic source mechanisms, installation effects and the perception of fan noise, and also the validation of acoustic simulation tools. Further research areas include the use of new materials, technologies and manufacturing processes as well as the development of profitably concepts for controlling and monitoring the operation of fans. Last but not least, better measurement techniques are applied and innovative analysis methods like psychoacoustic rating are being considered.

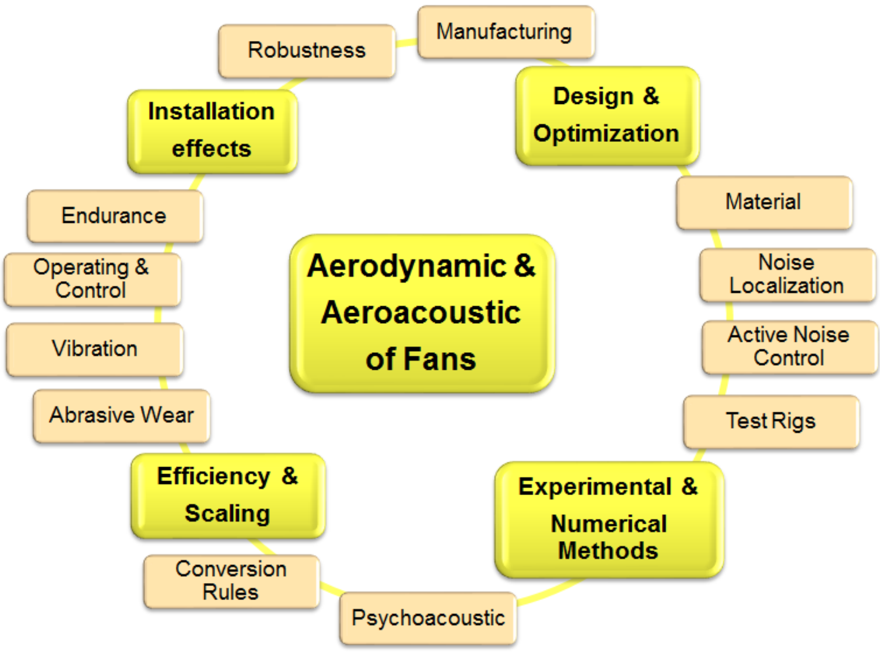

Figure 2: Research topics of the FLT Fan Working Group

Since the FLT was established in 1964, more than 300 research projects have been initiated. For the Fan Working Group Figure 3 gives a review of the last twelve years. The number of research projects is defined by the running projects per year. Decimal numbers result from projects being started or ending within one year. In the last 5 years, 6 projects have been carried out on average. For this purpose, annual subsidies of about 500,000 € were acquired. About 10 % of the funding came from the Research Association itself.

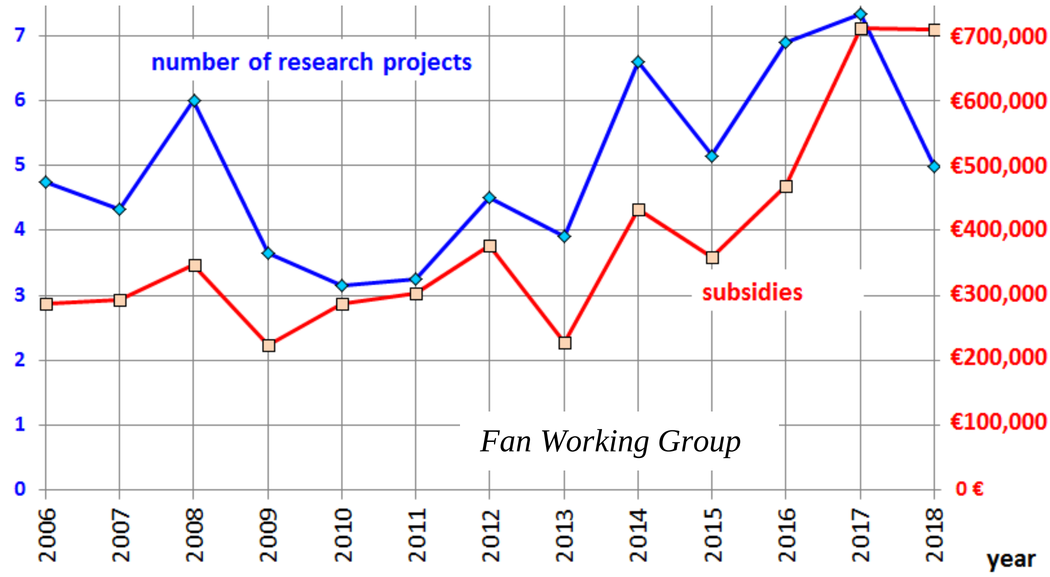

Figure 3: Running FLT research projects and subsidies over the last twelve years

Usually, the pre-competitive project ideas result from concrete questions that the industrial companies cannot answer using their own resources. In these cases, the FTL Workings Groups offer their members the possibility to define a new research project in consultation with a competent German research institute. Multi-year projects are funded 100% by financial resources of the Federal Ministry of Economics and Technology (BMWi) via the Industrial Cooperative Research Associations (AiF). Smaller projects with shorter duration are also financed using existing resources of the Research Association. The industrial participants of the accompanying project groups benefit from the direct knowledge transfer as well as from the free use of all research results.

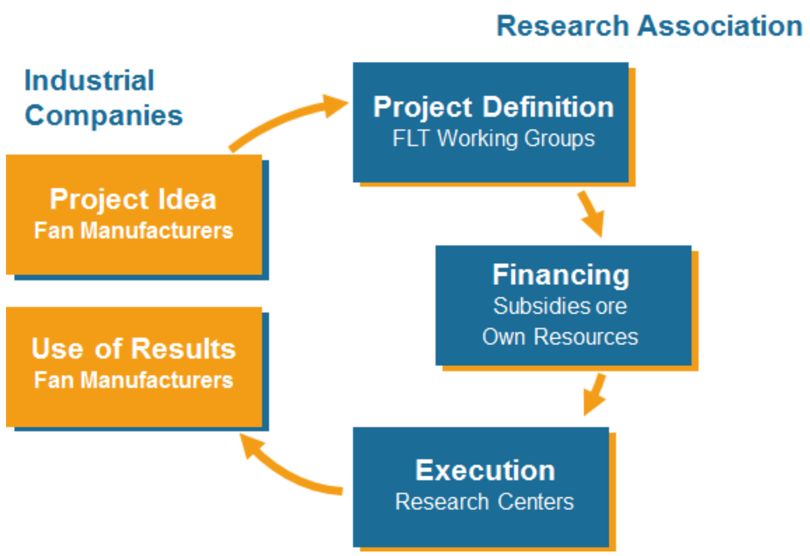

Figure 4: Procedure of pre-competitive research projects initiated by FLT-members

As can be seen in Figure 5, a great number of scientific institutes of German universities and research centers worked on various research projects in close cooperation. Figure 6 shows some test rigs of the research centers built ore used in the projects for measuring air performance and aerodynamic efficiency of fans. All these are available for further investigations.

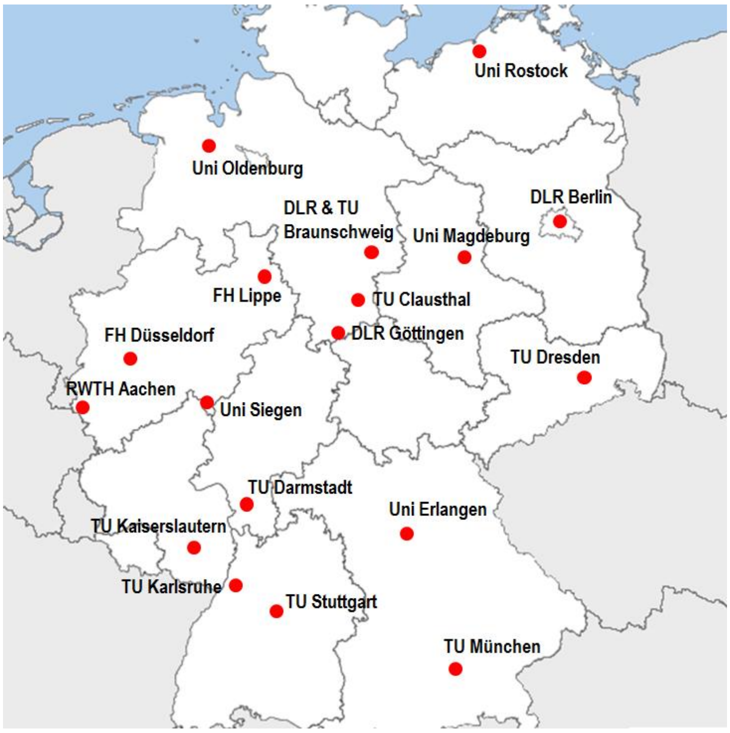

Figure 5: German universities and research centers

Figure 6: Air Performance Test Rigs according to ISO 5801 [1] and ISO 13347 [2]

SELECTED RESULTS

In this paper, some selected research results are presented and discussed. More than twenty years ago, Prof. Felsch and his team from the University of Karlsruhe experimentally investigated the aeroacoustic performance of axial fans [3]. Under disturbed inlet conditions, they found an acoustic benefit of up to 5 dB(A) for forward-swept blades compared to unswept blades (cf. left side of Figure 7).

The entire understanding of flow and noise mechanisms in the tip gap of axial fans with swept blades is still a goal for ongoing research projects. A team of scientists at the University of Braunschweig, under the direction of Prof. Friedrichs[1], has been investigating these topics for a few years in several projects initiated by FLT. In addition to innovative experimental analysis methods, modern numerical simulations are also used (cf. right side of Figure 7).

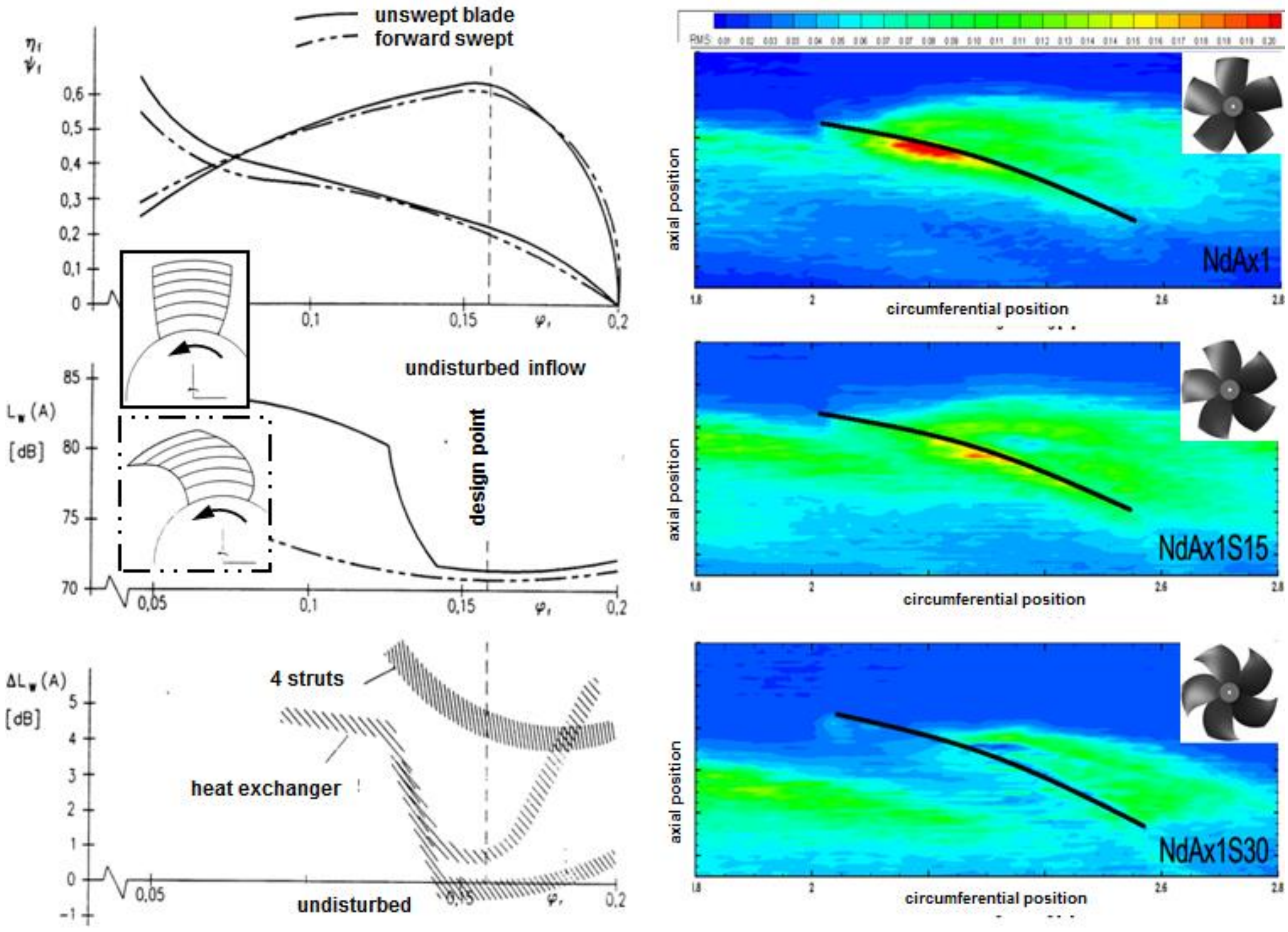

Figure 7: Left: Aeroacoustic measurings of axial fans with unswept and forward-swept blades [3]
Right: Pressure fluctuations in the tip gap of axial fans with different blade sweep [4-5]

Another research subject is the development of a universal scale-up method for axial and radial fans, as there is a need for manufacturers to reliably predict the performance of fans from the measuring results of down-scaled test fans. The commonly used scale-up formulas like Ackeret give satisfactorily results only close to the design point.

[1] Technical University of Braunschweig, Institute of Jet propulsion and Turbomachinery, www.ifas.tu-bs.de

The first investigations initiated by the FLT Fan Working Group started over ten years ago in 2006 at the Technical University of Darmstadt [6-8]. After many measuring runs of geometrically similar fans with different Re- and Ma-numbers, Prof. Pelz[2] and his team introduced a new physics-based and universally applicable scaling method in 2013 which shows good consistence with part- and overload [9]. In the last few years, this new scaling method was validated by further experimental data obtained with test stands at the Chair of Fluid System Technology [10]. Figure 8 show some results. The final step is to use these improvements for revising ISO 13348 [11], with special focus on chapter 7.1.5.2 "Efficiency of other sizes".

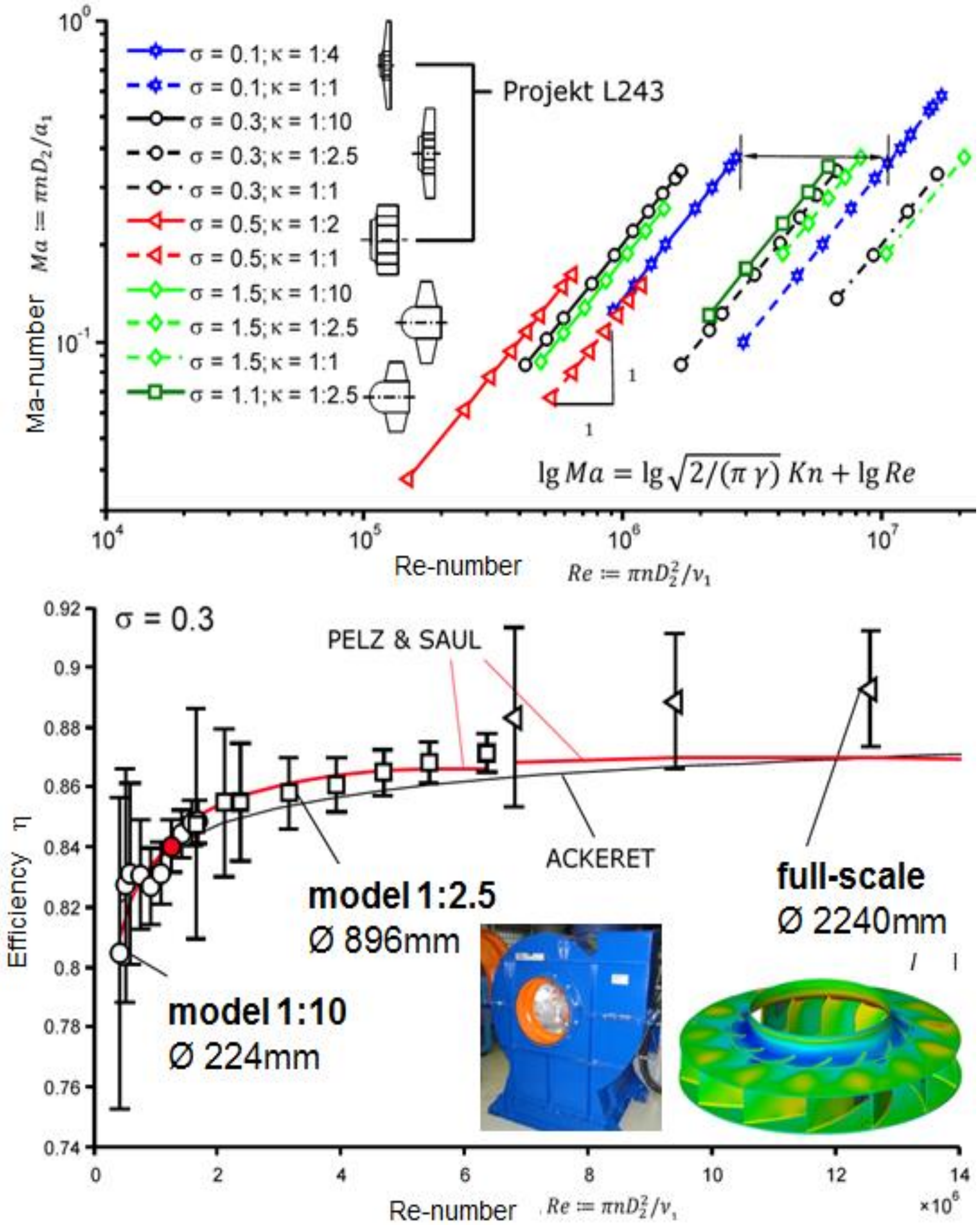

Figure 8: Above: Range of investigated fans at the Chair of Fluid System Technology of the University of Darmstadt Below: Measured efficiency of a radial fan and comparison between new scaling method (red) and Ackeret (black line)

[2] Technical University of Darmstadt, Chair of Fluid Systems Technology, www.fst.tu-darmstadt.de

A good example for providing a substantial contribution to the relevant tonal noise mechanisms of axial and radial fans are the experimental and numerical investigations done at the University of Siegen. Prof. Carolus[3] and his team investigated several axial and radial fans on a standardized measuring test rig in an anechoic room [12-22]. Supporting struts and other distortions are positioned far downstream, periphery components like inlet nozzles and wall rings are perfectly round and no obstructions are present at the intake. Hence, up- and downstream disturbances are considered to be minimal. In these cases, no BPF noise should occur, while measuring results show just the opposite is the case.

Studies with and without a hemispherical inlet honeycomb gave a first indication that inflow inhomogeneity must occur even under "undisturbed" inflow conditions (see Figure 9). However, there was no consensus about what causes those incoming inhomogeneous flow structures. Correlation analyses of hot wire probe signals allowed the identification of modes due to the unsteady flow field. Practically stationary coherent structures were detected. Finally, smoke visualizations and unsteady CFD results provided the evidence of self-induced stretched helical vortex structures at the intake interacting with the blade leading edge.

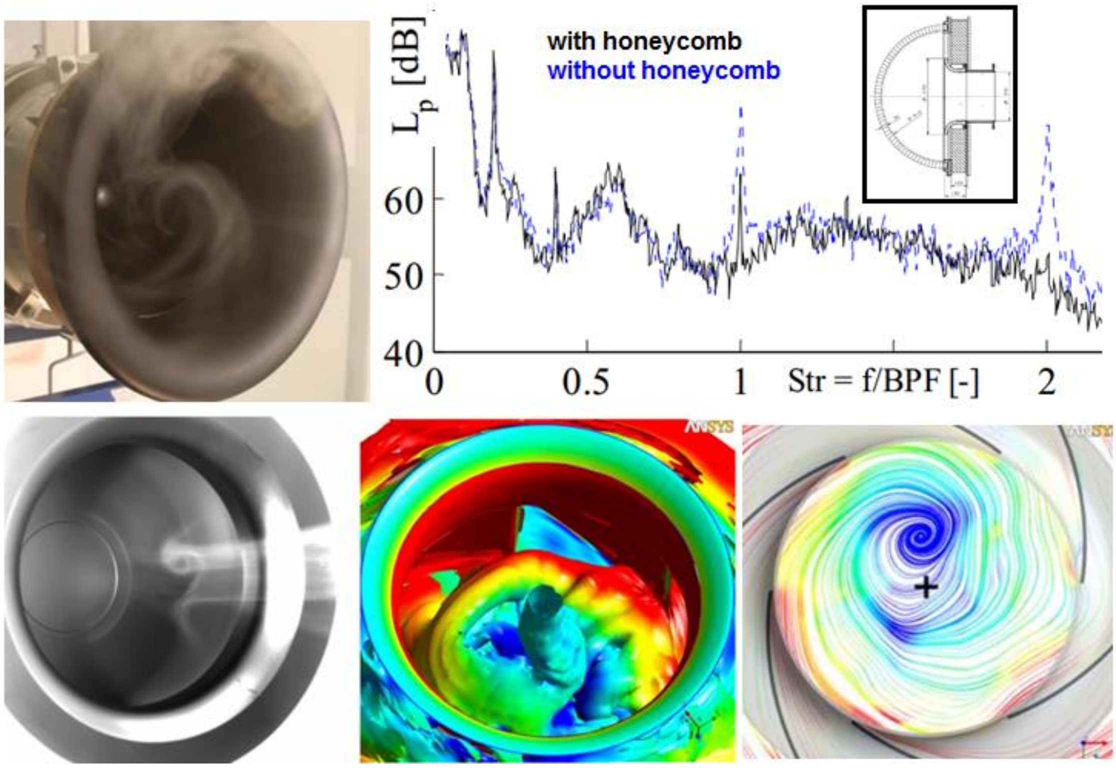

Figure 9: Self-induced vortex; Smoke visualization (left) and unsteady CFD (below)
Upper right: Noise measuring with and without a hemispherical inlet honeycomb

Parallel to the gradual building up of aerodynamic and aeroacoustic expertise, the FLT-research includes practical tests and validation of new experimental and numerical tools. In the last few years, the fan and blower industry has notably been making great efforts to implement numerical methods for aerodynamic optimization and sound prediction. For this purpose, validation data is available for a large number of fan geometries.

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[3] University of Siegen, Institute of Fluid- and Thermodynamics, Chair of Fluid Mechanics and Turbomachinery, www.mb.uni-siegen.de/iftsm

The low pressure rotor-only fan "USI7" with five cambered and swept blades shown in Figure 10 has been used as a generic test fan in several FLT projects. The fan geometry and the design philosophy are described in [23-24]. The main design parameters are listed in Table 1. Aerodynamic and aeroacoustic characteristics have been studied experimentally at the University of Siegen. Additionally, the nonstationary inflow conditions and pressure fluctuations at different positions on both sides of the fan blade and in the tip gap were determined in detail using hot wires and miniature pressure transducers. The following two studies are the most interesting: In one, the tip gap size was modified between 0.3 mm and 3 mm. In the other, measurements were carried out at different inflow conditions, i.e. with the turbulence-reducing honeycomb mentioned above and with a turbulence-generating grid (see Figure 10, right side).

Table 1: Design parameters of USI7

Nominal rotor diameter	d_2	300 mm
Hub diameter	d_1	135 mm
Rotational speed	n	3000 rpm
Design flow rate	$\dot{V}_{design}$	0.65 m³/s
Number of blades	z	5
Circumferential Mach number at d_2	$Ma = \pi d_2 n / a$	0.139
Reynolds number at d_2	$Re = C w_\infty / \nu$	$2.1 \cdot 10^5$

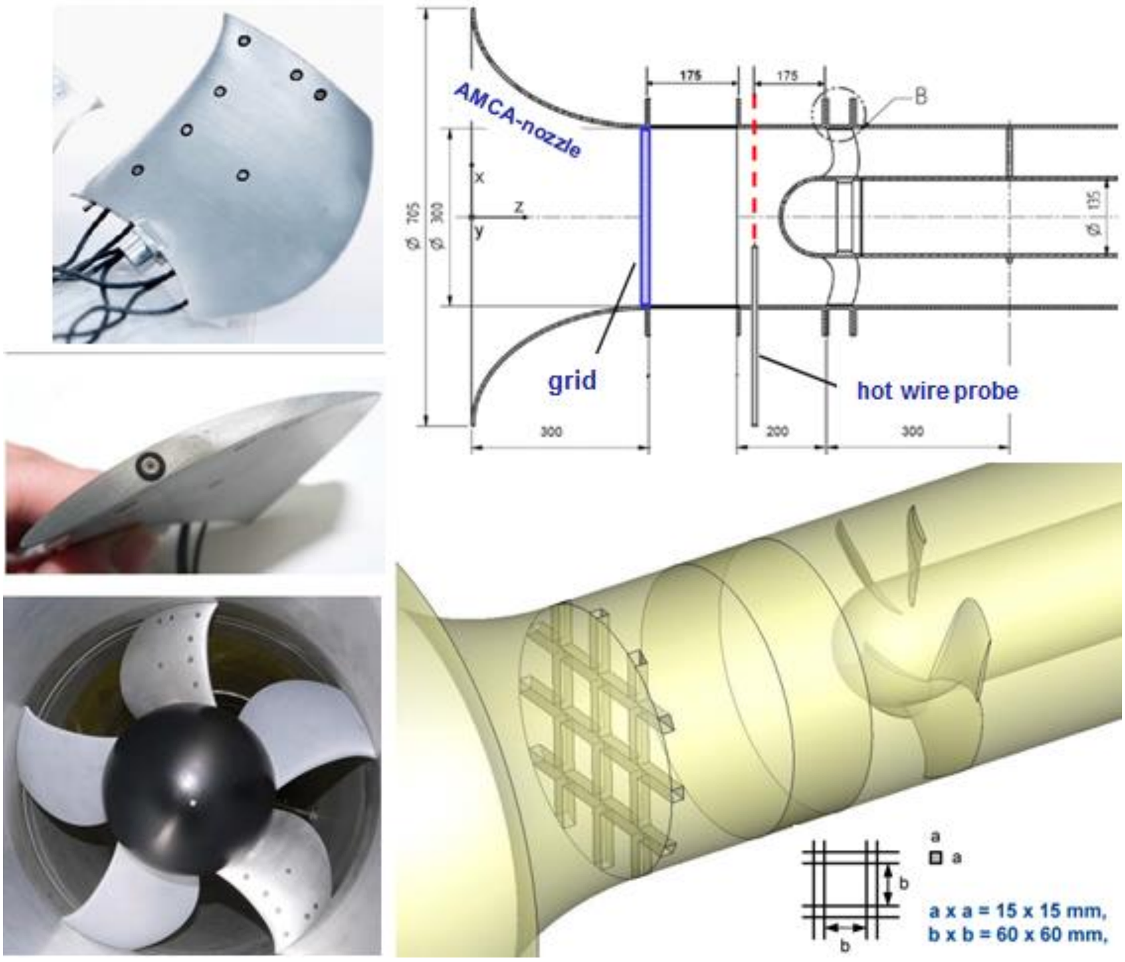

Figure 10: Low pressure rotor-only fan "USI7" with miniature pressure transducers (left) and installation setup with inflow turbulence grid (right)

In the last few years, both effects – the variation of the tip gap size and the inflow conditions – were analyzed in several research projects. In most cases, the main focus was on the validation of computational aeroacoustic methods (CAA). The aim was to catch the relevant source mechanisms and to allow a reliable sound prediction of fans. The accuracy of the results obtained with the different methods was compared, both with each other and with aerodynamic and acoustic measuring results. The investigations covered a wide range, from approaches with small numerical effort up to high-resolution simulations.

Prof. Delfs[4] and his team applied their CAA-tool PIANO [25-26] modelling the aeroacoustic fluctuations based on stationary CFD-RANSresults. Another team of researches led by Prof. Schröder[5] carried out Large-Eddy-Simulations (LES) with a block-structured mesh of up to over 10^9 cells for one blade channel with periodic boundary conditions in the circumferential direction. The turbulent flow and the acoustic fields were calculated for 24 rotations. Computing time for solving the acoustic perturbation equations (APE) was approx. 312 hours on 72000 cores [27-31].

The aerodynamic and acoustic fan performance predicted with a commercially available Lattice-Boltzmann code (LBM) yielded very good agreement compared to the experimental data [32-35]. Some results are shown in Figure 11. The non-stationarity and compressibility of the code allows a direct and simultaneous prediction of both the aerodynamic and the acoustic field. Moreover, the results of Prof. Carolus[6] and his team revealed important details of the sound generating mechanisms in the vicinity of the blade tip gap, both under disturbed and undisturbed inflow conditions.

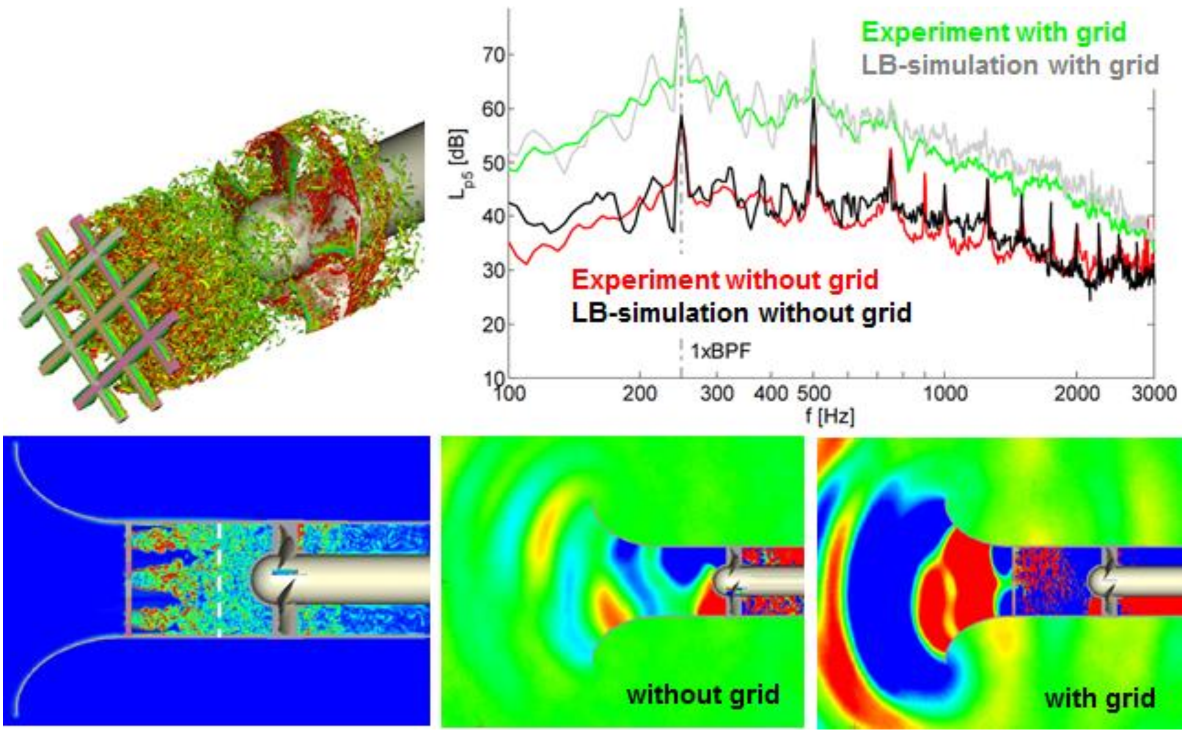

Figure 11: CAA-results with Lattice-Boltzmann Solver PowerFlow 5.0

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[4] German Aerospace Center DLR Braunschweig, Institute of Aerodynamics and Flow Technology, Technical Acoustics, www.dlr.de/as

[5] RWTH Aachen University, Institute of Aerodynamics, Chair of Fluid Mechanics and Institute of Aerodynamics Aachen, www.aia.rwth-aachen.de

[6] University of Siegen, Institute of Fluid- and Thermodynamics, Chair of Fluid Mechanics and Turbomachinery, www.mb.uni-siegen.de/iftsm

CONCLUSIONS

Since 1964, the German Research Association for Air and Drying Technology (FLT) has offered its members a platform for pre-competitive industrial community research. In this period, more than 300 projects were successfully conducted. Multi-year projects are funded 100 % by financial resources of the Federal Ministry of Economics and Technology (BMWi); smaller projects with shorter duration are also financed using resources of the Research Association.

Within the working group the FLT members determine and develop the technical topics, objectives and contents of the projects. The fan projects initiated by the 12 industrial members of the Fan Working Group are aimed at improving the efficiency and aeroacoustics of axial and radial fans used in industrial applications as well as in room ventilation and air conditioning. Other research topics are the development of know-how about aeroacoustic source mechanisms, installation effects, the perception of fan noise as well as the validation of simulations tools, the use of new materials, technologies and manufacturing processes and the development of concepts for controlling and monitoring.

By participating in the project-accompanying workgroups, the industrial members benefit from the efficient knowledge transfer with the research centers as well as from the free use of all research results.

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