INTERNATIONAL CONFERENCE ON FAN NOISE, TECHNOLOGY AND NUMERICAL METHODS

BOOK OF ABSTRACTS

15-17 APRIL 2015
L'Espace Tête d'Or, Lyon, France

www.fan2015.org

Institution of MECHANICAL ENGINEERS

CETIAT
ensemble, innover et valider

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CONTENTS

INTRODUCTION FROM THE CONFERENCE CHAIR

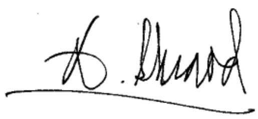
Welcome to Fan 2015. The Fan 2015 offers you a unique opportunity to network with those working in the air movement community. This three-day conference includes keynote lectures and technical presentations organised as three parallel sessions, focusing on fan technology, fan noise and computational methods. Panel sessions will also give you the chance to learn more about acoustics and the use of computational methods.

The conference exhibition provides you with access to those organisations working for and with the fan industry. I would encourage you to speak with the exhibitors about your business and the challenges it faces. Their business is helping you solve your business problems, and that is why they have come to Fan 2015.

Lyon is in east-central France in the Rhône-Alpes region, situated between Paris and Marseille. Together with its suburbs and satellite towns, Lyon forms the largest conurbation in France outside Paris. The city is known for its historical and architectural landmarks and is a UNESCO World Heritage Site. Lyon was historically known as an important area for the production and weaving of silk and in modern times has developed a reputation as the capital of gastronomy in France. I am sure that you will enjoy not only the conference itself, but also the location.

This is a particularly important time for the air movement community. Within the European Community air movement fan efficiency is regulated by Regulation 327. This regulation is under review and within the USA the Department of Energy is in the process of finalising its approach to the regulation of air movement fan efficiency. It is therefore an inevitability that the design of fans will have to evolve to meet the ever-increasing demands for higher efficiency. Market pressure is also driving manufactures to produce lower noise and cost designs. The result is both a challenge for and an opportunity. Higher efficiency fans are generally also high cost fans, and therefore those who choose to embrace the challenge will prosper and grow. By attending Fan 2015 you take an important step towards embracing the challenge our community faces. I look forward to welcoming you to the conference.

I would like to take those opportunity for and on behalf of the Fan 2015 organising committee to welcome you to Lyon, and to thank you for attending Fan 2015. Take your time to attend the sessions, listen to what is said and challenge what you hear. Above all, renew old acquaintances, form new friendships and enjoy the conference.



Geoff Sheard
Chairman – Fan 2015 Organising Committee

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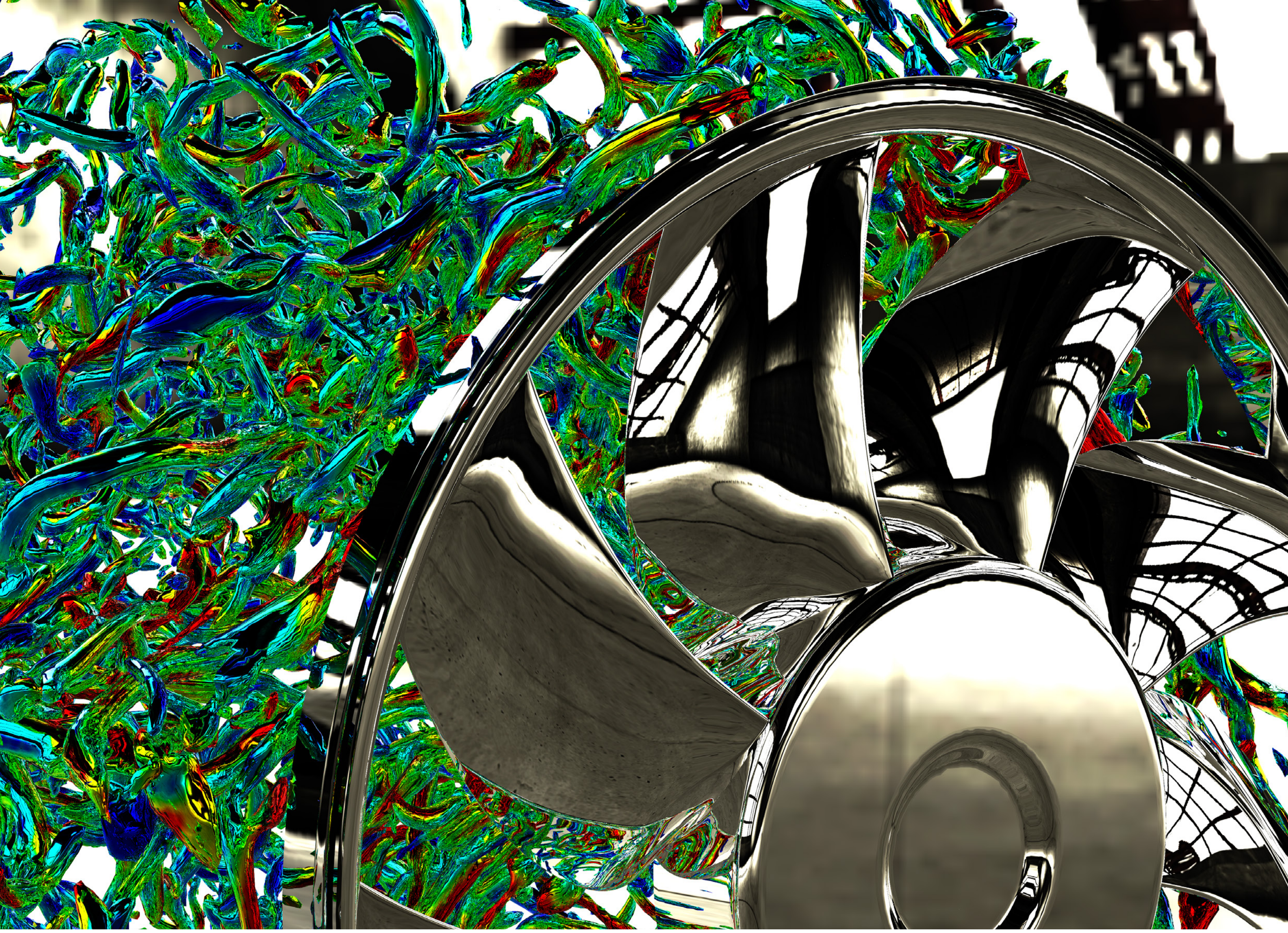


Why all the noise?

Did you know most of the global automotive and commercial vehicle OEMs and suppliers look to Exa for aerodynamic, aeroacoustic and thermal management simulations? Join what many engineers have already discovered — with Exa simulations you can quickly, efficiently and accurately design the quietest, most efficient fans and products with embedded fans.

Noise generation is, by definition, a transient phenomenon and simulating it accurately in a reasonable time frame has historically been difficult. Exa's fully transient simulations allow accurate, predictable results helping companies reduce fan noise that impacts everyone from the vehicle operator to the community.

PowerFLOW® simulations accurately predict both tonal and broadband noise due to its inherently transient lattice Boltzmann physics and rotating machinery capabilities — allowing customers to routinely perform complex aeroacoustic simulations within tight time constraints. Exa's easy-to-use aeroacoustic analysis and state-of-the-art 3D visualization software applications, PowerACOUSTICS® and PowerVIZ®, work with PowerFLOW to provide engineers detailed insight into noise sources.

At Exa Corporation, we've spent over twenty years developing solutions that not only improve the design engineering process...but redefine it. Please contact us to learn more about our fan noise and other simulation solutions. Stop by our booth for a demonstration and come hear what we have to offer. We want to help you keep the noise down and deliver quiet, efficient products.

Exa

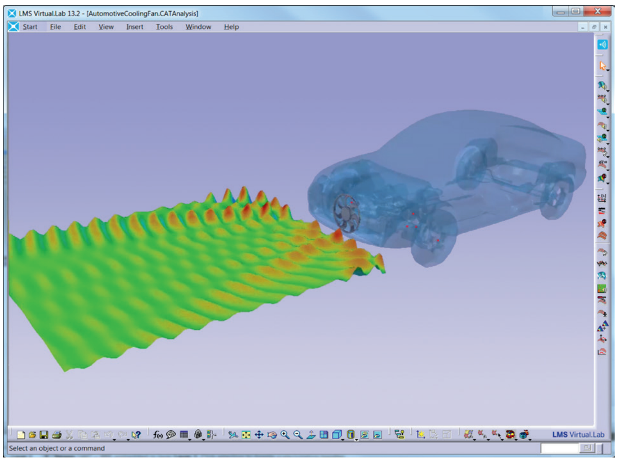
Make better engineering choices sooner

LMS solutions for real-life simulation

Innovative design and radical new product concepts represent a solid basis for growth and profitability. Winners of the product innovation race combine a talent to mobilize knowledge and creativity with product development and go-to-market speed. Manufacturing companies around the globe rely on LMS solutions to eliminate non-value-added tasks, frontload key design decisions early in the development phase, and explore new product concepts in the shortest possible time. Our solutions can also improve active system performance engineering – a key innovation driver in mechanical product design.

Making the right engineering choices sooner ultimately helps our customers to develop better products faster, products that reflect the right core brand values.

For more info, please visit **siemens.com/plm/lms**



Fan noise is a key differentiator for manufacturers due to increasing customer comfort requirements and noise regulations. LMS Virtual.Lab offers best in class, fast and accurate solutions for both tonal and broadband fan noise problems.

Realize innovation.

ORGANISING COMMITTEE

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Henrik WITT (Witt & Sohn, Germany)

CETIAT is a French laboratory, which provides research, product development, testing and calibration services in the air-handling, heating and acoustic fields. 140 employees work in this laboratory located in Lyon - France.

CETIAT has an extensive and practical knowledge of the aerodynamic and acoustic performance of fans, especially axial and centrifugal fans. In this field, as in others, CETIAT carries out research programs (technical know-how compilation, design tools development, expertise capitalisation and development of fan sound measurement standards,…). These acquired skills and expertise are used to offer services to the companies and manufacturers concerned.

Its customers are involved in the Heating, Ventilating and Air-Conditioning industry, but also come from others fields of activity where CETIAT skill and expertise may be useful, such as in the automotive industry for instance.

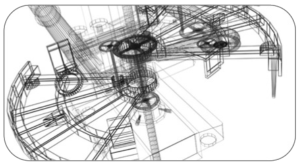
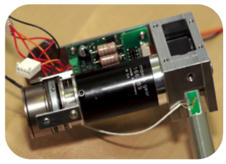
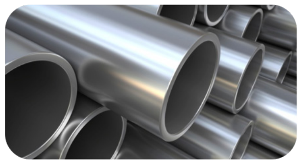
CETIAT provides assistance to its customers at all stages of their product or process development:

- Staff training;
- Technological survey;
- Design optimisation and integration of fans using 3D flow and heat transfer models and several metrological tools (clinometer, laser Doppler anemometry, acoustic and vibration sensors, …);
- Aerodynamic and acoustic fan performance measurement in accordance with ISO 5801, ISO 13347 and ISO 5136;
- Measuring instruments calibration.

Cetim
The French technological institute for mechanics

New concepts in mechanical engineering

As the leading French player in the fields of mechanical engineering innovation and R&D, Cetim has built up a wide network of partners. Its engineers and technicians operate in more than 30 countries each year.


R&D function is carried out either within specific sectors or cutting across sector boundaries, and within either a national or an international context. It embraces a range of complementary aspects, including prospective studies in conjunction with international scientific communities, R&D concerning all areas of mechanical engineering, industry-specific studies and projects, and the large-scale federative technological projects.

Cetim provides a comprehensive array of services to the mechanical engineering industry from consulting to testing and from engineering to training in new skills.

Cetim is a member of the Carnot Institutes network.

Noise and Vibration Engineering : one of the Cetim’s areas of expertise

For this area, our mission is to conduct experimental and numerical studies in the following fields:

- structural dynamics, diagnosis, monitoring and vibration expertise (rotating machines, industrial facilities…)
- noise and vibration reduction in industrial environment, vibro-acoustic design and expertise, machines and equipment certification

These studies are performed as well for mutualized actions (works requested and steered by representatives of each profession in the mechanical industry, support to SME’S and R&D) as for commercial services.

CONTACT
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Introducing The Institution of Mechanical Engineers

The Institution of Mechanical Engineers is the fastest growing professional engineering institution in the UK. Our 100,000 members work at the heart of the country's most important and dynamic industries.

With a 160-year heritage supporting us, today's Institution is a forward-looking, campaigning organisation. By working with leading companies, universities and think tanks, we create and share knowledge to provide government, businesses and the public with fresh thinking and authoritative guidance on all aspects of mechanical engineering.

We truly believe we can improve the world through engineering. So the Institution finds and nurtures new talent, helping engineers build their careers and take on the challenges that, when solved, will make a difference to all of us.

In the UK, engineering has achieved great successes, but in a quiet way. We're looking to shout about the achievements of our members and the industry, taking a positive, inspiring message into schools and out into the media. By being independent of both government and business, and avoiding strategic relationships with single-issue bodies or pressure groups, we can deliver genuinely impartial advice in a passionately committed manner.

As an Institution, we focus on four principal themes which affect and are affected by our engineers:

- Energy
- Environment
- Transport
- Education

Our Divisions and Groups however feature on numerous areas of mechanical engineering: www.imeche.org/knowledge/industries

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SUPPORTING ORGANISATIONS

AFM: Association Française de Mecanique

AMCA International: Air Movement and Control Association International

ATI: Associazione Termotecnica Italiana

CIDB: Centre d'Information et de Documentation sur le Bruit

EUROVENT: European Committee of Air Handling and refrigeration Equipment Manufacturers

FETA: Federation of Environmental Trade Associations

Fan Manufacturers Association

HEVAC: Heating, Ventilation and Air-Conditioning Manufacturers Association

INCE Europe: Institute of Noise Control Engineering – Europe

SFA: Société Française d'Acoustique

SIA: Société des Ingénieurs de l'Automobile

Uniclima

LIST OF SESSIONS

00 Keynote Lecture

Ecodesign Requirements on Fans: Current Situation and Future Developments

- GONZÁLEZ ÁLVAREZ Marcos – European Commission (Belgium)

Numerical and Analytical Predictions of Low-Speed Fan Aeroacoustics

- MOREAU Stéphane – Sherbrooke University (Canada)

Fan Design: Past, Present and Future

- GODICHON Alain – Consultant (France)

Wednesday 15 April 2015

A1 CEVAS Project (HVAC of cars)

The Noise Prediction of Automotive Axial Fan with Different Blade Sweep Angle using Unsteady CFD Analysis

- JUNG Wooyoul – Halla Visteon Climate Control Corp. (South Korea)
- SONG Sunghoon – Halla Visteon Climate Control Corp. (South Korea)
- PARK Minjun – KAIST (South Korea)
- LEE Duckjoo – KAIST (South Korea)

Inverse Method to Predict Fan noise

- LEGROS Maxime – Cetim (France)
- VILLE Jean-Michel – Université de Technologie de Compiègne - UTC (France)
- MOREAU Solène – Université de Technologie de Compiègne - UTC (France)
- GOTH Yvon – Cetim (France)
- CARNIEL Xavier – Cetim (France)

Acoustic Synthesis of an Automotive HVAC

- LEGROS Maxime – Cetim (France)
- VILLE Jean-Michel – Université de Technologie de Compiègne - UTC (France)
- MOREAU Solène – Université de Technologie de Compiègne - UTC (France)
- CARNIEL Xavier – Cetim (France)

Aeroacoustic Measurement of Automotive HVAC In-Duct Elements

- BENNOUNA Saâd – Valeo thermal Systems, Université de Technologie de Compiègne (France)
- OUEDRAOGO Boureima – Université de Technologie de Compiègne (France)
- MOREAU Solène – Université de Technologie de Compiègne (France)
- VILLE Jean Michel – Université de Technologie de Compiègne (France)
- CHERIAUX Olivier – Valeo Thermal Systems (France)

A2 Optimization & Design Methods

Optimization of Low Pressure Axial Fans and Effect of Subsequent Geometrical Modifications

- BAMBERGER Konrad – University of Siegen (Germany)
- CAROLUS Thomas – University of Siegen (Germany)
- HAAS Markus – Helios Ventilatoren GmbH + Co KG (Germany)

Advanced Integrated Design Optimization System Using 3D Aerodynamic and Aero-Acoustic Analyses for Design of an Axial Fan

- HEO Man-Woong – Inha University (South Korea)
- SEO Tae-Wan – Inha University (South Korea)
- SHIM Hyeon-Seok – Inha University (South Korea)
- KIM Kwang-Yong – Inha University (South Korea)

CFD-based Fan Optimization Considering the System Integration in a Heat Pump

- LÖRCHER Frieder – Ziehl-Abegg SE (Germany)

A3 Tip Leakage Noise of Axial Fans

Experimental and Numerical Investigation of Tip Clearance Noise of an Axial Fan Using a Lattice Boltzmann Method

- ZHU Tao – University of Siegen, Institute of Fluid- and Thermodynamic (Germany)
- CAROLUS Thomas H. – University of Siegen, Institute of Fluid- and Thermodynamic (Germany)

Noise Reduction for Automotive Radiator Cooling Fans

- ALLAM Sabry – Helwan University (Egypt)
- ÅBOM Mats – KTH (Sweden)

The Application of Microperforated Material to Control Axial Fan Tip Clearance Noise

- LEE Seungkyu – Ray W. Herrick Laboratories, School of Mechanical Engineering, Purdue University (United States)
- BOLTON J. Stuart – Ray W. Herrick Laboratories, School of Mechanical Engineering, Purdue University (United States)

B1 Signal processing for noise source location/characterization

Broadband Mode Decomposition of Ducted Fan Noise Using Cross-spectral Matrix Denoising

- FINEZ Arthur – MicrodB (France)
- PEREIRA Antonio – Laboratoire de Vibrations et d'Acoustique (France)
- LECLÈRE Quentin – Laboratoire Vibrations Acoustique, INSA Lyon (France)

Reevaluating Noise Sources Appearing on the Axis for Beamforming Maps of Rotating Sources

- HORVÁTH Csaba – Dpt of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics (Hungary)
- TÓTH Bence – Dpt of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics (Hungary)
- TOTH Péter – Department of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics (Hungary)
- BENEDEK Tamás – Dpt of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics (Hungary)
- VAD János – Dpt of Fluid Mechanics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics (Hungary)

Full Characterization of Fans as Aero-Acoustic Sources Using Multi-port Models

- SACK Stefan – KTH Royal Institute of Technology (Sweden)
- ÅBOM Mats – KTH Royal Institute of Technology (Sweden)
- SCHRAM Christophe – von Karman Institute for Fluid Dynamics (Belgium)
- KUCUKCOSKUN Korcan – von Karman Institute for Fluid Dynamics (Belgium)

Microphone Array Method for the Characterization of Rotating Sound Sources in Axial Fans

- HEROLD Gert – Brandenburg University of Technology (Germany)
- SARRADJ Ennes – Brandenburg University of Technology (Germany)

Noise Control for Two Axial-flow Cooling Fans in Series

- WANG Chen – Lab for Aerodynamics and Acoustics, Zhejiang Institute of Research and Innovation, and Dept. of Mechanical Engineering, The University of Hong Kong (China)
- ZHANG Weihao – Lab for Aerodynamics and Acoustics, Zhejiang Institute of Research and Innovation, and Department of Mechanical Engineering, The University of Hong Kong (China)
- HUANG Lixi – Lab for Aerodynamics and Acoustics, Zhejiang Institute of Research and Innovation, and Department of Mechanical Engineering, The University of Hong Kong (China)

B2 Theoretical & Numerical Methods for Axial Fans

Experimental and Numerical Investigation of a Gearless One-motor Contra-Rotating Fan

- HEINRICH Martin – Technical University Bergakademie Freiberg (Germany)
- FRIEBE Christian – ILK Dresden (Germany)
- BOTHE Franziska – Technical University Bergakademie Freiberg (Germany)
- SCHWARZE Rüdiger – Technical University Bergakademie Freiberg (Germany)

Numerical and Experimental Investigation into the Accuracy of the Fan Scaling Laws Applied to Large Diameter Axial Flow Fans

- AUGUSTYN Ockert – Eskom (South Africa)
- VAN DER SPUY Sybrand J. – Stellenbosch University (South Africa)
- VON BACKSTRÖM Theo – Stellenbosch University (South Africa)

Computation of the Unsteady Fan-system Coupling using Actuator Surface Approach

- CORSINI Alessandro – Dept. of Mechanical and Aerospace Engineering - Sapienza University of Rome (Italy)
- DELIBRA Giovanni – Dept. of Mechanical and Aerospace Engineering - Sapienza University of Rome (Italy)
- MINOTTI Stefano – GE Oil&Gas (Italy)
- ROSSIN Stefano – Ge Oil&Gas (Italy)

Increase the Efficiency of Rotor-Only Axial Fans with Controlled Vortex Design Blading

- MASI Massimo – University of Padova - Department of Management and Engineering (Italy)
- CASTEGNARO Stefano – University of Padova - Department of Industrial Engineering (Italy)
- LAZZARETTO Andrea – University of Padova - Department of Industrial Engineering (Italy)

B3 Measurement & Test

Lab-to-lab Variation in Testing Fans

- STEVENS Mark – AMCA International (United States)
- GYURO Marton – Greenheck Fan Corporation (United States)

Phase Locked PIV Measurements in Wake of an Automotive Fan Model

- SAMPATH Kaushik – Johns Hopkins University (United States)
- KATZ Joseph – Johns Hopkins University (United States)

Implementation of an Acoustic Stall Detection System using Near-field DIY Pressure Sensors

- CORSINI Alessandro – Sapienza University of Rome (Italy)
- FEUDO Sara – Sapienza University of Rome (Italy)
- SHEARD Anthony G. – Fläkt Woods Limited (United Kingdom)
- TORTORA Cecilia – Sapienza University of Rome (Italy)
- ULLUCCI Graziano – SED Soluzioni per l'Energia e la Diagnostica (Italy)

A Numerical and Experimental Test-Bed for Low-Speed Fans

- MOREAU Stéphane – Université de Sherbrooke (Canada)
- FOSS John – Michigan State University (United States)
- MORRIS Scott C. – University of Notre Dame (United States)

Thursday 16 April 2015

C1 Noise of Centrifugal Fans

Prediction of Aerodynamic Noise for Centrifugal Fan of Air-Conditioner

- IWASE Taku – Hitachi. Ltd., Hitachi Research Laboratory (Japan)
- SATO Daiwa – Hitachi, Ltd., Hitachi Research Laboratory (Japan)
- OBARA Hideshi – Hitachi Appliances, Inc. (Japan)
- YONEYAMA Hiroyasu – Hitachi Appliances, Inc. (Japan)
- KISHITANI Tetsushi – Hitachi Appliances, Inc. (Japan)
- YAMADE Yoshinobu – Tokyo University (Japan)
- KATO Chisachi – Tokyo University (Japan)

Noise Generation Mechanism and Noise Reduction Design on Bi-Directional Radial Fan

- KOYAMA Taihei – TOSHIBA (Japan)
- NAKAHAMA Takafumi – TOSHIBA (Japan)
- AIKURA Nobutake – TOSHIBA (Japan)
- KATSUKI Ryota – TOSHIBA (Japan)

Study of Aerodynamic Noise Generated from a Forward Curved Fan due to Rotating Stall Cell

- SASAKI Soichi – Nagasaki University (Japan)
- ONOMICHI Yuta – Nagasaki University (Japan)

Reduction of Turbulent Noise from Backward Curved Centrifugal Fan with Square Casing

- HAYASHI Hidechito – Nagasaki University (Japan)
- SHIRAHAMA Seiji – Panasonic Ecology Systems Co., Ltd. (Japan)
- ODA Ippei – Panasonic Ecology Systems Co., Ltd. (Japan)
- OKUMURA Tetsuya – Nagasaki University (Japan)
- HAMAKAWA Hiromitsu – Ooita University (Japan)

C2 Numerical Methods

Vortex Shedding Noise Reduction of a Mixed Flow Fan: Experimental and Numerical Investigation

- COLLISON Michael – Dyson (United Kingdom)
- STIMPSON Ryan – Dyson (United Kingdom)
- DESVARD Ludovic – Dyson (United Kingdom)

Efficient Large Eddy Simulation of a Low-Mach Number Axial Fan

- CHUMAKOV Sergei – Robert Bosch LLC, Research and Technology Center (United States)
- BOSE Sanjeeb T. – Cascade Technologies, Inc. (United States)
- HAM Frank – Cascade Technologies Inc. (United States)

Aeroacoustic Assessment of Leading Edge Bumps in Industrial Fans by Means of Hybrid LES/RANS

- CORSINI Alessandro – Dept. of Mechanical and Aerospace Engineering, Sapienza University of Rome (Italy)
- DELIBRA Giovanni – Dept. of Mechanical and Aerospace Engineering, Sapienza University of Rome (Italy)
- RISPOLI Franco – Dept. of Mechanical and Aerospace Engineering, Sapienza University of Rome (Italy)
- SHEARD Anthony Geoff – AGS Consulting, LLC (United States)

Flow Characteristics Beyond Time and Phase: A Modal Analysis of the Patterns in a Regenerative Pump

- MATTERN Philipp – KIT / FSM (Germany)
- KRIEGSEIS Jochen – KIT / ISTM (Germany)
- GABI Martin – KIT / FSM (Germany)

C3 Motors

Aerodynamic Characteristics of a Cooling Fan in a Low-voltage Electric Motor

- PARK Jae-Min – Inha University (South Korea)
- HEO Man-Woong – Inha University (South Korea)
- KIM Kwang-Yong – Inha University (South Korea)
- SHIM Hyeon-Seok – Inha University (South Korea)
- CHOI Kwang-Yong – Hyundai Heavy Iindustries Co., LTD. (South Korea)
- LEE Joon-Yeob – Hyundai Heavy Iindustries Co., LTD. (South Korea)

The Study on Vibration and Noise Characteristics of Fan Motors Caused by the Electromagnetic Force

- OGUSHI Masaki – Minebea Co.,Ltd. (Japan)
- SHIOHATA Koki – Ibaraki University (Japan)
- OTSUKA Takako – Minebea Co.,Ltd. (Japan)
- TARODA Atsushi – Minebea Co.,Ltd. (Japan)
- YAN Zhong – Minebea Co.,Ltd. (Japan)
- KAWAI Yoichi – Minebea Co.,Ltd. (Japan)
- FURUYA Miyuki – Minebea Co.,Ltd. (Japan)

Process Chain for Quick, Efficient Thermal Assessment with Motor Designs of a Fan

- PFAFF Christian – ebm-papst Mulfingen GmbH&Co.KG (Germany)

Identifying Torsional Resonance Problems Associated with VFD Driven Fans

- KAUFMAN Steven – Flowcare Engineering Inc (Canada)

D1 Prediction of Axial Fan Noise by Hybrid Methods (i)

A Low Pressure Axial Fan for Benchmarking Prediction Methods for Aerodynamic Performance and Sound

- CAROLUS Thomas – University of Siegen (Germany)
- ZHU Tao – University of Siegen (Germany)
- STURM Michael – University of Siegen (Germany)

Competing Broadband Noise Mechanisms of a Generic Low-Speed Axial Fan Including Acoustic Scattering

- KUCUKCOSKUN Korcan – von Karman Institute for Fluid Dynamics (Belgium)
- CHRISTOPHE Julien – von Karman Institute for Fluid Dynamics (Belgium)
- SCHRAM Christophe – von Karman Institute for Fluid Dynamics (Belgium)

Numerical Investigation of the Influence of Skewness and Gap Geometry on Sound Radiation of Axial Vehicle Cooling Fans

- BECHER Marcus – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- ZENGER Florian – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- TAUTZ Matthias – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- SCHEIT Christoph – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- BECKER Stefan – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)

Noise Prediction from a Low Mach Number Axial Fan With LES and BEM

- CHUMAKOV Sergei – Robert Bosch LLC, Research and Technology Center (United States)
- SHIN Yoon Shik – Robert Bosch LLC, Electric Drives Division (United States)
- BRÈS Guillaume A. – Cascade Technologies Inc. (United States)
- HAM Frank – Cascade Technologies Inc. (United States)
- NICHOLS Joseph – Department of Aerospace Engineering and Mechanics, University of Minnesota (United States)

D2 Theoretical & Numerical Methods for Centrifugal Fans

Hump-Shaped Broadband Noise on a Fan at Off-design Conditions

- HENNER Manuel – Valeo Thermal Systems (France)
- FRANQUELIN François – Valeo Thermal Systems (France)
- DEMORY Bruno – Valeo Thermal Systems (France)
- BEDDADI Youssef – Valeo Thermal Systems (France)
- ROLAND Charles – Valeo Thermal Systems (France)
- SERRAN Aurélien – Valeo Thermal Systems (France)

Automotive Blower Design with Inverse Method Applied on Wheel and Volute

- HENNER Manuel – Valeo Thermal Systems (France)
- BEDDADI Youssef – Valeo Thermal Systems (France)
- ZANGENEH Mehrdad – University College London (United Kingdom)
- DEMORY Bruno – Valeo Thermal Systems (France)

CFD Optimization of a Fan for Industrial Application

- ALDI Nicola – University of Ferrara (Italy)
- BURATTO Carlo – University of Ferrara (Italy)
- CARANDINA Alessandro – University of Ferrara & Fluid-A s.r.l (Italy)
- SUMAN Alessio – University of Ferrara (Italy)
- PINELLI Michele – University of Ferrara (Italy)
- ZANARDI Andrea – MZ Aspiratori S.p.A. (Italy)

D3 Fan Performance (i)

Use of High Pressure Stages in the Design of New Axial Fans for High Performance Blocks in Coal Electricity Power Plants

- CYRUS Vaclav – AHT Energetika Ltd (Czech Republic)

Study on Air Conditioning Thermal Comfort with New-type Fan

- ZOU Jianhuang – Refrigeration Institute of Gree Electric Appliances, Inc. of Zhuhai (China)
- ZHANG Youlin – Refrigeration Institute of Gree Electric Appliances, Inc. of Zhuhai (China)
- ZHUANG Rong – Refrigeration Institute of Gree Electric Appliances, Inc. of Zhuhai (China)
- LIU Zhongjie – Refrigeration Institute of Gree Electric Appliances, Inc. of Zhuhai (China)

Investigation of the Aerodynamic & Aeroacoustic Performance of Cross-flow Fans

- BAYRAKDAR Özgür – Vestel Beyaz Esya A.S. Air Conditioner R&D (Turkey)
- DEMIRKESEN Cem – Vestel Beyaz Esya A.S. Air Conditioner R&D (Turkey)
- SORGÜVEN Esra – Department of Mechanical Engineering, Yeditepe University (Turkey)
- GÜMÜS Ilhami – Vestel Beyaz Esya A.S. Air Conditioner R&D (Turkey)

Study of the Effect of Fan Tip Configuration on Air-Cooled Condenser Axial Flow Fan Performance

- WILKINSON Michael B. – Stellenbosch University (South Africa)
- VAN DER SPUY Sybrand J. – Stellenbosch University (South Africa)

Effect of Reduced Suction Side Volume on Cross-Flow Fan Performance

- SPINOLA Matteo – University of Padova - Department of Industrial Engineering (Italy)
- GOBBATO Paolo – University of Padova - Department of Industrial Engineering (Italy)
- LAZZARETTO Andrea – University of Padova - Department of Industrial Engineering (Italy)
- MASI Massimo – University of Padova - Department of Management and Engineering (Italy)

E2 Sound Quality

Psychoacoustic Evaluation of Fan Noise

- SCHNEIDER Marc – ebm-papst Mulfingen GmbH & Co. KG (Germany)
- FELDMANN Carolin – ebm-papst Mulfingen GmbH & Co. KG (Germany)

Sound Synthesis of Fan Noise and Modeling of its Perception in Car Passenger Compartment

- MINARD Antoine – Genesis (France)
- VIDAL Adrien – Genesis (France)
- LAMBOURG Christophe – Genesis (France)
- BOUSSARD Patrick – Genesis (France)

Friday 17 April 2015

F1 Lattice Boltzmann Methods (i)

Numerical Analysis of Unsteady Three-Dimensional Flow in a Propeller Fan Using Lattice Boltzmann Method

- KUSANO Kazuya – Hitachi, Ltd. (Japan)
- YAMADA Kazutoyo – Kyushu University (Japan)
- FURUKAWA Masato – Kyushu University (Japan)

Aeroacoustic Simulation of an Axial Fan Including the Full Test Rig by Using the Lattice Boltzmann Method

- STURM Michael – University of Siegen (Germany)
- SANJOSE Marlène – Université de Sherbrooke (Canada)
- MOREAU Stéphane – Université de Sherbrooke (Canada)
- CAROLUS Thomas – University of Siegen (Germany)

Numerical Optimization of the Tonal Noise of a Backward Centrifugal Fan using a Flow Obstruction - Part II: Flow Obstruction Optimization

- PAIN Romain – EuroXA (France)
- LE GOFF Vincent – Exa Corporation (France)
- PÉROT Franck – Exa Corporation (United States)
- GOTH Yvon – Cetim (France)
- CARNIEL Xavier – Cetim (France)
- SHESTOPALOV Andrea – Exa Corporation (United States)
- LEARNED BOUCHER Amanda – Exa Corporation (United States)

F2 Tonal Noise Modelling

On an Uniform Rotor-Stator Wake-Interaction Noise Model Based on a Mode-Matching Technique

- BOULEY Simon – Ecole Centrale de Lyon (France)
- ROGER Michel – Ecole Centrale de Lyon (France)
- FRANCOIS Benjamin – Ecole Centrale de Lyon (France)

Spectral Characterizations of Centrifugal Fan Noise via uRANS-based Noise Prediction Method

- ZAMIRI Ali – Korea University (South Korea)
- OH Hyeon Joon – Samsung Electronics Co.,LTD (South Korea)
- MOON Young J. – Korea University (South Korea)

Tonal Fan Noise Prediction and Validation on the ANCF Configuration

- SANJOSE Marlène – Université de Sherbrooke (Canada)
- DAROUKH Majd – CERFACS / Snecma /INP Toulouse / Université de Sherbrooke au Canada (France)
- MAGNET William – ENSEEIHT / INP Toulouse (France)
- DE LABORDERIE Jérôme – CERFACS (France)
- MOREAU Stéphane – Université de Sherbrooke (Canada)
- MANN Adrian – Exa Corporation (United States)

F3 Fan Design Methods

As Good As It Can Be – Ventilation System Design by a Combined Scaling and Discrete Optimization Method

- SCHÄNZLE Christian – Technische Universität Darmstadt, Chair of Fluid Systems (Germany)
- ALTHERR Lena – Technische Universität Darmstadt, Chair of Fluid Systems (Germany)
- EDERER Thorsten – Technische Universität Darmstadt, Chair of Fluid Systems (Germany)
- LORENZ Ulf – Technische Universität Darmstadt, Chair of Fluid Systems (Germany)
- PELZ Peter F. – Technische Universität Darmstadt, Chair of Fluid Systems (Germany)

A General Inverse Design Method for Hydraulic Characteristics of Axial Fans Respecting Curved Streamlines

- VOGEL Patrick – Institute of Fluid Dynamics Friedrich-Alexander-Universität Erlangen-Nürnberg (Germany)
- SEMEL Matthias – Institute of Fluid Dynamics Friedrich-Alexander-Universität Erlangen-Nürnberg (Germany)
- DELGADO Antonio – Institute of Fluid Mechanics, Friedrich-Alexander University Erlangen-Nuremberg (Germany)

Prediction of Noise Emission, Power Consumption and Airflow Performance using Multidimensional Fan Curves

- NELSON David – Nelson Acoustics (United States)

G1 Installation Effect

Noise Prediction of Outdoor Unit of Air Conditioning with Different Sizes Based on CFD

- WU Yadong – Shanghai Jiao Tong University (China)
- TIAN Jie – Shanghai Jiao Tong University (China)
- OUYANG Hua – Shanghai Jiao Tong University (China)
- DU Zhaohui – Shanghai Jiao Tong University (China)

Experimental Investigation of the Effect of Grille Structure to the Outdoor Unit of Room Air Conditioner

- WU Yadong – Shanghai Jiao Tong University (China)
- TIAN Jie – Shanghai Jiao Tong University (China)
- OUYANG Hua – Shanghai Jiao Tong University (China)
- DU Zhaohui – Shanghai Jiao Tong University (China)

Challenge and Opportunities for Flow Noise Prediction in HVAC Systems

- KÅREKULL Oscar – Fläkt Woods / KTH - Marcus Wallenberg Laboratory (Sweden)
- EFRAIMSSON Gunilla – KTH - Aeronautical and Vehicle Engineering (Sweden)
- ÅBOM Mats – KTH - Marcus Wallenberg Laboratory (Sweden)

Influence of Inflow Turbulence on Aeroacoustic Noise of Low Speed Axial Fans with Skewed and Unskewed Blades

- ZENGER Florian – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- BECHER Marcus – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)
- BECKER Stefan – Friedrich-Alexander University of Erlangen-Nuremberg (Germany)

G2 Prediction of Axial Fan Noise by Hybrid Methods (ii)

Prediction of the Broadband Noise of a Low-Speed Axial Fan by CFD Simulations and an Empirical Wall-Pressure Spectral Model

- GUEDEL Alain – CETIAT (France)
- ROBITU Mirela – CETIAT (France)

Broadband Trailing-Edge Noise Prediction of a Four-Bladed Axial Fan using a Semi-Analytical Method

- GRASSO Gabriele – von Karman Institute for Fluid Dynamics (Belgium)
- CHRISTOPHE Julien – von Karman Institute for Fluid Dynamics (Belgium)
- SCHRAM Christophe – von Karman Institute for Fluid Dynamics (Belgium)

Fan Noise Prediction from Local Experimental Source Terms and Numerical Sound Propagation

- LEGROS Maxime – CETIM (France)
- GOTH Yvon – CETIM (France)
- GUEDEL Alain – CETIAT (France)

G3 Fan Efficiency

Achievable Total-to-Static Efficiencies of Low-pressure Axial Fans

- BAMBERGER Konrad – University of Siegen (Germany)
- CAROLUS Thomas – University of Siegen (Germany)

Eco-Design of a Small Size Industrial Fan for Ceramic Tile Cooling

- ALDI Nicola – University of Ferrara (Italy)
- DAVOLI Giacomo – University of Modena and Reggio Emilia, F.M. S.r.l. (Italy)
- PINELLI Michele – University of Ferrara (Italy)
- ROSSI Luca – F.M. S.r.l. (Italy)
- SUMAN Alessio – University of Ferrara (Italy)

Fan Retrofits to Achieve Improved Energy Efficiency: What is Required to Make this Work Effectively?

- MARTIN Vern – Flowcare Engineering Inc. (Canada)

H1 Lattice Boltzmann Methods (ii)

Computational Analysis of Noise Generation and Propagation Mechanisms using the Example of an HVAC Blower

- NEUHIERL Barbara – Exa GMBH (Germany)
- FELFÖLDI Attila – Exa GmbH (Germany)

Towards a Full Digital Approach for Aeroacoustics Evaluation of Automotive Engine Cooling Fans and HVAC Blowers

- LE GOFF Vincent – Exa Corporation (France)
- LE HENNAFF Benoît – Delphi Thermal Systems (Luxembourg)
- PIELLARD Mélanie – Delphi Thermal Systems (Luxembourg)
- PIHET David – Delphi Thermal Systems (Luxembourg)
- COUTTY Bruno – Delphi Thermal Systems (Luxembourg)

H3 Fan Performance (ii)

Impact of a Skewed Inlet Boundary Layer on the Aerodynamic Performance of a Stator-hub Equivalent High-turning Compressor Cascade

- BODE Christoph – Technische Universität Braunschweig Institut für Flugantriebe und Strömungsmaschinen (Germany)
- STARK Udo – Technische Universität Braunschweig Institut für Strömungsmechanik (Germany)
- FARD AFSHAR Nima – Technische Universität Braunschweig Institut für Flugantriebe und Strömungsmaschinen (Germany)

Influence of Compressibility on Incidence Losses of Turbomachinery at Subsonic Operation

- SAUL Sebastian – Technical University Darmstadt (Germany)
- STONJEK Stefan S. – Technical University Darmstadt (Germany)
- PELZ Peter F. – Technical University Darmstadt (Germany)

Panel Session - Sound Quality: a New Requirement for Fan Manufacturers

Human Perception and Fan Noises

- NAJI Said – Valéo Thermal Systems (France)
- SANON Anne – Valeo Visibility Wiper Systems (France)

ABSTRACTS

ECODESIGN REQUIREMENTS ON FANS: CURRENT SITUATION AND FUTURE DEVELOPMENTS

Marcos GONZÁLEZ ÁLVAREZ European Commission (Belgium)

Abstract : Motor Driven Systems, including fans, represent around 50% of the electricity consumption in Europe. They were identified as a priority group to be analysed under Ecodesing already in 2005. As a consequence Regulation 327/2011 setting minimum requirements for the fans placed in the European market was published. The coming into force of the requirements set out on the Regulation represented a major mile-stone for industry, for Member States and for other stakeholders. The time has now come to re-evaluate the requirements applied at European level, also taking into consideration the latest development in the rest of the world. The current state of play of this evaluation will be presented together with the future steps that will need to be taken in order to review the currently in force Regulation.

Marcos González is currently working at the Energy Efficiency unit of the Directorate General for Energy (European Commission). He is in charge of several Ecodesign and Energy Labelling Regulations or proposals covering several product groups including motor driven systems and heating equipment. Before joining the Commission he worked at the Institute for Energy Saving and Diversification, the Spanish Energy Agency, where he collaborated on the transposition of the Energy Efficiency in Buildings Directive into the Spanish legislation. He has also worked as consultant specialised in energy efficiency in London and Madrid.

He studied industrial engineering at the Universidad de Oviedo and the École Nationale Supérieure d'Arts et Métiers (Paris).

NUMERICAL AND ANALYTICAL PREDICTIONS OF LOW-SPEED FAN AEROACOUSTICS

Stéphane MOREAU Sherbrooke University (Canada)

Keynote Lecture

Stéphane Moreau obtained his engineering degree and MSc from ISAE- Sup'Aéro (France) in 1988. He then got his PhD in Mechanical Engineering with a minor in Aeronautics and Astronautics from Stanford University in 1993.

He then worked for a start-up company AC2 on plasma physics in 1994 where he developed the plasma micro-thruster concept used nowadays on most satellites. He then worked for a year at the turbo-engine builder Snecma on nozzle designs (Safran group). Late 1995 he joined the automotive Tier-1 supplier Valeo where he worked for 13 years on engine cooling fan system design. He joined the Mechanical Engineering faculty of Université de Sherbrooke in 2009 as an associate Professor. He became a full professor in 2011. Since 2014, he also has a joint-appointment at Ecole Centrale de Lyon.

His research topics include aeroacoustics, turbomachinery design and CFD (Computational Fluid Dynamics). He has more than 300 scientific publications with more than a half in aeroacoustics with significant contributions in analytical noise modeling, experimental noise measurements and large scale numerical aeroacoustic simulations (requiring high power computing for instance).

Fan Design: Past, Present and Future

Alain GODICHON Consultant (France)

Alain Godichon is an engineering graduate from The "Ecole Nationale Supérieure de la Métallurgie et de l'Industrie des Mines (E.N.S.M.I.M.)" located in Nancy, France. While studying for his degree he specialized in Fluid Mechanics. In 1972 Alain started work as a Research and Development Engineer at Solyvent-Ventec. He went on to become the Technical Director of Fläkt Solyvent-Ventec, taking an active role in research and development projects worldwide within the Fläkt Woods Group. In a career spanning 42 years Alain has studied all aspects of fan design, with a particular focus on aerodynamics, acoustics, mechanical design and vibration analysis. This broad-based background enabled Alain to trouble-shoot in-service issues, further contributing to his experience. He has leveraged this experience, developing software systems that systematically capture his knowledge.

Alain is the inventor of patents relating to fan technology and fan application. During the course of his long carrier he has taken part in the EUROVENT Working Group "Fans". He has published technical papers at conferences focused on fan technology. He has also collaborated with the Sapienza University of Rome on the development of computational methods and their application to the design of air movement fans. Alain is currently working as an independent Consultant.

THE NOISE PREDICTION OF AUTOMOTIVE AXIAL FAN WITH DIFFERENT BLADE SWEEP ANGLE USING UNSTEADY CFD ANALYSIS

Wooyoul JUNG Halla Visteon Climate Control Corp. (South Korea)
Sunghoon SONG Halla Visteon Climate Control Corp. (South Korea)
Minjun PARK KAIST (South Korea)
Duckjoo LEE KAIST (South Korea)

This study is carried out for automotive axial fan with the three types of swept blade: forward, backward and straight, using three dimensional unsteady CFD analysis. Acoustic analogy by Ffowcs-Williams-Hawkings is used to predict the sound propagation in the far-field. Unsteady RANS and SST turbulence models are used for CFD analysis. The predicted results are validated with the following experiments. The three fans with different sweep angles show quite different performance and noise levels. Especially the overall noise of the forward swept fan shows 2 to 3 dB which is lower than the straight blade and backward swept fans' at the same flow rate. The main purpose of this study is to explain what causes the differences in performance and noise level in terms of flow characteristics, and how the sweep angle of blade affects the overall fan noise level. The corresponding setup in CFD analysis and experiment include just cooling fan and shroud without heat exchangers

INVERSE METHOD TO PREDICT FAN NOISE

Maxime LEGROS Cetim (France)
Jean-Michel VILLE Université de Technologie de Compiègne - UTC (France)
Solène MOREAU Université de Technologie de Compiègne - UTC (France)
Yvon GOTH Cetim (France)
Xavier CARNIEL Cetim (France)

Predicting the noise radiated by a fan can be done using several methods from the simplest (ASHRAE, very fast estimation of the spectrum without linking it to the air-flow phenomenon) to the most demanding in terms of computing resources (CFD and aero-acoustics module for instance).

Model predictions have been developed to characterize the components whose noise sources are due to fluid flow. These methods permit to determine the acoustic behavior of a component such as the fan, taking into account the operating point. In this paper, an inverse method is developed to define the acoustic source terms of a fan in a complex environment which require setting up a protocol for testing and calculating.

Based on a theoretical approach from the Euler equations, the fan is represented by a source term reflecting its ability to produce a sound. The value of the source term is quantified using a test bench to determine the intrinsic capacity of the fan to produce the sound measured, regardless of the measurement environment. Then, one may calculate the noise produced when the fan is placed inside any acoustic medium. In this paper, one will use the cavity of an automotive HVAC to correlate the noise prediction with experimental results comparing the outlet sound power level.

This work has been developed in the FUI project called Cevas.

ACOUSTIC SYNTHESIS OF AN AUTOMOTIVE HVAC

Maxime LEGROS Cetim (France)
Jean-Michel VILLE Université de Technologie de Compiègne - UTC (France)
Solène MOREAU Université de Technologie de Compiègne - UTC (France)
Xavier CARNIEL Cetim (France)

The acoustic synthesis is a design and/or diagnosis approach used to analyze and predict the acoustic behavior of a complex system. Based on the components found in the system, an acoustic pattern is implemented in which the acoustic sources and pathways from the source to the reception point are identified. At this point of reception a performance criterion is usually assigned that has to be optimized (sound pressure level, sound power level, psychoacoustic criterion ...). The acoustic synthesis provides a conception tool to the designer to predict the noise produced by a system considering the chosen components and the operating conditions.

In this paper, an acoustic synthesis is performed on an automotive HVAC considering operating conditions. Based on the requirements of a sound synthesis in terms of time spent, accuracy and outcomes, one will present a synthesis of a simplified model using experimental results, empiric laws and theoretical approach. The final result is the sum of the contributions of each sources modified by the transfer functions (transmission losses) of pathways encountered.

The synthesis is developed in order to propose an approach which take into account the integration effects and some interaction effects. In this case, the pathways are represented by diffusion elements and the sources by volumetric strength. In an automotive HVAC, the fan is the most important source while the flaps and heat exchangers are weaker sources and mainly diffusion elements.

The integration effects are due to the acoustic cavity in which is located a source. The interaction effects are, for instance, the change of the operating point due to a variation of flap opening or the effects on a flap of turbulent flow created by an uphill component.

This work has been developed in the FUI project called Cevas

AEROACOUSTIC MEASUREMENT OF AUTOMOTIVE HVAC IN-DUCT ELEMENTS

Saâd BENNOUNA Valeo thermal Systems, Université de Technologie de Compiègne (France)
Boureima OUEDRAOGO Université de Technologie de Compiègne (France)
Solène MOREAU Université de Technologie de Compiègne (France)
Jean Michel VILLE Université de Technologie de Compiègne (France)
Olivier CHERIAUX Valeo Thermal Systems (France)

An HVAC is a compact system composed of moving (blower) and fixed (flap, thermal exchangers…) elements designed to provide thermal comfort inside the vehicle. These in-duct elements which interact with air flow generate noise inside car cabin.

Assuming that the aeroacoustic properties of all these elements can be modelized by 2N-ports linear systems, the UTC (Université de Technologie de Compiègne) has developed a test bench to perform the measurements of these properties. The facility satisfies the Valeo Thermal Systems' requirements in terms of dimensions, duct geometries, airflow rate and frequency range. In addition, aeraulic measurements are conducted using a laser based method: Particle Image Velocimetry (PIV).

The 2N-ports model describes an induct element by its passive and active acoustic properties assuming N propagative modes. The acoustic passive property is represented by its multimodal scattering matrix (reflection and transmission coefficients) and is first estimated with a 2N-source method. The acoustic active property is represented by its N-component source vector and is secondly measured. Then, based on the Nelson & Morphey's theory for low Mach numbers ($M<0.1$), the coefficient depending on the Strouhal number, K(St) which characterizes the aeroacoustic source is deduced from the measurements of source vector and element's pressure loss. The PIV aeraulic measurement method provides mean velocity field around element but also RMS velocity which describes airflow's turbulence state.

Under CEVAS project, the measurement methods described above are applied to academic elements (diaphragm and separately close diaphragms). For automotive HVAC components (flap, flap + small barrier and blower), the studies are performed in vehicle conditions of airflow rate. The measurement results are used under CEVAS project as input data for acoustic synthesis studies and as numerical simulations validation.

In this paper, the duct flow facility is described and the experimental methods are presented. Then, the acoustic and aeraulic properties of in-duct elements are defined. Finally, the results of the measurements carried-out with academic and industrial elements are presented and analyzed.

Optimization of Low Pressure Axial Fans and Effect of Subsequent Geometrical Modifications

Konrad BAMBERGER University of Siegen (Germany)
Thomas CAROLUS University of Siegen (Germany)
Markus HAAS Helios Ventilatoren GmbH + Co KG (Germany)

A low pressure axial fan is optimized by an evolutionary optimization algorithm. The target function is maximization of total-to-static efficiency at one design point while fulfilling a complete targeted performance curve. Additional constraints are limitation of axial depth, number of blades, and a fixed blade sweep which is selected for low sound generation. The target function is evaluated by artificial neural networks of the multi-layer perceptron (MLP) type. The MLPs were trained in earlier studies by the authors and are based on around 13,000 performance curves simulated by the Reynolds-averaged Navier-Stokes (RANS) method. While most of the common geometrical parameters of axial fans were varied for the simulations, the tip clearance was hold constant at a rather small value (0.1% of the fan diameter) and a cylindrical hub extending over the complete axial length of the blade was assumed. Hence, the MLPs are only valid for designs with these two features meaning that they are also assumed for the optimized fan of this paper.

After the optimization, the MLP-predicted performance curves are compared with RANS simulations. Additionally, a prototype is built to determine experimental performance curves. The results of the three methodologies (MLP, RANS, Experiment) show very good agreement with respect to total-to-static pressure rise and efficiency proving the adequacy of the optimization method used. However, the aforementioned properties regarding tip clearance and hub design are often violated in practice. The consequent aerodynamic penalty is determined experimentally. Firstly, the tip clearance is increased to 0.3% and 0.5% resulting in a reduction of peak efficiency by 3.5 and 7 percentage points, respectively. In addition, the operating range is decreased significantly. Secondly, the cylindrical hub is replaced by a thin disk which is only constructed to connect the blades with the shaft, but no longer separates the blade's suction and pressure side. The consequence is significantly increased secondary flow in the hub region which leads to a reduction of peak efficiency by around 7 percentage points as compared to fans with equal tip clearance but cylindrical hub.

It is concluded that we have developed an extremely quick and reliable optimization method, which was successfully validated. However, the direct practical application requires a small tip clearance and a hub which separates the blade's suction and pressure side. Ongoing work is dealing with measures to avoid the dramatic drop of efficiency when violating these features.

ADVANCED INTEGRATED DESIGN OPTIMIZATION SYSTEM USING 3D AERODYNAMIC AND AERO-ACOUSTIC ANALYSES FOR DESIGN OF AN AXIAL FAN

Man-Woong HEO	Inha University (South Korea)
Tae-Wan SEO	Inha University (South Korea)
Hyeon-Seok SHIM	Inha University (South Korea)
Kwang-Yong KIM	Inha University (South Korea)

In this work, an integrated fan design system, namely, Total FAN Plus®, was developed to carry out a series of design process, i.e., computational preliminary design, three-dimensional (3-D) aerodynamic and aero-acoustic analyses, and design optimization, for four different types of fan (axial, forward and backward blades centrifugal fans, and regenerative blower).

In the design part, a computerized preliminary design system is used for constructing 3-D blade and casing geometry of a fan and predicting aerodynamic performance based on the simple analytical methods. And, in the analysis part, 3-D computation domain is automatically generated on the basis of data obtained from computerized preliminary design and configured to a grid type, i.e., coarse, standard or fine. And, aero-acoustic characteristics are estimated in the noise part. The noise analysis is implemented in a finite./infinite element framework by solving the variational formulation of Lighthill's analogy, using the transient analysis results obtained from the analysis part. Finally, in the optimization part, single- or multi-objective design optimization of the fan is performed using surrogate model.

CFD-BASED FAN OPTIMIZATION CONSIDERING THE SYSTEM INTEGRATION IN A HEAT PUMP

Frieder LÖRCHER Ziehl-Abegg SE (Germany)

The selection of a fan for integration in a higher level system is often based on the fan performance data obtained from fan-alone experiments, such as duty points, total-to-static efficiencies, total-to-total efficiencies or sound power levels measured in standard fan configurations. In the present work however, system integration effects of fans in an air-to-water heat pump are investigated and taken into account for an adapted fan design carried out by an optimization process relying on CFD simulations.

The operation condition of a typical heat pump is varying significantly during a one-year operation cycle due to both varying climatic conditions and a varying heat demand. Further, air-to-water heat pumps usually underlie, in a big part of the seasonal cycle, icing-and-defrosting cycles of shorter period (cycle period typically about 30 minutes), resulting in high variation of pressure drop and heat transfer due to ice formation on the coil. These variable conditions have direct impact on the fan operating conditions.

The aim of the fan design is it to minimize the fan energy consumption for a typical one-year operation cycle of the heat pump. A representation of the known spectrum of operating conditions of the heat pump including icing conditions by 4 representative duty points with weighting factors is basis of the optimization.

The required heat transfer from ambient air to the coil is assumed to be realized under any condition by adjusting the fan rotation speed.

The heat transfer not only depends on air mass flow, humidity and coil properties, but also on the air flow distribution on the coil. A model for the heat transfer depending on local velocities on the coil was worked out for different icing conditions in accordance to experimental data. Implemented in the CFD setup, this model allows it to adapt the fan rotation speed in the simulation to the heat transfer demand. The main result of one simulation run then is the electric power demand (using a model for the electric fan drive), which is the principle optimization target.

In order to analyze one fan geometry, CFD simulations of the 4 representative duty points of the heat pump are carried out, and the annual electrical power requirement is summed up using the weighting factors.

This annual electrical power requirement contains system effects such as interactions of the fan flow with the coil and inhomogeneous velocity distributions on the coil.

In a semi-automatic optimization loop, the fan geometry is optimized analyzing over 100 fan designs.

This work is carried out in the context of the EU-funded research project “Green Heat Pump“. In this research project, a consortium of research institutes and heat pump component suppliers develops a next-generation 30 kW heat pump for retrofitting buildings in urban areas.

Experimental and Numerical Investigation of Tip Clearance Noise of an Axial Fan Using a Lattice Boltzmann Method

Tao ZHU University of Siegen, Institute of Fluid- and Thermodynamic (Germany)
Thomas H. CAROLUS University of Siegen, Institute of Fluid- and Thermodynamic (Germany)

The secondary flow through the tip clearance is one of the well-known sources contributing to the overall noise of axial fans. Aerodynamic losses and sound radiation increase significantly as the tip clearance is increased. The objective of this study is to revisit the mechanisms for tip clearance noise from a rotating fan impeller.

The unsteady and compressible numerical Lattice-Boltzmann-Method (LBM) is utilized which allows a direct and simultaneous prediction of both aerodynamic and acoustic field. Overall aerodynamic and acoustic fan performance data as predicted with the LBM were validated with experimental data. The agreement was quite satisfactory which justified looking at the LBM-predicted field data in detail. The flow and acoustic field in the vicinity of an axial fan impeller's tip gap revealed important details of the sound generating mechanism. A large tip clearance is responsible for a complex vortex system with a considerable degree of inherent unsteadiness. The consequences are fluctuations of static pressure in the flow field in the adjacent tip region and on the blade surfaces. Those pressure fluctuations generate sound that is then radiated away from the complete impeller upstream into the free field with the typical hemispherical directivity pattern. At the part load operating point sound pressure level increase in both broad and narrow frequency band were observed, which could be attributed to the complex tip clearance flow.

NOISE REDUCTION FOR AUTOMOTIVE RADIATOR COOLING FANS

Sabry ALLAM Helwan University (Egypt)
Mats ÅBOM KTH (Sweden)

Engine cooling fans have long been recognized as one of the major noise sources in a vehicle. As the engine and other vehicle components are made quieter, the need to reduce fan noise has become more and more urgent. To reduce fan noise in a cost-effective manner, it is necessary to incorporate the component of noise reduction into an early design stage. In this paper a detailed experimental study on an automotive vehicle cooling system is presented.

The aim is to investigate the flow generated noise, characterize the heat exchanger damping properties and investigate the use of near-field noise control by so called micro-perforated plates (MPP) and quarter-wave resonators (QWR). Different concepts were tested ranging from exchanging the plastic shroud with micro-perforated plates and the use of quarter-wave resonators. For the tested standard automotive cooling fan system the MPP shroud gave a reduction in the range 1.5 to 4.5 dB(A) depending on the fan speed. Also the absorption on the back-side is significantly increased which can reduce the noise further. The near-field QWR concept is also promising and gives a reduction around 3 dB(A) at the operating points.

THE APPLICATION OF MICROPERFORATED MATERIAL TO CONTROL AXIAL FAN TIP CLEARANCE NOISE

Seungkyu LEE Ray W. Herrick Laboratories, School of Mechanical Engineering, Purdue University (United States)
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Axial fans are widely used to cool electronic devices, and the fans typically generate noticable amounts of noise during their operation. Among the various sources responsible for fan noise, tip clearance noise is one of the more critical components. It has been demonstrated, in gas turbine applications, that tip clearance noise can be reduced by installing a finite flow resistance, circumferential strip in the housing of the fan immediately adjacent to the turbine blade tips. It is possible, for example, that the finite level of flow resistance created by the slightly permeable housing may reduce turbulence levels in the tip region, thus decreasing the noise generation. In the present work, a similar approach was taken to the control of noise generated by a 120 mm axial fan.

In this case, a microperforated film material was used as the finite flow resistance strip built into the scroll housing of the fan, spanning the axial region through which the blade tips sweep. Measurements of both sound radiation and of flow performance of a number of prototype fans having microperforated strips of varying flow resistances were conducted using an ISO plenum. A hemispherical array of ten microphones was used to measure the sound power of the fan as a function of fan operating point. The fan noise was quantified primarily on the basis of the blade passage sound power level. it was found that there were areas in the fan performance map within which tonal and/or overall noise levels could be consistently reduced by the use of the microperforated housing element. It was also found that the flow resistance needed to obtain an optimal noise reduction was a function of the fan operating point. Further, it was found that the inclusion of the microperforated strip in the fan housing had a negligible impact on the fan performance: that is, there was no performance penalty associated with the fan noise reduction. Therefore, optimized microperforated housing designs for certain operating conditions of axial fans will be suggested in this presentation.

BROADBAND MODE DECOMPOSITION OF DUCTED FAN NOISE USING CROSS-SPECTRAL MATRIX DENOISING

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In the prospect of classifying ducted fan broadband noise sources, an accurate description of the acoustic pressure field in the duct is required. In this respect, it is possible to compute the cut-on mode amplitudes for each frequency using surface pressure measurements. This study deals with the application of such a mode decomposition technique to ducted fan noise measurements on the broadband part of noise spectra. The originality of the study concerns the microphone cross-spectral matrix (CSM) denoising applied to measurements. It is indeed well known that surface pressure measurements are strongly polluted by the wall turbulent boundary layer evanescent field. A basic but now standard denoising pre-processing consists in removing the CSM diagonal but it raises a non-physical CSM, leading to negative energy values.

In this study, three new denoising techniques are compared:

1/ CSM diagonal reconstruction from the off-diagonal terms given a model coherence function of the acoustic field,

2/ Alternating projections of the CSM onto two convex sets which forces a statistical and spatial structure to the reconstructed matrix,

3/ CSM decomposition into a low rank matrix (carrying the acoustic information) and a sparse matrix carrying the noise information.

The three methods are compared using simulations including additional white noise on a CSM loaded with both correlated and uncorrelated modes.

An accurate computation of the mode amplitude and correlation is obtained even with a -10 dB Signal to Noise Ratio (SNR). After validation, the denoising methods are applied to fan measurements and compared to the noisy matrix case. A standard output of the mode decomposition method is a power spectrum for all cut-on modes.

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Reevaluating Noise Sources Appearing on the Axis for Beamforming Maps of Rotating Sources

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Beamforming investigations focusing on the dominant noise sources of turbomachinery have become very common. As legislations and regulations have become more stringent along with the expectations of the customers, the amount of research in the field of turbomachinery aeroacoustics has progressively increased. Beamforming processes developed specifically for rotating sources, such as the Rotating Source Identifier (ROSI) method [1] and the Rotating Beamforming method [2], have provided a nonintrusive means by which the noise sources can be localized. What these methods have in common is that they apply a so called dedopplerization step in order to place the rotating noise sources into a rotating reference frame. Utilizing phased array microphones and these advanced beamforming algorithms we are therefore able to collect data for identifying aeroacoustic noise sources, which is becoming a common practice [1-4]. The results, on the other hand, are not so easily understood. Most beamforming algorithms assume that the noise is generated by compact stationary incoherent noise sources, in most cases resulting in beamforming maps which localize the noise sources to their true source locations. On the other hand, if the noise sources are coherent, then the results can be misleading. The publications of Horváth et al. have recently shown that this is also true for rotating coherent noise sources, which play a key role in complicating the beamforming results of rotating noise sources, pinpointing noise sources to their respective Mach radii rather than their true locations [5].

The present investigation looks at ROSI beamforming maps for an axial flow fan test case investigated from the axial direction. The focus of the investigation is the noise source appearing on the axis of the fan. In many similar investigations noise sources located on the axis have been associated with motor noise [1, 4]. Taking into account what is now known about rotating coherent noise sources appearing at their respective Mach radii, this investigation shows that the results have in some cases been misinterpreted, providing an explanation as to why these noise sources appear on the axis as well as providing information as to their true noise source locations.

[1] Sijtsma, P., Oerlemans, S., and Holthusen, H., “Location of rotating sources by phased array measurements,” National Aerospace Lab., Paper NLR-TP-2001-135, 2001.

[2] Pannert, W., and Maier, C., “Rotating beamforming – motion-compensation in the frequency domain and application of high-resolution beamforming algorithms,” Journal of Sound and Vibration, Vol. 333, Issue 7, 2014, pp. 1899-1912.

[3] Kennedy, J., Eret, P., Bennett, G., Sopranzetti, F., Chiariotti, P., Castellinni, P., Finez, A., and Picard, C., “The application of advanced beamforming techniques for the noise characterization of installed counter rotating open rotors,” 19th AIAA/CEAS Aeroacoustics Conference, Paper AIAA 2013-2093, 2013.

[4] Benedek, T., and Tóth, P., “Beamforming measurements of an axial fan in an industrial environment,” Periodica Polytechnica: Mechanical Engineering, Vol. 57, No. 2, 2013, pp. 37-46.

[5] Horváth, Cs., Envia, E., Podboy, G. G., “Limitations of phased array beamforming in open rotor noise source imaging,” AIAA Journal, Vol. 52, No. 8, 2014, pp. 1810-1817.

FULL CHARACTERIZATION OF FANS AS AERO-ACOUSTIC SOURCES USING MULTI-PORT MODELS

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The generation and scattering behaviour of fluid machines in connected duct or pipe systems is of great interest to minimize disturbing and harmful sound emission, for instance of air condition systems. Such systems may be described as networks of passive elements that only scatter existing sound fields and active elements which emit noise themselves. Within the framework of the European project “IdealVent“ the acoustic behaviour of air condition systems in aircrafts is investigated in detail in order to develop strategies to abate sound emission and hence augmenting safety and comfort within the air-plane. In air condition systems noise is mainly emitted by a combination of a fan and downstream obstacles in the form of orifices and valves. One approach to handle such numerically and experimentally sophisticated systems is to apply a linear multi-port model that includes direction-depending transmission and reflection coefficients for the propagating wave modes and the sound generation. These parameters may be ascertained in two steps and either numerically or experimentally.

In a first step, a number of external sound fields dominating the existing sound filed are applied, in order to determine the system scattering. As the second step, the reflection free source strength can be computed. Once those characteristic data are determined for all elements of interest, the sound scattering and emission behaviour of every considerable combination of those elements can be calculated easily. This paper documents an approach to measure the multi-port field created by an axial fan connected to a straight duct. For the application at hand it was decided to use a model with 8 propagating modes on each side of the fan creating a multi-port of order 16. To separate the modes in up- and downstream propagating waves an array with 16 microphones was used on each side together with 12 external sources (loudspeakers) to excite different incident modes. The microphone and source positions was selected in order to minimize the condition number for the matrix inversions involved in the extraction of the multi-port data. Here the results of the measurements on the tested fan will be presented and discussed in relation to the numerical modelling also done within "Idealvent".

MICROPHONE ARRAY METHOD FOR THE CHARACTERIZATION OF ROTATING SOUND SOURCES IN AXIAL FANS

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To successfully reduce the noise emitted by an axial fan it is mandatory to gain as much knowledge as possible about the source mechanisms on the fan. Methods based on microphone array measurements provide a powerful tool for the characterization of acoustic sources. In order to determine source positions and respective magnitudes of the emitted noise, sophisticated algorithms working in the frequency domain are being used widely.

These methods, evaluating the measured cross-spectral matrix, have proven to be able to successfully and accurately reconstruct the source parameters. However, their application is limited to stationary sources, whereas for moving sources less accurate time-domain methods have to be applied.

When dealing with rotating sources, as is the case with axial fans, it is often possible to overcome this constraint by arranging the microphones such that the measured signals can easily be interpolated between the microphone positions, simulating an array rotating at the exact same rate as the presumed sources.

The method presented in this contribution implements a virtual rotating microphone array in order to regard the rotating sources as being non-moving and thus allow the application of algorithms based on cross-spectral matrix evaluation. The possibility of separating stationary and rotating sources using this method will be discussed and prerequisites for its application will be specified.

For experimental validation, microphone array measurements with a four-bladed common household axial fan were conducted and evaluated using the new method. The presented results include the localization of different sources at various frequencies as well as their quantitative contribution to the overall noise emission.

NOISE CONTROL FOR TWO AXIAL-FLOW COOLING FANS IN SERIES

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Fan noise is a serious issue in electronic cooling applications. When pressure drop is high, two axial-flow fans are often used and the noise created by the two fans is complex. This experimental study analyzes the noise signature of two identical small axial-flow cooling fans in series (120 mm in diameter) in free field and the source distinction guides the efforts to control the overall noise radiation.

To study the discrete frequency noise, different rotational speeds are used for the two fans to distinguish the noise sources. The technique of time-base stretching synchronous averaging is used. For the broadband noise, the method of subtraction is used to estimate the contribution of each fan. In this method, the noises made by one and two fans are measured and the difference is considered to be the noise made by the downstream fan.

Acoustic directivity measurement and noise source analysis are conducted for two configurations. In the first, the inlet flow to the upstream fan is a free-field. The effect of a flow straightener is studied as well when it is placed between the two fans. In the second, the inlet flow is distorted by typical obstacles, a simplified flat plate covering one half of the inlet flow passage being studied.

With the knowledge derived from these diagnostic studies, one possible noise control measure is taken and evaluated. The same flow straightener is mounted at the inlet of the upstream fan in an attempt to reduce the negative effect of the inlet flow distortion caused by the flat plate. Averaged 2.5 dB SPL reduction is achieved for the six positions studied and the variations of contributions from each noise source component of each fan are analyzed.

EXPERIMENTAL AND NUMERICAL INVESTIGATION OF A GEARLESS ONE-MOTOR CONTRA-ROTATING FAN

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Compared to single rotor fans with discharge guide vanes, contra-rotating fans reduce the swirl in the wake flow as well as achieve a higher power densities. In practice, this approach is already being used to expand the application range of axial fans due to the higher total pressure rise and increased efficiency.

Conventional contra-rotating fans utilize one motor for each rotor or a gear for power transmission. This installation is more complicated, expensive and requires more maintenance compared to single rotor fans. In order to overcome these disadvantages, a new gearless one-motor concept was developed for compact fans at the Institute of Air Handling and Refrigeration in Dresden, Germany. Its diameter is 200mm with an design point of 650 m^3/h at 2100 rpm. Due to the innovative design, the torque is equally distributed between both rotors improving the flow field inside the fan.

Different setups were experimentally investigated. Firstly, the performance map of a single stage fan was measured with and without a discharge guide vane with 10 and 19 blades, respectively. The additional guide vanes improve the performance of the single rotor fan. Secondly, the newly developed contra-rotating fan was analysed. The results show an improved efficiency and performance compared to a single rotor fan. Finally, stereo particle image velocimetry was utilized to visualize the flow field and detect optimization potential.

In a second step, numerical computations are conducted to furthermore analyse the flow field of the single-rotor and contra-rotating fan. The incompressible flow is simulated using the open-source CFD library OpenFOAM. Steady-state simulations are performed using the multiple reference frame approach for modelling the movement of the rotors. The SST k-omega turbulence model is utilized.

The simulation of the performance map and the velocity profiles show a good agreement with the experimental data.

NUMERICAL AND EXPERIMENTAL INVESTIGATION INTO THE ACCURACY OF THE FAN SCALING LAWS APPLIED TO LARGE DIAMETER AXIAL FLOW FANS

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The cooling effectiveness of air-cooled steam condenser (ACSC) units is impacted by the performance of the large diameter axial flow cooling fans, which ultimately affects the overall efficiency of the power plant. Due to the large diameters of these fans, tests are carried out at test facilities with smaller, standardized diameters and measuring equipment. The performance of the large scale fans can be predicted based on the small scale test results using the similarity laws and scale-up formulae. This paper details the results of small scale experimental tests and numerical simulations that were performed on a pair of 1.25 m diameter axial flow fans. Full scale, 10.360 m, diameter simulations of the same axial flow fans were subsequently performed and compared to the experimental results that were scaled up using the fan scaling laws. The results show that the scaled fan results are within 5% of the experimental results.

COMPUTATION OF THE UNSTEADY FAN-SYSTEM COUPLING USING ACTUATOR SURFACE APPROACH

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Fan performances are assessed in airway configurations according to the ISO-5801 standard. On the other hand, the design process of industrial fans usually relies on CFD that assumes the same standard configurations or at most minor variations such as, for example, the inclusion of inflow distortions. Mostly these variations are introduced only in special cases and only if these are located near the fan itself. However, in the recent years, due to the tough industry market and the request to reduce system size while increasing ventilation efficiency, the needs to simulate complex ventilation systems by means of CFD based methodologies drastically increased. In such situations, including real fan geometry inside the computational domain would be extremely expensive from a computational point of view and too slow for industrial purposes. When the element to be studied is not just the fan but the whole ventilation system, single components must be described by means of synthetized methodologies. In particular, fans can be represented by simple pressure rise or actuator disks which introduce them in the duct systems by means of body forces inside the momentum equation.

Different methodologies were proposed in open literature (van der Spuy et al., 2009), here we focus on a new actuator disk and line methodology to simulate the presence of an axial fan, and a pressure discontinuity to account for the presence of a gravity damper. These methodologies are able to account for radial flows in the actuator disk and, if run in unsteady mode, to include the effect of rotation of the fan, as well as the real number of blades, with a modification similar to the one assessed in Sorensen and Shen (2002) for wind turbines actuator disks.

In the final paper the methodology will be validated with a parametric study that account for a fan and a gravity damper placed downstream. The capability of the model will be assessed against different mesh densities and will account for different relative positions between the fan and the gravity damper.

[1] van der Spuy, Sybrand J., von Backström, T. W., Kröger, D. G., 2009, Performance of low noise fans in power plant air cooled steam condensers, Noise Control Engineering Journal, Volume 57, Number 4, 1 July 2009, pp. 341-347(7)

[2] Sorensen, J. N. and Shen, W. Z., 2002, Numerical Modeling of Wind Turbine Wakes, J. Fluids Eng. 124(2), 393-399 (May 28, 2002)

Increase the Efficiency of Rotor-Only Axial Fans with Controlled Vortex Design Blading

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Controlled Vortex Design (CVD) by the second half of the last century has shown to be attractive for the performance increase of axial-flow rotors originally designed according to the free vortex criterion. During the last decade, the advancements in the knowledge of the effect due to non-radial staking line of the blade have allowed to improve performance and to reduce noise of tube-axial industrial fans. However, many highly loaded rotor-only axial fans of current production reach an efficiency level which hardly complies to the restrictions imposed by the newer European directives.

The paper starts with a conceptual discussion of the efficiency losses involved with the adoption of CVD bladings in rotor-only tube-axial fans. Then, a design criterion aimed at increasing the efficiency without reducing total pressure of this type of fan is introduced. Finally, the criterion is applied to a production axial fan model featuring a value of 0.44 for the hub-to-tip ratio, an almost constant swirl velocity distribution at the rotor outlet. and a quite low blade Reynolds number. The criterion is exploited performing experimental tests on each rotor defined by the successive steps suggested in the design guidelines. The experimental data show that the design criterion allowed an increase of peak efficiency up to 5% at blade positioning angles higher than design condition and an extension of the high efficiency operation keeping similar values of the total pressure.

Lab-to-lab Variation in Testing Fans

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AMCA International conducted a round robin series of test on three fans to investigate lab-to-lab variation in air performance and sound test results. The purpose of the round robin was to advance the science of testing fans in accordance with ISO and AMCA standards, specifically ISO 5801, ISO 13347, AMCA 210 and AMCA 300, and to advance our knowledge of test result uncertainty such that tolerances for certification programs and acceptance tests are fair and realistic.

Three fans were part of the round robin, and all three were tested on multi-nozzle chambers. Centrifugal and tubeaxial fans were tested using a chamber at the fans' outlet, and both were powered by dynamometer. A vaneaxial fan was tested on a chamber at the fan's inlet and was powered by a calibrated motor. All three fans were sound tested in a reverberant room.

What we found is that the agreement between labs is actually very good. The determination of air power, power consumption and sound power through the measurement of pressure, temperature, torque, rotational speed and sound pressure is quite consistent from lab-to-lab, leading to good agreement in test results if the fans are well-behaved. If the fans are not well-behaved, meaning there is a significant amount of swirl at the fan's outlet or the fan's vibration is excessive, lab-to-lab variation can be quite high.

During an analysis of the air performance data from a high swirl fan we were able to tease out from the test results a correlation between air performance and the ratio of the outlet area of the fan to the area of the test chamber. This correlation is well known, but the results appear correlated to fan to chamber area ratios at ratios much higher than had previously been accepted. Sound power data, of course, was strongly correlated to fan vibration. An interesting note is that the uncertainties published in the aforementioned standards do not take into account errors associated with fan outlet area or fan vibration.

The CFD portion of this work focuses on gaining insight into the above mentioned correlation between air performance and the ratio of the outlet area of the fan to the area of the test chamber. To mimic the above experiments a three factoral DOE is designed to cover the fan type, the area ratio and the test chamber area shape as variables. Full description of preferred solver setup, post processing method and simulation quality metrics is provided. Relative comparison of experimental vs. CFD data is presented. Finally, conclusions about performance predictions are offered.

Phase Locked PIV Measurements in Wake of an Automotive Fan Model

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Particle Image velocimetry (PIV) measurements focus on the flow structure and turbulence in the wake behind an automotive fan model. The experiments have been performed in an optically index-matched visualization facility located at JHU. The fan, its shroud and the housing are made of acrylic, and the liquid is an aqueous solution of 62% NaI that has the same refractive index (1.49) as that of acrylic. Consequently, the fan blades become almost invisible, facilitating measurements using optical techniques at any desired region within the machine. The 30 cm diameter fan was designed by Bosch, and its geometry as well as tip Reynolds number have been matched with that of a fan operating in air, at both RAM and idle conditions. The flow in the closed loop facility is generated by a variable speed, 20 hp pump, while the fan is operated by a 0.5 hp motor. In addition to visualizations, the facility is equipped with a flowmeter, pressure taps across the shroud and a fan torque-meter, i.e. to determine its performance and efficiency. The orientation of the fan blades (phase) is monitored by a shaft encoder that feeds a signal to the PIV system, enabling us to record phase-locked data.

The present paper mostly describes measurements in the wake of this fan. The data has been acquired in nine 50x50 mm sample areas, which are patched together to provide a field of view of 105x125 mm in an axial-radial plane. The vector spacing is 0.4 mm. An overlap between neighboring sections is used for comparison, and accurate patching. Phase locked data has been recorded in the same axial-radial plane for 10 different rotor phase angles, separated equally by 7.2 degrees, covering an entire blade passage. Each of the 90 datasets consists of over 1250 instantaneous velocity distributions. Data analysis includes image enhancement, followed by cross correlations using in-house software, and compares favorably to calculations by commercial software (DaVis) implementing velocity gradient-based deformable windows. Phase averaged mean velocity and turbulence distributions reveal many features of the near wake. They capture three generations of blade wakes and tip vortices, providing a comprehensive view of the evolution of flow in the rotor wake. Included are e.g., the very turbulent tip leakage vortex that expands and diffuses with axial distance, the rotor wake with elevated turbulence and velocity deficit, and the high turbulence in the separated region behind the hub of the fan.

IMPLEMENTATION OF AN ACOUSTIC STALL DETECTION SYSTEM USING NEAR-FIELD DIY PRESSURE SENSORS

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In this paper the authors suggest the use of an unconventional measurement method based on dynamic DIY transducers to measure the pressure instabilities in a low speed industrial axial fan, with the purpose of rotating stall detection. Rotating stall is an aerodynamic instability with a frequency typically half the rotor frequency, and in slow turbomachines such as industrial fans this frequency has a value even lower than 10 Hz.

The authors carried out the acoustic pressure measurements using a dynamic transducer and a piezoelectric sensor, in order to feature the former using the latter as a reference. The classical methods use piezoelectric sensors such as microphones in the far field and pressure transducers in the near field, collecting signals recorded in a wide frequency range. Other classes of sensors, such as electret microphones, may be not suited for pressure measurements, especially in the ultrasound region since their cut-off frequency is at least 20 Hz.

The authors comparea low cost and DIY technology and a high precision piezoelectric sensor already tested and widely described in literature. They implemented and set-up a measurement chain that is the basis of a stall warning system able to identify the rotating stall typical pattern. In this work the system is been test on a low speed axial fan. The results have been validated respect to the state of the art of the acoustic control techniques described in literature.

The signals acquired using the two technologies have been analysed though the frequency spectrum and the phase space reconstruction. The analysis aim was the detection of the distinguishing features of the investigated phenomenon. The patternacoustic recognition obtained through the phase space reconstruction for both the devices shows that the dynamic sensor is a good candidate solution for the rotating stall acoustic analysis.

A NUMERICAL AND EXPERIMENTAL TEST-BED FOR LOW-SPEED FANS

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An extensive experimental and numerical data base provides detailed information on some transition and noise mechanisms encountered in the low-Reynolds number flows of low-speed axial fans for the first time. Two different similarly-instrumented mock-ups built from the same industrial Controlled-Diffusion airfoil have allowed the first consistent comparison of wall-pressure and near-field velocity statistics on the same geometry with and without rotation in perfect similitude of Mach and Reynolds numbers. The experimental and numerical results on the stationary airfoil constitute the largest unique aeroacoustic data set for airfoil trailing-edge noise characterization including installation effects.

A similar experimental aeroacoustic data base has been built on the Rotating Controlled-Diffusion Blade in the MSU-AFRD test facility for different fan configurations, rotational speeds and flow rates. This yields a unique test-bed for fan code validation. The comparisons between the stationary and rotating airfoils suggest that the wall pressure statistics are hardly influenced by rotation in the trailing-edge region, and that the differences in the velocity statistics in the near-wake are a more energetic wake with smaller velocity deficits and diffusion, and far-less uniform inviscid region in the rotating case.

PREDICTION OF AERODYNAMIC NOISE FOR CENTRIFUGAL FAN OF AIR-CONDITIONER

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Development of silent air-conditioners is one of the most important problems in recent changes to life-styles, such as demands of silent office and home. Aerodynamic noise from fans contributes to a large percentage of the overall noise from air-conditioners. Therefore, the development of silent fans would contribute to reducing the noise levels of air-conditioners. In this study, flow fields in the centrifugal fans for the indoor units of air-conditioners were calculated with finite element method-based large eddy simulation (LES) with the aim of predicting aerodynamic noise. The intended centrifugal fans were two types, old and new, and they had different blade shapes and fan performances. Calculations were implemented by using K computer, which is Japanese national super computer developed in order to high performance computing. The numerical simulation code employed throughout the LES was called FrontFlow/blue (FFB). The code was based on the finite element discretization of filtered incompressible continuity and Navier Stokes equations. The Dynamic Smagorinsky model was used as a sub-grid scale model. The computational model consists of three parts, i.e., the inlet, impeller, and outlet parts. The impeller part is in the rotating frame of reference. The inlet and the outlet parts are in the stationary frames. The grid is composed of hexahedral elements. Aerodynamic noise was calculated with Curle's equation. The sound source was assumed to be acoustically compact. We compared 60 million grids (60M-grid) and 500 million grids (500M-grid) calculation results for investigation of influence on grid resolution. The 500-Mgrid was implemented by parallel computation with 1,024 nodes (8,192 cores) of K computer. Calculated distributions of velocities at blade exit agreed with experimental results. The accuracy of 500M-grid was improved compared to 60M-grid. Calculated sound pressure level by 500M-grid was also improved compared to 60M-grid calculation results. Number of captured streaks on the blade by 500M-grid increased as compared to those by 60M-grid. As a result, size of streak by 500M-grid became smaller than that by 60M-grid. The proper capturing of the streaks was contributed to improvement of calculation results. We confirmed that high performance computing by K computer was effective for improvement of calculation accuracy.

NOISE GENERATION MECHANISM AND NOISE REDUCTION DESIGN ON BI-DIRECTIONAL RADIAL FAN

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Motor which rotates both clockwise and counterclockwise is used for traction motor of train, traction motor of the elevator and industrial motor. Bi-directional radial fan is applied to these motors so that the same cooling capability can be obtained whichever direction it rotate. Wind is inhaled from inner circumference side of the fan, and its direction is changed 90 degrees by a main plate. Finally, wind flows to the radial direction away from the fan blades. Because of such a complicated wind flow, as compared with an axial fan, noise of bi-drectional fan is loud in order to shear wind at a edge of a fan blade. Conventionally, the various-shaped fans were made and low noise fans were qualitatively determined in the experiment. Although Computational AeroAcoustics (CAA) is commonly used in recent years, it is not yet clear what kind of flow is the cause of noise increase of bi-directional radial fan concretely. In this research, the noise generating cause of the bi-directional radial fan was clarified by calculating flow correctly by Computational Fluid Dynamics(CFD). And, frequency and noise level were comfirmed by comparison of experiment and analysis. Moreover, the relation between airflow rate and noise was clarified, and the blade structure of reducing fan noise without lowering cooling capability was investigated. As a result, it turned out that the blade shapes of air inlet and outlet are related to noise increase. Based on the result, blade structure which controlled noise radiation was designed and the effect of noise reduction was comfirmed by measuring the sound. At the rotation speed up to 2000 rpm, it was confirmed that an about 2 to 3dB noise level can be reduced. This paper introduces the noise generation mechanism and presents low noise blade structure of the bi-directional radial fan.

STUDY OF AERODYNAMIC NOISE GENERATED FROM A FORWARD CURVED FAN DUE TO ROTATING STALL CELL

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In order to clarify the influence of rotating stall cell on the properties of a forward curved fan, the aerodynamic characteristic and noise of the fans have been estimated experimentally. Moreover, the influence of unsteady internal flow on the aerodynamic noise in the low frequency domain has been analyzed by the numerical simulation. A two-dimensional forward curved blade was employed for the impeller. The diameter of the impeller is 125 mm; the chord length is 9 mm; the span length is 50 mm; the number of blades is 40. The forward curved fan with a shroud is named as MF9S, and the fan without shroud is called as MF9. The two examined impellers are totally same dimensions except for the existence of the shroud. The CFD code of SCRYU/Tetra produced by Software Cradle Co., Ltd. was used for the numerical simulations. In the numerical simulation, the representative length of the impeller and the diffuser is modeled equivalently to the actual system. Approximately 4.5 million grid elements were employed to solve the entire flow field of the fan. The spatial distribution of the sound source was visualized by using the right-hand side of Powell-Howe's equation. The static pressure of MF9S became high than that of the MF9. The maximum efficiency of MF9S was increased 1.6% than MF9 due to the improvement of the static pressure. On the other hand, the fan noise of MF9S at the maximum efficiency point became approximately 1 dB larger than MF9 due to the influence on the broadband noise in the vicinity of the 200 Hz. The rotating stall cell was formed at the front side of the impeller of MF9. The cell was rotated around the impeller with 40% rotation speed of the impeller. The cell formed seven pseudo blades around the impeller. We clarified experimentally that the broadband noise in the low frequency domain is generated at the vicinity of the frequency which is rotational speed of the cell.

Reduction of Turbulent Noise from Backward Curved Centrifugal Fan with Square Casing

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The backward-curved centrifugal fan with square casing is used to the air conditioners and the air cleaners that is required the compact and flexible design. We have pointed out that the performance of the fan is better than the fan with scroll casing at the large flow rate. But the noise characteristics of this type fan are not cleared yet. It is investigated the noise characteristics in relating to the interaction between the impeller and the square casing by experiments and numerical simulation.

It is pointed out that the turbulent noise is consists from the three frequency ranges that have the different noise sources. The low frequency range noise is generated from the impeller, the middle frequency range noise is generated from the casing wall and the high frequency range noise is in relating to the shroud flow. The side walls are the main sources of the middle frequency range noise and the one of the side walls is the most important to the middle and high frequency noise. The secondary flow near the shroud causes the large turbulence and generates the high frequency and large turbulent noise. We proposed the obstacle setting to reduce the noise level.

Vortex Shedding Noise Reduction of a Mixed Flow Fan: Experimental and Numerical Investigation

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The support for this paper is a mixed flow fan unit designed for use in the Dyson Air MultiplierTM desk fan. Early versions of the unit had a hissing noise perceptible to the user. As sound quality is a key feature of a desk fan, it was important to reduce this noise, and if possible, eliminate it all together. This paper explores the mechanisms and geometrical parameters that affect the frequency and level of the hissing noise. A combination of computational fluid dynamics and experimental in-duct measurements are used to confirm the noise production as vortex shedding off the trailing edge of the impeller. Using compromised fidelity CFD and acoustic measurements of various prototypes, a design was proposed to reduce the coherence of the vortical structures to eliminate the hissing noise. Although it was shown that adjusting simple geometric parameters, such as the trailing edge thickness, could change the frequency content from the vortex shedding, this alone was not enough to completely remove the hissing noise. The different iterations of design attempting to understand and improve the vortex shedding hissing noise have been prototyped. They have been tested across a full operational map, varying flow rates and running speeds, collecting performance and acoustic data which are reported in this paper. The final design provided an elegant solution which kept the original thickness distribution. Throughout this investigation it was imperative that the aerodynamic performance of the compressor unit was not decreased in any way. Furthermore, psychoacoustic metrics were used to evaluate the sound quality of the different designs explored. Resulting performance, acoustics and sound quality were assessed for the mixed flow fan in isolation. The methodology described in this paper can be used as a basis for identifying trailing edge vortex shedding noise and ways of decreasing its acoustic impact.

EFFICIENT LARGE EDDY SIMULATION OF A LOW-MACH NUMBER AXIAL FAN

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A weakly-compressible formulation for Large Eddy Simulation (LES) is shown to be a suitable tool for simulation of fan flow as a part of a fan noise prediction effort. LES can directly capture the inertial-range turbulence that produces the broadband component of the noise. In the present formulation, the density and pressure are coupled in each time step through an isentropic relationship. When solved using a fractional-step method, this density-pressure coupling leads to a Helmholtz system for pressure that implicitly captures the acoustics without introducing additional numerical stiffness. The method is applied to an experimental configuration and shows good agreement with both integral parameters and flow velocity statistics.

AEROACOUSTIC ASSESSMENT OF LEADING EDGE BUMPS IN INDUSTRIAL FANS BY MEANS OF HYBRID LES/RANS

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Numerical computations of industrial turbomachinery usually rely on high-Reynolds RANS approach for design and verification. Low-Reynolds RANS and URANS are usually adopted for analysis purposes. In recent years hybrid LES/RANS has became a vialable approach following the constant reduction of computational costs and increase of availability of massively parallel hardware (Corsini et al., 2013). Key issues for hybrid LES/RANS methodology are i) numerical robustness and ii) accuracy. These aspects can be respectively related to the blending of LES and RANS and the capability of the baseline RANS model to correctly predict the characteristics of the turbulent flow. For this reasons here we focus on the application of a hybrid LES/RANS methodology based on an elliptic relaxation model (Delibra et al., 2010) that was found to be numerically robust and able to correctly internal flows in turbomachinery.

Here this methodology is applied to the prediction of noise emissions from a tunnel and metro fan blade for high temperature applications with a modified leading edge (Corsini et al., 2014). This methodology is applied in order to reconstruct the pressure and velocity fluctuations of the large-scales of motions in order to acquire information on the acoustic performance of the modified leading edge with respect to the datum (straight) configuration.

[1] A. Corsini, G. Delibra, and A. G. Sheard, A Critical Review of Computational Methods and Their Application in Industrial Fan Design, ISRN Mechanical Engineering, vol. 2013, Article ID 625175, 20 pages, 2013

[2] A. Corsini, G. Delibra and A. G. Sheard, The application of sinusoidal blade-leading edges in a fan-design methodology to improve stall resistance, Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy May 2014 228: 255-271.

[3] G. Delibra, K. Hanjalić, D. Borello, F. Rispoli, Vortex structures and heat transfer in a wall-bounded pin matrix: LES with a RANS wall-treatment, International Journal of Heat and Fluid Flow, Volume 31, Issue 5, October 2010, Pages 740-753.

FLOW CHARACTERISTICS BEYOND TIME AND PHASE: A MODAL ANALYSIS OF THE PATTERNS IN A REGENERATIVE PUMP

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The purpose of this paper is to introduce the proper orthogonal decomposition (POD) as an efficient method to understand the complex flow behavior of fluid machinery in case of appearing periodicity. Despite progressively mature application for reduced-order-model approaches (ROM), only little attention is paid to POD as a tool for pattern identification and subsequent intensity quantification. The hidden beauty of this method for fluid/turbo machinery is emphasized in the present manuscript, with the main focus on a complementary discussion of conventional post processing (time and phase average, qualitative topology analysis) and the POD approach. The discussion is supported by high-speed 2D-3C PIV measurement data within the side channel of a regenerative pump, which reveals the interaction between the side channel and the impeller.

AERODYNAMIC CHARACTERISTICS OF A COOLING FAN IN A LOW-VOLTAGE ELECTRIC MOTOR

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In the present work, flow characteristics of a centrifugal cooling fan in a low-voltage electric motor have been investigated numerically using three-dimensional Reynolds-averaged Navier-Stokes equations. The k-ε turbulence model was used for analysis of turbulence through a turbulence model test. The finite volume method and unstructured tetrahedral grids were used in the numerical analysis. The optimal grid system in the computational domain was selected through a grid-dependency test. From the results of the flow analysis, considerable energy loss by flow separation was observed in the flow passage. A parametric study was performed for the aerodynamic performance, and the parameters related to the geometry of the blade and fan casing were selected for the study. It was found that mass flow through the cooling fan can be increased by controlling the flow separation in blade passage and fan casing. And, various types of impeller have been suggested to improve the aerodynamic performance of the cooling fan.

THE STUDY ON VIBRATION AND NOISE CHARACTERISTICS OF FAN MOTORS CAUSED BY THE ELECTROMAGNETIC FORCE

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The fan motors is combined with motor and fan for cooling of the equipments. The fan motors are using many equipments such as Information equipment, OA equipment, electrical household appliances, in-vehicle equipment, and industrial equipments. Commonly the fan motors are required for high efficiency, high air capacity, and low vibration and noise. In particular, recently market focus to lower noise and vibration. Vibration and noise in the fan motors have been studied separately as problems of fluid dynamics, mechanical structural dynamics, or electromagnetic dynamics. Recent trends in many people's lifestyles brought up reduction of vibration and noise of the fan motors as an important issue. In order to solve these issues, analyses on fluid dynamics, electromagnetic dynamics, and mechanical structural dynamics of the fan motors are needed to be performed not separately but simultaneously. This is because in a fan motor vibration and noise can be caused electromagnetically, mechanically, or fluid-dynamically at the operated speed. In other words, the vibrations and noises caused in three different mechanisms overlap one another. Fluid dynamics, electromagnetic dynamics, and mechanical structural characteristics are important factors for vibration and noise in the fan motor.

In this study, effect on the noise caused by electromagnetic dynamics and fluid dynamics the small fan motor is clarified. The noises of the fan motor caused by the blade-passing force and the electromagnetic force were prominent. Intense peaks were present at frequencies at which both the blade-passing force and the electromagnetic force have their harmonic components. In particular, noise becomes maximum at a frequency that the harmonic frequency of the electromagnetic force and the natural frequency in the fan in the axial direction to match. This noise in the axial direction is highest. Regarding the vibration and noise in the fan motor, radiated noise generated structure vibration cause by the electromagnetic force, and fluid noise characteristics caused by fluid dynamic are clarified.

PROCESS CHAIN FOR QUICK, EFFICIENT THERMAL ASSESSMENT WITH MOTOR DESIGNS OF A FAN

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For driving fans, electric engines are developed which work in an energy-efficient way and for the manufacture of which resources are carefully used. In order to achieve this and a reduction in cost, the components have to be optimally utilised.

In the development process of electric engines, simulation tools are used for the new designs to enable assessment of a large number of variants as quickly as possible. The operating behaviour of the motor is calculated via a design programme based on Maxwell's equations. Relevant temperatures are calculated via CFD simulation. The problem here is that losses in the magnetic components depend on their temperature. Motor temperature, however, depends to a decisive degree on the losses occurring. This interdependency has to be taken into account in the design process.

As specification parameters in the development of a fan drive, installation space and desired speed/torque behaviour are usually considered first. Based on them and further parameters, the electromagnetic design tool will yield information on the operating behaviour of the motor, distribution of the losses occurring and the geometry of the magnetically active components. The losses established via the magnetic design are based on assumed, not actual, temperatures.

In case all thermal parameters and the exact loss sources are known, actual temperatures in the motor can be calculated via aero-thermal simulation, yet now the geometry of the entire motor needs to be given. However, the development process at this point in time does not have such a motor geometry yet, so it would have to be constructed now, which would result in a substantial delay of the process. This problem is solved by using a parametric CAD model generating the geometries not coming from the magnetic design (components for mounting or cooling of the motor), and which now, together with the geometries coming from the magnetic design represent the calculation geometry for the aero-thermal simulation. The most important thermal parameters here are thermal conductivity of the materials used and the contact resistances between the individual components.

The aero-thermal simulation yields the temperatures for the components for which the temperatures were assumed in the magnetic design, allowing you to start once more with the magnetic design. If there is a difference between the temperature assumed and the one calculated in a first aero-thermal simulation, the thermal power loss is changed. This in turn changes the temperature distribution of the aero-thermal simulation. The loops are now repeated until there are no further changes in temperature or losses.

This process chain results in an assessment of the operating behaviour of the motor, maximally occurring temperatures and complete motor geometry. The advantage offered by this process chain is the establishment of the ideal magnetic design and thermal optimisation of the motor using the parametric CAD models.

IDENTIFYING TORSIONAL RESONANCE PROBLEMS ASSOCIATED WITH VFD DRIVEN FANS

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The use of Variable Frequency Drives (VFDs) has become very common for controlling fans even for large horsepower motors. Controlling the inrush of electrical current during the start of an AC induction motor, the ability to accurately control the fan speed and the potential for significant energy savings are common elements justifying the application of VFDs for fan control. The initial cost of a VFD is often recovered quickly by productivity improvements and reduced electrical costs.

Due to the ease with which VFDs can be applied, they are often installed without due consideration for their potential negative impact. Three basic questions generally need to be answered; i) Can the predicted energy savings actually be obtained? ii) Can the aerodynamic operating points be obtained in a manner that does not compromise system aerodynamic stability? iii) What is the potential that the fan can suffer mechanical problems if controlled on variable speed? This technical paper addresses the latter question and specifically mechanical resonance of torsional natural frequencies caused by motor ‘air gap torque harmonics’ that may lead to shaft and coupling failures.

The potential effect the electronics and electrical switching that takes place in a variable frequency drives (VFD) on the voltage and current harmonic feedback into the electrical supply is generally understood and there are well documented standards for control and regulation of those harmonics such as IEEE519-1992. However, VFD electrical harmonics in the output electrical feed to the driven equipment is not so regulated. Mechanical torsional fluctuations caused by ‘air gap torque harmonics’ associated with the VFD fundamental and carrier frequencies have resulted in catastrophic failures of fan shafts and couplings of variable speed fans using variable frequency drives.

This paper will provide illustrated examples of field measured torsional pulsations that led to shaft and coupling failures and identify the correlation with potential excitation due to "air gap torque harmonics".

A Low Pressure Axial Fan for Benchmarking Prediction Methods for Aerodynamic Performance and Sound

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Great efforts into implementing numerical methods for performance and sound prediction can be observed in the fan and blower industry. Trust in results from simulation, however, often re-lies on experimental validation. The purpose of this paper is to describe the low pressure rotor-only fan ""USI7"" which has been used as a generic test fan in several projects at the University of Siegen and elsewhere for several years. We present our own experimental results such as per-formance and sound characteristics, turbulent inflow statistics and sound spectra as well as the test rigs employed to obtain the data. The idea behind is to foster benchmarking of present and new steady-state and unsteady aerodynamic and aero-acoustic prediction methods within the community. Thus, to any individual we will provide full geometry of the fan as well as all ex-perimental data.

COMPETING BROADBAND NOISE MECHANISMS OF A GENERIC LOW-SPEED AXIAL FAN INCLUDING ACOUSTIC SCATTERING

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This paper focuses on the semi-analytical modeling of broadband noise generated by a low-speed axial fan and its scattered field by an obstacle. Two different broadband noise mechanisms will be investigated, turbulence-interaction noise -so called leading-edge noise- and trailing-edge noise. The former is due to impingement of the turbulent flow field to the leading edge of the fan blade. The later is due to the development and possible separation of the boundary layer and scattering by the trailing edge of the blade. This paper addresses both broadband noise mechanisms for a generic axial fan operating in different flow conditions.

The theory of Amiet on turbulence-interaction noise will be employed including a geometrical-near-field extension. The same geometrical-near-field extension will also be applied to the trailing-edge noise Amiet's theory. The required inputs for both broadband Amiet's theories will be provided from RANS CFD computations over a flat plate using OpenFOAM. The necessary incoming turbulence spectrum for the leading-edge theory will be computed from the von Karman spectrum model using flow data extracted upstream the leading-edge. The wall-pressure spectrum upstream the trailing-edge required in trailing-edge noise theory will be obtained from a wall-pressure reconstruction model using boundary layer informations. Such a model has been already published by the authors.

The second part of the paper focuses on the scattering of the broadband noise by an obstacle. The scattering of the broadband noise of the axial fan will be taken into account by means of Acoustic Transfer Vector (ATV) approach in the Boundary Element Method (BEM) framework. A flat screen will be introduced as a scattering obstacle in vicinity of the fan. The results will then be compared to an analytical solution which accounts for an infinite screen and an image source. The scattering of the turbulence-interaction noise has been already published by the authors. The final paper will also include the scattering of the trailing-edge noise generated by a low-speed axial fan.

NUMERICAL INVESTIGATION OF THE INFLUENCE OF SKEWNESS AND GAP GEOMETRY ON SOUND RADIATION OF AXIAL VEHICLE COOLING FANS

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The overall acoustic impression is an important factor in the decision of a customer to purchase a particular vehicle. To optimize vehicles, specific components and systems which are responsible for noise generation are considered individually. One dominant noise source and central part of the engine cooling is the axial cooling fan. CFD programs have been used successfully in the fluidic design of fans for years. For the acoustic design, however, numerical simulations have only seen limited use so far.

In the present numerical investigations, a hybrid approach is chosen where first a CFD simulation based on the Navier-Stokes-Equations is performed and the acoustic is calculated in a second step. An integral method described by Ffowcs-Williams-Hawkings (FW-H) is used for the acoustic simulation.

In the FW-H method, the flow quantities of interest are the velocity components, the pressure and the density. Using an in-house solver for the FW-H calculation, these quantities are interpolated to a so-called integration surface placed around the acoustic sources caused by the impeller and are exported from the CFD calculation at every time step. From this integration surface, Green's function is used to calculate the acoustically relevant parameters at a point that corresponds to the microphone position in experiments.

The radiation of sound of three different fan configurations is calculated. On the one hand, a forward skewed fan is compared to a backward skewed one. The influence of the blade skew on the gap flow and the radiation of sound of both configurations are demonstrated. On the other hand, a backward skewed fan with a modified gap geometry is derived from the already mentioned fan configurations which leads to a lower radiation of sound and a higher efficiency.

The acoustical results are validated with measurements based on sound pressure spectra. The results are found to be in good to excellent agreement with measurements dependent on frequency.

NOISE PREDICTION FROM A LOW MACH NUMBER AXIAL FAN WITH LES AND BEM

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The acoustic radiation of an axial fan can be predicted from low-Mach number Large Eddy Simulation (LES) flow data by propagating the acoustic signals arising from the transient pressures on the rotating surfaces. For a fan that rotates inside a stationary shroud in a duct, it is necessary to adopt a projection method that accounts for sound radiation from both rotating and stationary surfaces, along with reflection and absorption of sound from the duct boundaries. The acoustic Boundary Element Method (BEM) can be used to project sound from either purely stationary or purely rotating surfaces in an environment with reflecting and absorbing boundaries. However, application of BEM method to a combination of moving and stationary sources is much more challenging. In such a situation it is preferable to record the air velocities and pressures on a permeable surface surrounding the fan, and use that surface as a radiating source input to a BEM or finite element (FEM) acoustic projection.

In the present study, this approach is used to calculate the sound generated by a shrouded axial fan in a duct. The fan is efficiently simulated with a low Mach number compressible LES by using local mesh adaptation to concentrate computational grid cells in the vicinity of the fan blades and their turbulent wakes. Unsteady velocities and pressures are recorded on a virtual surface enclosing the fan, from which the acoustic signal is projected to the duct and shroud surfaces and to the receiver upstream via the linear Ffowcs Williams-Hawkings (FWH) equation. Among other advantages, this approach alleviates the need for large number of grid cells in the region of relatively uniform laminar flow upstream of the fan, resulting in significant computational savings. For accurate prediction, both direct acoustic propagation (based on free-space Green's functions) as well as acoustic reflections from the duct must be modeled. To account for the reflections we use newly developed massively parallel FWH and BEM tools which are able to treat large number of acoustic source points and boundary elements and are fully integrated into the unstructured mesh framework used by LES solvers. The calculated broadband noise results are in good agreement with experimental measurements.

HUMP-SHAPED BROADBAND NOISE ON A FAN AT OFF-DESIGN CONDITIONS

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Automotive fan systems are sometime used at off-design conditions, for instance at high flow rate when the car is moving. It has been observed that the resulting under-incidence of the flow on blades can trigger a particular acoustic phenomenon, with increased broadband noise in the frequency range of 3500-4500 Hz.

Some phenomenological studies were conducted by numerical means to understand this mechanism.

Velocities have been extracted from a 3D simulation of the fan, and these local conditions were applied in a compressible Large Eddy Simulation (LES) around the blade profile extruded in 3D. Results have shown that the under-Incidence creates a large boundary layer on the lower side of the profile, starting at roughly 20% of the chord.

At the same time, some vortical structures appear at the trailing edge and are convected in the wake with an almost constant periodicity. Even if this observed frequency corresponds to the hump observed on the fan acoustic spectrum, it does not explain the noise recorded during the experiment on the fan unless the flow fluctuations on the upper side of the profile are taken into account. In this area (where no turbulent boundary layer is developed), some instabilities are predicted by the compressible simulation: pressure and density vary at the frequencies of the structures in the wake, and act as an dipolar acoustic source on the blade. These fluctuations correlate with the frequency of the vortex shedding.

A second profile with a different camber distribution was additionally studied with a second LES. Results have shown that this phenomenon of pressure and density fluctuation can be strongly reduced with a less smooth profile.

AUTOMOTIVE BLOWER DESIGN WITH INVERSE METHOD APPLIED ON WHEEL AND VOLUTE

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Expectations in terms of energy efficiency, thermal and acoustic comfort are increasingly important in the automotive industry. The radial fan that is used for thermal management of the interior is particularly concerned because ventilation performance contributes to the well being of passengers, and to the reduction of electrical consumption of on-board systems. Recent attempts to optimize this machine have shown the difficulty to improve them while respecting the numerous operating point (ventilation of different areas, heating, air conditioning, defrost, dehumidification), the limited packaging in the dashboard and the constraints of manufacturing.

A design method aimed to reduce the development time is investigated in the present study. It is based on an inverse design method and the objectives are to improve the efficiency, to reduce the losses and flow unsteadiness.

A first detailed simulation of an existing blower was done accordingly to our test rig conditions, allowing reproducing the behavior of the complete system. Overall performance obtained were compared to experiment and discussed to assess the validity of the numerical results. Further analysis of the flow were performed to get the blade loading and to determine velocity triangles at wheel inlet and outlet. These results were used to specify targets for the 3D inverse design method to redesign the wheel.

Several wheels with different levels of complexity have been produced, and two of them were selected for study: the first one respects constraints of the plastic injection process, whereas the second one is intended to assess the remaining potential if constraints are relaxed. Numerical simulations conducted on these wheels showed improved performances when measured in term of total pressure between blade inputs and outputs.

Further possible gains were identified in the scroll which was designed for a different type of wheel and which produces significant losses. Post-processing of speed and flow distributions at the wheel exit were used to conduct a very quick re-optimization of the volute with a inverse design method for volute design. Results obtained after these two steps were verified by numerical simulation and compared to the original design in terms of overall performance and detailed flow analysis in the wheel and the volute. As expected, efficiency gains have resulted in a reduction of secondary flows in the volute, to the benefit of attenuated interaction at the tongue.

CFD OPTIMIZATION OF A FAN FOR INDUSTRIAL APPLICATION

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Energy consumption and operating ranges in industrial application of fans have grown in importance in the latest years and now, in order to be attractive for the market, the product must fulfill a number of requirements like:

(i) good efficiency inside all the operative range,

(ii) higher maximum flow rate,

(iii) minimum manufacturing and maintenance costs.

The design procedure for centrifugal fans with backward curved blades is well documented and experimental analysis had confirmed its reliability but in most cases these methods don't match the installation and process requirements (such as space constrains, electrical power limits, national and international directives in the field of health and safety). So the Computational Fluid Dynamic (CFD) can assist the design and optimization procedures in order to discover internal flow issues, to help conceiving new solutions and reducing the prototyping and experimental activity and in general the time to market.

In this article a CFD study, regarding three industrial centrifugal fans for low, medium and high pressure applications, will be carried out showing how the impact of design optimization on the meridional passage and blade shape changes according to the specific speed.

The meridional passage shape has the most influence in the low pressure fan because of the high passage area variation between the aspiration and the leading edge. The blade angle distribution has direct impact on the blade loading in all the three fans: increasing the blade angle means increasing the total pressure increase, the power consumption and in most cases also the efficiency. The increase in efficiency depends on the increase of the blade loading with same overall losses but often is not a suitable solution because of the consequent power consumption increase.

Experimental campaign on a limited number of the modified fans confirmed the overall design guidelines deducted from the CFD analysis allowing the the fulfillment of different demands such as energy saving, process and market requirements.

USE OF HIGH PRESSURE STAGES IN THE DESIGN OF NEW AXIAL FANS FOR HIGH PERFORMANCE BLOCKS IN COAL ELECTRICITY POWER PLANTS

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Our paper includes several key research results relating to three new axial, high pressure gain and high flow rate, axial flow fan stages designed for the manufacture of modern axial flow fans used in electricity power plants. Two stages were designed with the hub/tip ratio of 0.60 and two design flow coefficient options: Option No. 1 – 0.60 and Option No. 2 – 0.35. Third option had the hub/tip ratio of 0.50 and flow coefficient of 0.45. Design pressure coefficient values of new stages were within the range of 0.43 to 0.83. Design software was used to design the axial compressor stages and the flow simulation to determine the aerodynamic performance map was carried out using dedicated software package.

New stages had high aerodynamic loading of the rotor and stator blade row cascades. The rotor row cascade diffusion factor near the hub was within the range of 0.56 to 0.58. Thus the loading was subcritical from the viewpoint of the flow separation onset and consequently the maximum efficiency observed in tests at a design point was slightly above 90%. Further increase in aerodynamic loading would decrease the stage efficiency as it follows from acquired test and flow simulation data.

Aerodynamic performance map of the new high pressure stages, with the rotor blades stagger angle adjustment of ± 20°, generated large work area with good efficiency of 85% to 90% over a wide range of flow coefficient values of 0.15 to 1.2. For comparison, we present measurement results of a standard, less aerodynamically loaded, stage (design flow coefficient of 0.4, pressure coefficient of 0.3 and the hub/tip ratio of 0.5), which currently is used in design of fans designated for coal fired power plants. Differences between the maximum pressure coefficient of new stage and conventional standard stage become larger with the flow coefficient increase.

Axial flow fans with new stages, inlet chambers and exhaust diffusers were tested on ISO test rig with external diameter of 600 mm. As an example the paper presents comparison of measured and calculated aerodynamic characteristics of single, Option 1, stage fan. We note acceptable agreement between the measured and calculated values within the rotor blades adjustment of ± 20 deg.

The new stage aerodynamic characteristics allow optimising the design of modern axial fans in terms of production costs and attaining maximum pressure gain and efficiency. In this connection, analysis based on one dimensional flow model of axial flow fan, is able to clarify the effect of energy losses in the inlet chamber and outlet diffuser and stage parameters relating to the axial flow fan efficiency.

Our paper gives example of optimisation of the flue gas axial fan with a diameter of 4.3 m and peripheral speed of 167 m/s destined for a large coal fired 660 MW power plant block. Required volumetric flow rate of the flue gas and fan specific work at a nominal point were Q = 830 m^3/s and Y = 8,500 J/kg or at a point of maximum flow Q = 1,250 m^3/s and Y = 10,800 J/kg. Use of standard stage with the hub ratio of 0.5 in two stage fan is able to meet the assignment requirements.

Using analysis it was found that one, new Option 1, stage with the design pressure coefficient of 0.83, may be used as a replacement for two standard stages. In this design option the same peripheral speed and outside diameter were used as in the original fan design. Denoted working points in measured performance map of modelled fan show projected efficiency values. In estimating the prototype fan efficiency we used results of similarity analysis of modelled fan (external diameter of 600 mm) and prototype fan (external diameter of 4,300 mm) and with the use Reynolds number and relative surface roughness.

STUDY ON AIR CONDITIONING THERMAL COMFORT WITH NEW-TYPE FAN

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The conventional floor standing air conditioning's inlet is in the bottom and it's outlet is in the top in cool mode and heat mode, it's thermal comfort is not good, it is hard to supply the thermal air to the human's knees below. It is difficult to meet the human's comfort requirements for thermal feet and cool head. In order to improve the status, with new technology of wind tunnel of air conditioning, the conventional airflow field of floor standing air conditioning was changed to independent double-airflow field. The conventional static wind tunnel is changed to dynamic wind tunnel by fan. The new wind tunnel realizes the top air supply and the bottom air return for cool mode and the top air return and the bottom air supply for heat mode. It is realized by rotating propeller housing.The new wind tunnel supplies the thermal air to the human's knees below directly, it improves the human thermal comfort, it increases the room's temperature for 2-4 °C below 1.5 m height in heat mode, it improves the uniformity of the temperature field. The experiment data indicates that the nonuniformity coefficient of temperature of new air conditioning reduces about 70 percent. The new-type air conditioning improves the indoor air quality and realizes the energy conservation.

INVESTIGATION OF THE AERODYNAMIC & AEROACOUSTIC PERFORMANCE OF CROSS-FLOW FANS

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For the air conditioner industry, cross flow fan (CFF) design is important to assure an efficient heat transfer from the heat exchanger and also to reduce the overall sound pressure level of the indoor air-conditioning unit. Theoretical and experimental studies about cross flow fans (CFF) are scarce in the literature, especially the ones where numerical or analytical calculations are validated with experimental measurements.

Air flow and noise generation mechanisms in a CFF are fundamentally different than axial or centrifugal fans. Air flows across the blades of a CFF, which causes that both ends of blades switch from leading to trailing edge throughout one rotation. The flow structure inside the fan consists of two regions: the through-flow region and the eccentric vortex region. Efficiency of a CFF is fundamentally limited by the unavoidable recirculation flow within the impeller at all fan speeds.

Design of the impeller effects acoustic and aerodynamic performance of the CFF dramatically. Our studies show that impellers, having the same outer diameter and operating in the same casing with the same rotational speed, result in a large variation both in the aerodynamic and acoustic performance. In the measurements overall sound power level changed in a range of 56 to 59 dB(A) and the flow rate changed in a range of 640 to 710 m^3/h. This flow rate difference can change the seasonal coefficient of performance (SCOP) up to 0.5, which can result in a quieter air-conditioning unit in a higher energy class.

This study investigates the effect of the impeller design to the aerodynamic and aeroacoustic performance. The impeller is designed parametrically, where the effect of each parameter on noise generation and flow rate is tested via computational fluid dynamics. Results of the numerical simulations are evaluated to gain insight on the complex noise generation mechanisms and to design a CFF with high flow rate and low overall sound power level. Optimum geometries are produced via rapid prototyping. Their aerodynamic performance is measured via particle image velocimetry (PIV) and measurements in the psychrometric test chamber.

Study of the Effect of Fan Tip Configuration on Air-Cooled Condenser Axial Flow Fan Performance

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Large air-cooled heat exchangers (ACHEs) and air-cooled condensers (ACCs) are popular in countries such as South Africa where water is scarce and wet cooled systems are not viable. These systems consist of heat exchanger bundles which have multiple large axial flow fans mounted below or above them. Due to the scale of ACC units at large power plants such as Eskom's Matimba plant, the fans are major power consumers. Therefore it is desirable to make the fans as efficient as possible in order to reduce power consumption and increase plant efficiency.

Research has indicated that the blade tip region plays an important role in the performance of axial flow fans. The configuration of this region has a profound impact on both fan performance and - noise. Tip clearance tests conducted by Kröger and Venter (1992) on the "V-fan" indicate a correlation between tip clearance and fan static efficiency. Research undertaken by Corsini et al. found that endplate configurations for fan blades have an impact on both fan performance and noise (Corsini et al., 2007). It was therefor decided to combine an investigation into fan blade endplate configuration with an investigation into fan blade tip clearance and to measure the effect of these on the performance of an axial flow fan.

The experimental fan used in this investigation was the 1.5 m diameter B2-fan, which is a 1/6th model of a fan that was developed specifically for use in large ACCs. The experiments were performed on a standard BS848 type A fan test facility. The first set of tests consisted of blade angle and tip clearance tests. Based on these results an updated correlation for the effect of tip clearance and fan static efficiency was derived and compared to the results of Kröger and Venter. Using the results of the first set of experiments, several basic endplate configurations were tested at the optimum blade angle and the ideal tip clearance value. The results of this investigation were used to derive an improved blade endplate configuration and tip clearance combination.

The results of this research indicate that a specific combination of tip clearance and endplate do make a significant difference to the performance of an axial flow fan. Such a configuration may either increase or decrease the static efficiency of the fan at its operating point, depending on the configuration used.

[1] Kroger D.G., Venter S.J., 1992. The Effect of Tip Clearence on the Performance of an Axial Flow Fan. Energy Conversion and Management, 33(2), pp. 89-97.

[2] Corsini A., Rispoli F., Sheard, A., 2007. Development of improved blade tip endplate concepts for low-noise operation in industrial fans. Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, Volume 221, pp. 669-681.

EFFECT OF REDUCED SUCTION SIDE VOLUME ON CROSS-FLOW FAN PERFORMANCE

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Cross-flow fans are widely used in industrial and domestic applications in which the radial space availability for fan installation is limited. Unlike other type of fans, the cross-flow fan internal flow field is characterised by an eccentric vortex resulting from blades circulation, which forces the flow to be worked out two times by the rotor blades. A vortex stabiliser wall is needed to fix the position of the vortex core and avoid its revolution along a circular path centred on the impeller axis. The fan casing is completed by a rear wall, which guides the flow through the impeller, and by two side walls perpendicular to the impeller axis.

In most of the high-performance cross-flow fans appeared in the literature the position of the vortex stabiliser wall and the shape of the rear casing yield an approximately ninety degrees air flow deflection between inlet and outlet sides. However, applications in ventilation/air conditioning, aircraft propulsion and automotive systems may require different layouts due to physical constraints which limit the radial width of the fan and reduce its suction side volume, and there are very few studies in the literature which deal with similar restrictions.

In the present work, the effect of the suction side volume limitation along the radial direction on the performance of a small cross-flow impeller is experimentally investigated. A baseline fan configuration is chosen among several configurations featuring different rear wall shapes and vortex wall positions because of its best trade-off between efficiency, maximum flow rate, pressure rise and stability of the performance curve. Two sets of tests were performed by modifying this baseline configuration. In the first set, the effect of the inlet wall size was investigated. Then, the suction side was constrained by using a flat plate parallel to the outlet flow direction to achieve an in-line flow layout. The flat plate was gradually moved to reduce the available volume at the suction side. Fan performance was measured for each position of the flat plate to evaluate the performance reduction with respect to the baseline configuration. Results may support fan design choices when the application imposes limited operating volumes.

PSYCHOACOUSTIC EVALUATION OF FAN NOISE

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Besides aerodynamic properties the sound quality of fans gains increasingly in importance. In contrast to technical parameters like efficiency, fan noise is directly perceived and evaluated by human beings. Hence differences in the sound character which are not always captured by the commonly used physical parameters like sound pressure levels and even more detailed spectral analysis can lead to very different product assessment.

It should therefore be an aim to develop a measure to characterize the sound quality of fan noise which is more oriented towards the subjective felt noise impressions and which is able to represent the sound emissions of fans in different applications more aurally-equivalent, i.e. in a manner that corresponds better to our hearing. The concerned special field of acoustics is the science of psychoacoustics.

For that reason the company ebm-papst built up a psychoacoustic lab with one moderator and eight listening work stations where hearing comparisons of recorded fan noise signals can be conducted by listening to the sound examples with loudspeakers and headphones.

In these listening tests the annoyance level and other acoustic relevant attributes are queried from a number of test persons by means of two methods: the semantic differential and the paired comparison.

Several examples of axial and radial fans in undisturbed laboratory setup and in different applications are investigated. One measurement series addresses the comparison between the acoustic (physical) and psychoacoustic (subjective) behaviour of different fans under different installation situations. In another investigation effects of varying operating point and rotational speed are studied.

The influence of dedicated acoustic phenomena like for example tonal components is investigated by means of signal manipulation.

In summary one can say that the annoyance level is decisively influenced by the objective psychoacoustic parameter loudness. Furthermore the tonality and especially in fan operating points near stall the roughness and the fluctuating strength can play an important role.

SOUND SYNTHESIS OF FAN NOISE AND MODELING OF ITS PERCEPTION IN CAR PASSENGER COMPARTMENT

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In the context of either hybrid or electric cars, motorization sound has become an issue of less importance as compared to thermal motor sound. However, other sound sources that used to be masked by the motor sound may now be audible and cause annoyance to users. The CEVAS project in which the present study takes part addresses the problem of modelling the sound produced by either air conditioning (HVAC) or electric battery cooling (BTM) systems from the definition of the sound sources to their perception by users. The main aim of the project is to build a reliable and efficient tool for designing new systems according to high quality standards in terms of acoustic comfort. In the scope of the CEVAS project the present work addresses the question of how the HVAC and BTM sounds are perceived. This includes the synthesis of an audio sound corresponding to acoustic characteristics defined at the dashboard (for example the air vent outlets), the modelling of sound propagation inside the passenger compartment and the sound perception by users.

This paper focuses on the two first points. The sounds at the dashboard are obtained through an additive synthesis algorithm that can generate both broadband noise and tonal components. Several resolutions of spectrum description were tested. A perceptual similarity test was conducted with both recorded and synthesized sounds. It revealed that 1/3-octave-band resolution was sufficient for a reliable reproduction of the recorded broadband noise, while separate modelling of tonal components was also necessary to take into account any possible tonal emergence.

For modelling the sound propagation the passenger compartment transfer functions between specific points on the dashboard and the driver's ears were measured with a specifically designed electroacoustic source and a binaural head recording system. These transfer functions were then convolved with the anechoic synthesized sounds in order to recreate the sound spatial aspect as it is perceived in a real environment. In the end the tools presented here enable the reproduction of sound sources defined at the dashboard only by spectral characteristics. HVAC and BTM sounds can thus be synthesized as they would be perceived at the listener's ears in a real inner car compartment.

NUMERICAL ANALYSIS OF UNSTEADY THREE-DIMENSIONAL FLOW IN A PROPELLER FAN USING LATTICE BOLTZMANN METHOD

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Reduction of turbulent flow noise generated from fans is a crucial issue. The direct approach in computational aeroacoustics is a powerful tool for such a problem. Lattice Boltzmann Method (LBM) is a promising approach to directly simulate flow and acoustic fields with low Mach number. In fact, there have been many engineering applications of LBM to aeroacousic simulations in the automotive industry. On the other hand, only a few applications to turbomachinery such as fans have been reported. The goal of this study is to establish the prediction method of turbulent flow noise radiated from low speed fans using LBM. The present paper provides the validation result of LBM for a complicated flow field around a propeller fan.

In the present simulation, solid boundaries of the rotor and the shroud were calculated by a simple immersed boundary scheme. The computational grid around the propeller fan was generated by the Building-Cube Method (BCM). The grid was refined locally near the solid boundaries based on Cartesian grid. The multi-scale model was introduced into LBM to allow the calculation with such grids. The number of grid points amounts to 1.7 billion in total. Although the grid resolution was still not enough, the direct numerical simulation (DNS) was attempted. In the present simulation, any subgrid scale models were not introduced. In order to suppress the numerical instabilities which occurred in a part of the domain with coarser grid, the low pass filtering operation was used.

It is important to capture the three-dimensional vortex structure near the rotor tip which is called tip vortex, because the tip vortex dominates the flow field around the propeller fan. In regard to vortex structures, the result of LBM was compared with the result of detached eddy simulation (DES) which solved the Navier-Stokes equations using a body-fitted grid. The structure of tip vortex calculated by LBM agreed well with the result of DES. Furthermore, pressure fluctuations on blade surfaces were compared with the experimental results. The highest pressure fluctuation was observed on the suction surface near the leading edge of the tip region in the both results. The simulation showed that the fluctuation was caused by the leading edge separation vortices. The pressure fluctuations caused by the tip vortex and the corner separation were also captured in the both results. These results validated the applicability of LBM to the numerical analysis of unsteady three-dimensional flows in the propeller fan.

AEROACOUSTIC SIMULATION OF AN AXIAL FAN INCLUDING THE FULL TEST RIG BY USING THE LATTICE BOLTZMANN METHOD

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The measurement of the sound emission of axial fans is standardized by internationally accepted guidelines. These guidelines require an undisturbed cubic volume upstream of the fan with the minimum length of the edge of two rotor diameters. In recent experimental studies it has been found by the authors that these requirements may be insufficient for acoustic fan tests. Even if the fan intake is placed in a vented empty room with a volume more than 1000 times larger a low-motion recirculating flow can develop which eventually causes a disturbed inflow to the fan rotor. Tonal "interaction" sound is a result which one must not attribute to the fan itself. In principle the recirculating flow field in large rooms is difficult to quantify. Unless expensive field measurement methods like particle image velocimetry are used, high-resolution probes (e.g. a hot wire or hot film probe) provide data only at a very limited number of data points in space. On the other hand Navier-Stokes based computational fluid dynamics simulations are limited to small computational domains when one needs to resolve the acoustically relevant spatial and temporal flow. It is the objective of this study to apply the numerical Lattice-Boltzmann method (LBM) to the flow in a computational domain comprising two very disparate sub-domains, a large inflow region and a comparably small fan. Not only the unsteady flow field is of interest, LBM promises the direct computation of the acoustics (here the inflow induced interaction tones) from the unsteady flow field data.

The flow in the entire aeroacoustic test rig for axial fans of the University of Siegen is modeled with the Lattice-Boltzmann Solver PowerFlow 5.0. The large room the fan takes air from is an anechoic chamber. The fan is the generic rotor-only axial fan "USI7" with five cambered and swept blades. Its aerodynamic and acoustic characteristics have been studied experimentally in numerous recent studies. The large scale environment is varied in terms of two different arbitrarily chosen variations to study the impact of the flow conditions far upstream of the fan section on the tonal sound emitted by the fan.

It turns out that a certain characteristic simulation time is needed to account for the impact of the large scale environment and eventually predict the tonal sound accurately. Geometrical variations of the large scale environment far upstream of the fan section can finally have a distinctive impact on the tonal sound emitted by the fan. A Fourier analysis of the inflow and the visualization of the blade pressure fluctuations reveal that the tonal sound emerge in the tip region of the blades and that the spectral distribution of the tonal sound depends on the inflow conditions and eventually on the flow conditions even far away from the fan.

Numerical Optimization of the Tonal Noise of a Backward Centrifugal Fan using a Flow Obstruction - Part II: Flow Obstruction Optimization

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International regulations on safety and acoustic comfort are making fans and integrated systems suppliers consider more and more sound quality as one of their first design criterion and market differentiator for their products. Indeed noise emissions can be perceived as a strong annoyance for people staying in their vicinity and can affect working conditions of operators. Therefore broadband and even more tonal contributions of the noise of such systems have to be addressed as early as possible in their development process.

In that context, the noise radiated by a rotating fan, and particularly its contributions at the Blades Passing Frequency (BPF) and its harmonics, must be controlled. Previous studies have shown that using a passive noise control device so-called flow obstruction in front of a centrifugal fan-heat exchanger module significantly reduces the BPF noise and having little effect on the broadband content [1]. But because this type of device has to be calibrated in axial and angular position, finding its optimum shape and location would require an expensively high number of prototypes and extensive experimental tests campaign.

A recent study [2] showed how PowerFLOW, a compressible and unsteady Computational Fluid Dynamics (CFD) solver based on the Lattice Boltzmann Method can be used to accurately predict the 3-dimensional turbulent flow of a truly rotating centrifugal fan and its corresponding acoustic field in a realistic underhood environment including a heat exchanger and a simplified engine. The noise reduction brought by a particular flow obstruction at the fan BPF was accurately captured and simulation results were used to bring more understanding on the flow mechanisms at the origin of the phenomenon.

In this paper, the same numerical approach will be used and associated to an optimization method in order to automatically design and calibrate optimized flow obstruction in a short development time. Transient and spectral analysis of the simulation results will be performed to bring more understanding on the flow features at the origin of the tonal noise reduction.

[1] A. Gerard, A. Berry, P. Masson, Y. Gervais, "Passive adaptive control of tonal noise from subsonic axial fans using flow control obstructions", Fan Noise 2007 international conference, Paper 09, Lyon, France

[2] F. Pérot, M-S. Kim, V. Le Goff, X. Carniel, Y. Goth, C. Chassaignon, "Numerical optimization of the tonal noise of a backward centrifugal fan using a flow obstruction", Noise Control Eng. J., Vol. 61, No. 3, 2013, pp. 307-319.

ON AN UNIFORM ROTOR-STATOR WAKE-INTERACTION NOISE MODEL BASED ON A MODE-MATCHING TECHNIQUE

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The work addresses the noise generated as rotor wakes impinge on a row of outlet guide vanes in a ducted subsonic axial-flow fan architecture. That noise, referred to as wake-interaction noise, is a dominant contributor to the total aerodynamic noise of a fan. Its prediction requires a substantial, most often not affordable, effort using numerical approaches. The present analytical approach is believed a consistent alternative, especially at the early design stage. Previous analytical works based on a single-airfoil response function cannot reproduce the cascade effect of the stator. Conversely existing cascade-response functions lead to mathematical complexity and cannot be declined easily in a cylindrical coordinate system for which they require approximations. The proposed new approach allows introducing simply the cascade effect, both in an unwrapped representation in Cartesian coordinates and in cylindrical coordinates. The problem is formulated in the frequency domain. Only its declination in a two-dimensional Cartesian coordinate system (axial and tangential) is detailed in the paper for the sake of illustration. The three-dimensional generalization is straightforward though more complicated.

A linear and non-viscous analysis is considered, for which the vortical and acoustic modes of oscillation in a gas are uncoupled except at solid boundaries. The velocity disturbances associated to the wakes are expanded in oblique sinusoidal vortical gusts. Each gust is frozen and characterized by its vorticity. Its impingement on the stator front-face generates acoustic modes which propagate upstream and are also transmitted downstream in the inter-vane channels. The latter are assimilated to a periodic array of bifurcated waveguides. The front-face (and similarly the back-face) of the stator is considered as an interface on both sides of which field variables are matched relying on continuity conditions. The continuity of pressure and of axial velocity is commonly used in the literature of acoustic wave transmission. The same is retained here. Furthermore the vorticity is also assumed continuous across the interface. This allows deriving an infinite set of equations that is solved by modal projections and matrix inversion. The acoustic waves are directly determined from the incident gust. The acoustic field is uniformly obtained in the whole domain.

The interest and the robustness of the approach for further fan broadband-noise modelling are discussed.

Spectral Characterizations of Centrifugal Fan Noise via uRANS-based Noise Prediction Method

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Centrifugal fans are used in a wide range of industrial applications due to the ability to generate high pressure differences and large capacity of mass flow, considering the size. Nowadays, there are numerous studies on the impeller-diffuser interactions and the resulting tonal noise. Prediction of generated noise in centrifugal fan is so complex due to its three-dimensional internal passages, turbulent flows inside, and the flow separations.

As far as prediction of fan noise is concerned, it is important to realize that the far-field acoustics are very much dominated by the internal pressure fluctuations created by the fan inside the housing. For this reason, accurate predictions of the internal pressure fluctuations are crucial and can be used for estimating and analyzing the fan noise characteristics.

In the present work, a prediction method based on uRANS approach is utilized to predict aerodynamics performance and noise characteristics of the centrifugal fans, primarily comprised of impellers, diffusers return channels, and electric motor coils.

The present approach is first validated by the experimental results in aspects of hydrodynamic fan efficiency and sound pressure level spectrum of fan for different air flow rates.

In addition, to reduce the noise, we introduced splitter, as a flow guidance device, and applied between the impeller blades at the inlet of flow passage for various study cases. Using splitter, it is shown a significant improvement in noise reduction of overall sound pressure level and tonal noise generated by impeller diffuser interaction.

TONAL FAN NOISE PREDICTION AND VALIDATION ON THE ANCF CONFIGURATION

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The NASA Active Noise Control Fan (ANCF) rig has been intensively studied at the Aeroacoustic Propulsion Laboratory facility at NASA providing both aerodynamic and acoustic measurements (D. Sutliff et al.). This low hub-to-tip ratio axial fan provides an excellent test bed for aeroacoustic code validation. Recently a 3D compressible unsteady simulation has been performed on this fan using a Lattice-Bolzmann Method particularly adapted to the low-speed Mach number of this configuration (A. Mann et al.). This simulation including the full geometry of the installation reproduce accurately the acoustic measurements made in the anechoic facility. It complements the experimental database providing a direct insight into the aerodynamic sources (mainly the rotor wakes impacting on the stator), the in-duct and far-field acoustic propagation.

The present work aims at validating an analytical noise prediction code OPTIBRUI on the well documented ANCF configuration. The software accounts for the complex description of the rotor and stator geometry including varying lean, sweep stagger and camber angles, non-uniformly spaced blades and several analytical models are implemented including free-field or in-duct acoustic propagation models and isolated (Goldstein, M. E., Amiet R. K.) or cascade blade responses (de Laborderie, J.) The analytical models require flow modeling as input and the results obtained with analytical, experimental and numerical flow descriptions will be compared. In particular, the effect of the skewed excitations will be investigated. Some recommendations on the flow extractions from the CFD will be made using the unsteady results from the above mentioned LBM simulation. An extrapolation model to compute the gust at the stator vane leading edge from an upstream extraction will be investigated.

In a second step, the analytical model for rotor/stator interaction will be extended for heterogeneous stator following the work of M. Roger. As a demonstration, a parametric study of the acoustic radiation based on typical stagger angle variations require for proper load balancing will be built upon the original homogeneous ANCF stator geometry.

AS GOOD AS IT CAN BE – VENTILATION SYSTEM DESIGN BY A COMBINED SCALING AND DISCRETE OPTIMIZATION METHOD

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Designing complex ventilation systems is a challenging task. A required operation can be fulfilled with numerous different combinations of fans, and the application engineer has to choose an adequate set-up. The focus often remains on the functional quality of the system whereas its energy consumption plays a subordinate role.

Fans are well-engineered products i.e., their individual energy efficiency is already highly optimized. It is common practice to choose one fan that fulfills the peak operation load and that is driven in its best operating point in this maximum loading condition. When it comes to a temporal distribution of different loading conditions multiple smaller fans may be more appropriate considering energy consumption. However, due to the multitude of different fan combinations and operating strategies even for an experienced engineer it is impossible to keep track of all possibilities.

In this paper we use the methods of the new research direction at TU Darmstadt called Technical Operations Research (TOR) for the design of energy optimal technical systems. It is based on mixed integer programming, a discrete optimization technique known e.g., from the field of Operations Research. This approach follows the understanding that optimized components do not imply energy-efficient systems. Instead of optimizing the energy efficiency of single components we set the attention on the entire technical system. With TOR we design the most energy-efficient ventilation system out of a given kit of fans and derive the optimal control settings for different probability distributed loading conditions.

We illustrate our optimization approach by designing an energy optimal ventilation system for an office floor. The required operation contains four different volume flow rates that result from the time dependent occupation density of the office rooms. The ventilation ducts are fixed i.e., the system characteristic is given as an input to the optimization model. The task of our optimization algorithm is to find the energy optimal combination of fans and their control settings for each loading condition. The fans are represented by dimensionless head curves: pressure coefficient and efficiency versus flow coefficient. By applying affinity and scaling laws the variation of fan size and rotating speed allows one to find the optimal ventilation system out of a huge number of fans.

A GENERAL INVERSE DESIGN METHOD FOR HYDRAULIC CHARACTERISTICS OF AXIAL FANS RESPECTING CURVED STREAMLINES

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A novel procedure has been modelled and implemented with the aim to enable precise calculations of the off-design flow field in an axial fan accounting for the existence of curved meridional streamlines. This is achieved by combining off-design radial equilibrium calculations, the streamline curvature method and the surface vorticity method. The written program is used to calculate the head curves and velocity components of a reference fan for a specified range of operating points. Results of the implementation are validated by comparison with CFD simulations and found to be in good agreement.

PREDICTION OF NOISE EMISSION, POWER CONSUMPTION AND AIRFLOW PERFORMANCE USING MULTIDIMENSIONAL FAN CURVES

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The airflow performance of a proposed fan-cooled product or air-moving system is typically assessed early in the design process using fan curves. The same degree of forward-looking certainty can be achieved using multi-dimensional fan curves that include noise emission and power consumption data. The airflow performance curve is simply the locus of pressure-flow states achievable under various loads for a given speed, and could be called the "iso-speed" curve. Likewise, the iso-acoustic curve documents the operating points achievable for a given noise emission, and the iso-power curve for a given power consumption.

As with airflow performance, these curves are determined a priori by measurement on existing fans or by aeroacoustic computation and adapted by fan similarity laws to homologous cases. A designer may then confidently compare options including air mover type, diameter, number of parallel air movers and series stages to simultaneously meet airflow performance, noise emission, and power consumption goals. This method may also be used to document the influence of non-optimal inflow conditions, which may also then be included in the predictions. The paper will include a description of the method as well as applications involving typical curves for common air movers and recent experiences with design optimizations.

NOISE PREDICTION OF OUTDOOR UNIT OF AIR CONDITIONING WITH DIFFERENT SIZES BASED ON CFD

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Recently, the market shows a demanding of quieter outdoor air conditioning unit. The stringent noise radiation requirement from the air conditioning has driven us to investigate the noise source and noise radiation regulations of the outdoor unit experimentally and numerically, and to develop an effective method in predicting aerodynamic noise of the outdoor unit. In this investigations, the noise of two types of residential air conditioners, up side blow-out outdoor units and front side blow-out outdoor units are presented, Totally fourteen different sizes are investigated in this study. Heat exchanger and associated rotor are the main parts of the studies. Aerodynamic performance is measured to evaluate the effect of changing structure size upon the flow rate and the results are used as the boundary condition for CFD simulation. Based on noise generation mechanism, a corrected program has been developed based on Fukano's vortex shedding noise model to predict the broadband noise level using CFD results as the input. With correctional of stagger angle, as well as A-weighted SPL has been used in this program. The noise prediction accuracy of two types of outdoor units is quite well. Through the predict results, the effect of the structure size of outdoor unit to the noise level is obvious. The size of outdoor unit will affect the flow rate, noise radiation. For the up side blow-out outdoor unit, the decrease of height of heat exchanger could increase noise level and decrease flow rate. The distance from side board to the rotor tip must be suitable; a well-designed distance could make the noise level down. For the front side blow-out outdoor unit, the thickness of heat exchanger has great effect to the flow rate and noise radiation. The distance from side board to the rotor tip must not be too short, otherwise the internal space could become small and the flow field could become complex. The program demonstrates of meeting the demand of engineering application for design the size of outdoor unit quickly.

EXPERIMENTAL INVESTIGATION OF THE EFFECT OF GRILLE STRUCTURE TO THE OUTDOOR UNIT OF ROOM AIR CONDITIONER

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Aerodynamic and noise performance parameters and flow fields near the exit of the outdoor unit of air conditioner with and without grilles are studied with a standard test rig and Particle Image Velocimetry (PIV). The grilles used in this study include two common grilles from the market and one newly-designed grille. The newly-designed grille is designed according to the detailed flow field of the outdoor unit and has an involute-curve shape. Experimental measurements are carried out to validate the effect of grille to the noise and the flow field of outdoor unit. The results indicate that the grille structure will affect the flow rate, the flow field, and the noise level of outdoor unit. The effect of the rectangle shape grille was greatest among three grilles, and the newly-designed grille with involute-curve shape is better, which make the flow uniform and reduce the noise level of the outdoor unit compared with two common grilles. And the methods that combine flow field and noise radiation presented in this research are useful to the designer to decide which grille will be chosen.

Challenge and Opportunities for Flow Noise Prediction in HVAC Systems

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This paper investigates the possibilities of semi empirical scaling laws for noise prediction in Heating Ventilation and Air Conditioning (HVAC) systems. Semi empirical scaling laws are an option for noise predictions to avoid a time consuming fully resolved simulation. The scaling laws can be seen as a combination of generalized noise measurement data and component flow characteristics, where the latter can be gained from Computational Fluid Dynamics (CFD) simulations of low complexity. An approach is here presented where the general noise reference spectra are combined with Reynolds Average Navier Stokes (RANS) simulations. To evaluate which HVAC geometries that can be included in a general model, both literature data and new measurement data are included. Focus is at applying the suggested noise prediction approach to common HVAC components but also to discuss the differences in other properties, e.g. radiation characteristics. Air terminal devices at the end of a duct will be compared to in duct components and silencers with baffles of different length will be evaluated. A model is concluded using a momentum flux assumption of the noise sources enabling a range of HVAC system components to be included. Since flow generated noise from non-rotating components is becoming more important in HVAC systems, the suggested approach is seen as a promising tool for noise prediction of HVAC components.

INFLUENCE OF INFLOW TURBULENCE ON AEROACOUSTIC NOISE OF LOW SPEED AXIAL FANS WITH SKEWED AND UNSKEWED BLADES

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The aeroacoustic noise radiation has become a key parameter to be taken into account during the design and development of low speed axial fans. On the one hand, noise radiation is dependent on the fan's design and operating point, on the other hand it is highly influenced by the boundary conditions under its operation, like e.g. inflow turbulence intensity.

To investigate the influence of inflow turbulence on noise generation subject to blade geometry, three different fans with one common operating point were designed with a 2D blade element method: an unskewed fan, a forward-skewed fan with a constant sweep angle and a backward-skewed fan with the same sweep angle (without dihedral on both fans).

Performance and sound pressure distribution measurements were conducted in a test rig according to DIN EN ISO 5801. The fans were installed in a short duct with l = 3D. Different grid were mounted to the inlet in order to increase turbulence intensity. Velocity distribution and turbulence intensity measurements were performed in the ducted flow field on the suction side of all fans with a 2D Laser Doppler Anemometry system (LDA).

LDA results show increased turbulence intensities with mounted grids. Effects on the sound power spectra due to increased turbulence intensity can mainly be seen at frequencies below 2 kHz. The extent of this is dependent on the blade geometry. Explanations will be given, how aeroacoustic sound radiation of axial fans under influence of increased inflow turbulence can be reduced by blade geometry parameters.

PREDICTION OF THE BROADBAND NOISE OF A LOW-SPEED AXIAL FAN BY CFD SIMULATIONS AND AN EMPIRICAL WALL-PRESSURE SPECTRAL MODEL

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Since several years CETIAT has started a research program with scientific and industrial partners to predict the broadband noise of axial fans, especially the blade trailing-edge noise which is the major source of broadband noise when the turbulence intensity of the inlet flow is moderate, i.e. less than about 2%. The test fan used all along the study is a propeller fan of 800-mm diameter running at 600 rpm, with 2 or 4 blades with an adjustable blade pitch angle. Two of the blades are equipped with wall-pressure transducers to obtain the input data of an analytical model of blade trailing-edge noise based on Amiet's formulation.

The first part of the paper presents an overview of the experimental and prediction results obtained from the beginning which shows that the prediction deduced from the analytical model of trailing edge-noise compares fairly well with the experiment but another important source that contributes to the overall sound power level of the fan is the tip clearance noise. The contribution of this second source besides trailing-edge noise is highlighted by tests with and without casing around the impeller as well as by fitting winglets on the blade tips to modify the flow of the tip vortex at the origin of this noise mechanism. Further work is still needed to clearly understand and assess the actual contribution of tip vortex noise to the broadband noise generated by the impeller.

In the second part of the paper preliminary results of a recent research program are presented, the goal of which is to try to predict the wall-pressure spectra close to the trailing edge of the blades by an empirical model proposed by Rozenberg in which the input data are deduced from CFD simulations (RANS model). This new work is motivated by the fact that the measurement of the wall-pressure spectra on rotating blades is tricky and costly. A replacement of this experimental procedure by a prediction using non-expensive CFD calculations could be valuable if this approach provides reasonably accurate results. Comparisons of measured and predicted wall-pressure spectra are presented and discussed.

BROADBAND TRAILING-EDGE NOISE PREDICTION OF A FOUR-BLADED AXIAL FAN USING A SEMI-ANALYTICAL METHOD

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The trailing-edge noise is the minimum broadband sound that a lifting surface would produce in absence of other sound mechanisms as turbulence interaction at the leading edge. This source of sound, caused by the scattering of the boundary-layer disturbances into acoustic waves, remains the only broadband noise contributor for subsonic fans operating in homogeneous stationary flows, in absence of any upstream, downstream and tip interaction. The present study aims at predicting the trailing-edge noise of a four-bladed low-speed axial fan on which an experimental campaign has been conducted at CETIAT. The available experimental database is shared in a collaborative project including VKI, CETIAT and CETIM, for development and validation of numerical flow and noise prediction methods.

In the present work, the flow and acoustic prediction is based on methods keeping balance between cost and accuracy that can be easily integrated in optimization chains. The procedure uses stationary flow computation and semi-analytical Amiet’s theory. The flow is first solved using OpenFOAM, where a 3D steady RANS computation is performed using a Multiple Reference Frame method. The wall-pressure spectrum upstream the trailing-edge required in the trailing-edge noise theory is then obtained from a wall-pressure reconstruction model of Panton and Linebarger using boundary-layer information. Finally, the far-field sound pressure spectrum is computed by means of Amiet’s theory. The blade is decomposed using a strip theory where every blade strip is approximated by a rectangular flat plate, the overall noise radiated from the blade being the sum of noise radiated from the different blade strips. The sound produced by the tip vortex and its possible interaction with the shroud is neglected in the present study.

Comparisons with experimental available data is made for the different steps of the noise prediction procedure. The flow is validated in terms of global fan performances available experimentally. The wall-pressure reconstruction spectra is compared to measured wall-pressure spectra at two locations on the suction side of the blade while the sound emitted from the fan is compared to overall sound measured in the CETIAT reverberant room.

FAN NOISE PREDICTION FROM LOCAL EXPERIMENTAL SOURCE TERMS AND NUMERICAL SOUND PROPAGATION

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Modeling and numerical approaches are favored ways to investigate the mechanisms of noise generation by fans. Several approaches are conceivable, from the simpler band-octave correlation to the costly and technically challenging aero acoustic computing.

In an industrial context, a mid-way approach, relying on experimental data to define the acoustic source term, and on well known computational method to propagate it, is still of interest.

The paper investigates a fan noise synthesis approach based on the following items:

- The noise source located on the fan blades is defined from experimental data obtained on wing profiles. This source is represented by a distribution of volumetric forces in a volume close to the blades, or by a surface source term.
- The noise is computed by propagating the source either by using analytical laws in an open space, or by using a finite element code to take into account the effects of the surroundings.

The test of the method has shown that the source term adjusted on the Brook-Pope-Marcolini trailing edge noise database was insufficient to represent the noise measured on a four-blades 800 mm fan. The pertinence of some auxiliary source terms liable to fill the gap between the model and the experimental results, as interaction between the tip blade and the volute, leading edge noise, blade-vortex interaction, is then evaluated.

ACHIEVABLE TOTAL-TO-STATIC EFFICIENCIES OF LOW-PRESSURE AXIAL FANS

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Limits regarding total-to-static efficiency of axial fans are investigated as a function of design point. The design points examined are limited to the typical realm of axial fans according to the Cordier diagram. Initially, a purely theoretical approach is taken in which the optimal hub-to-tip ratio as well as the optimal swirl distribution are found by a local optimization algorithm. Friction losses are neglected. This approach yields a first estimate of the effect of design target in terms of flow coefficient and pressure coefficient on unavoidable exit losses due to the kinetic energy in the meridional and circumferential flow velocity downstream of the fan. However, realistic estimation of exit losses and hydraulic losses requires more advanced methodologies. Here, the realistically achievable total-to-static efficiency is estimated using an evolutionary optimization algorithm in which the target function is evaluated by multi-layer perceptrons (MLPs). The MLPs were trained based on the CFD simulation of 13,000 characteristic fan curves in an earlier study. Assuming a tip clearance ratio S/D = 0.001 and Reynolds numbers around 200,000, the maximum achievable total-to-static efficiency amounts to 68% and can be realized with medium specific fan speeds and comparatively large specific fan diameters. At most design points, the difference between theoretically optimized and MLP-optimized efficiency is mainly due to hydraulic losses. However, at some design points the MLP-optimized fans also feature significantly higher exit losses. Finally, the MLP-optimization is repeated with distinct geometrical constraints which are (i) imposing fixed sweep angles, (ii) restricting the allowable axial depth and (iii) avoiding undercuts. The impact of all three constraints changes with design point.

ECO-DESIGN OF A SMALL SIZE INDUSTRIAL FAN FOR CERAMIC TILE COOLING

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Energy consumption and savings in domestic and industrial applications of fans have recently gained attention in Europe. In a recent European Directive (2009/125/EC), eco-design demands for products that can have a critical environmental impact and, at the same time, can present significant potential for improvement through innovative design, have been set.

Fan design must fulfil a number of requirements in order to ensure: (i) minimum energy consumption (also of installed auxiliary devices), (ii) proper fluid dynamic performances (air flow rate, pressure rise and efficiency) and (iii) minimun manufacturing and maintenance costs.

In most cases installation and process requirements (such as space constrains, electrical power limits, national and international directives in the field of health and safety) do not match with consolidated fluid dynamic design approaches. In this context, Computational Fluid Dynamics (CFD) is the key tool which can complement traditional one-dimensional and bi-dimensional design approaches.

In this paper, mono-dimensional design and three-dimensional optimization through CFD numerical simulations of an industrial fan are carried out. The fan under consideration provides the airflow used for controlling the thermal gradient of ceramic tiles before entering the digital printer stage. For this reason, the air velocity field at the blowing device outlet is also considered as a design constraint during the three-dimensional optimization.

In order to establish the specific application requirements, a simplified numerical model of the tile heat exchange is developed and used to fix the air velocity threshold value above which tile cooling is sufficiently efficient.

During the design process, the existing Sirocco runner, often used for heating and cooling applications for its capability to deliver more air volume than other centrifugal fans of the same size and rotational speed, is substituted by a backward-curved centrifugal fan in order to meet increased process and eco-design requirements.

Experimental campaing on a backward-curved fan prototype with optimized air blowing device demonstrates that fan performances (air volume and efficiency) meet the eco-design demands and the air velocity field at the blowing device outlet is suitable to obtain the expected heat exchange. The new design can also reduce acoustic emissions up to 3 dB(A).

The coupling of one-dimensional design and three-dimensional CFD simulations allow the fullfilment of different demands such as energy saving, process requirements and health legislation.

FAN RETROFITS TO ACHIEVE IMPROVED ENERGY EFFICIENCY: WHAT IS REQUIRED TO MAKE THIS WORK EFFECTIVELY?

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In recent years, it has become relatively common to have fan manufacturers sell retrofit fan products on the basis of 'efficiency gains'. This has primarily targeted the installation of higher efficiency impellers for centrifugal fans as retrofitted into existing casings and has included not only fans that some of these manufacturers sold originally but on their competitor's products as well. However, such an approach has raised numerous issues that need to be addressed to ensure that the end-users will be properly served and won't be left disappointed by a less than satisfactory energy efficiency improvement or worse, a project that has serious application problems associated with it.

This technical paper will provide an overview of the following:

- It is frequently the case that for fan retrofit projects (as opposed to new system installations), there is no engineering firm that is involved in the design, installation and verification of the project. These projects are often managed simply as a transaction between the end-user and the fan vendor. Oftentimes, the end-users don't have the expertise to properly evaluate what they are being told and this raises many questions i.e. How many of these retrofits actually achieve their 'efficiency objectives? What are the obstacles to verification of the efficiency retrofit upgrade? How many of these have been independently tested and verified? What are the common denominators of projects that have failed to meet expectations? This paper will address a methodology that end-users should be encouraged to adopt to avoid disappointments.

- Not all fan applications are worthy of upgrading and this paper will examine the ideal case for when an energy efficiency upgrade should be considered with the objective of establishing some straightforward 'rules of thumb'. Conversely, the paper will address those cases where the end-user would be advised against venturing into an energy efficiency project.
- It is often the case that an energy efficiency upgrade project bypasses the examination of a wide variety of fundamentals and this leads to a number of questions involving the science and engineering behind claiming efficiency improvements with a retrofit. This paper will examine the practical limitations that are naturally imposed on retrofitting to higher efficiency impeller types.
- Computational fluid dynamics has played an increasingly important role in system design improvements and the approach of using this technique for fan retrofits will be briefly explored in this paper.
- Retrofitting fans also needs to consider the application considerations and this primarily means that dust loading and erosion issues will need to be addressed. This issue will be discussed with the objective of providing information that will mitigate problems from arising.

COMPUTATIONAL ANALYSIS OF NOISE GENERATION AND PROPAGATION MECHANISMS USING THE EXAMPLE OF AN HVAC BLOWER

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This paper describes a computational approach to simulate passenger car HVAC blower noise. Besides validation, the purpose of the study is also to analyze flow structures that might influence noise generation.

In general, in early product development phases, fans and blowers are typically evaluated "standalone" in experiment, without the HVAC system or cooling package, but mounted in a test environment instead, nevertheless representing the crucial mechanisms that lead to noise generation and affect the fan or blower performance. The test environment used for the examinations discussed in this paper consists of a settling box, placed inside an anechoic chamber, with an imposed mass flow, where the rotating blower is mounted at an opening. Outside the box, within the anechoic environment, microphones are positioned.

The experiment can give overall results, like e.g. sound pressure measured in different microphone positions, showing general differences and enabling the comparison of different designs in terms of the noise generated. But this means that for each variation a prototype is necessary. By performing simulations, on the other hand, the variations can be tested virtually, thus reducing the number of physical prototypes. In order to validate such approach, microphone results were compared to experiments and showed good correlation.

Analyzing in detail the flow properties inside the system that lead to the generation of sound is costly if not impossible at all. So, another advantage of simulation is the possibility to gain more insight into the flow. Detailed analysis both in time and frequency domain are done to analyze and understand better the noise generation and propagation mechanisms.

In order to avoid a two-step approach where first a fluid simulation is performed and then e.g. acoustic analogies are used to predict sources for a standalone acoustic propagation simulation, the Lattice-Boltzmann method, a kinetic scheme modeling the dynamics of particle distributions, was used in combination with rotating meshes to represent the blower movement. This allows the prediction of both the transient hydrodynamic flow structures as well as the generation and propagation of the acoustic waves within the fluid at the same time.

TOWARDS A FULL DIGITAL APPROACH FOR AEROACOUSTICS EVALUATION OF AUTOMOTIVE ENGINE COOLING FANS AND HVAC BLOWERS

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In the automotive industry, the reduction of the main noise contributors of passenger cars such as engine, rolling, and aerodynamic noise, is giving more and more value to the acoustic efficiency of components and subsystems. This is particularly true with rotating machines, such as engine cooling fans and Heating Ventilation and Air Conditioning (HVAC) blowers. Since it can represent a strong competitive advantage and be a real market differentiator, automotive suppliers have to address the products' acoustic performances as early as possible in the development phase.

Experimental methods have been used historically to reduce the most obvious noise sources and led to acoustically efficient products. But they have also shown limitations such as time, cost of prototypes, mechanical and aerodynamic constraints. In addition, the targets specified by car manufacturers are becoming harder to achieve. When dealing with experiments, the lack of insight into acoustic phenomena can reduce innovation opportunities. With the decreasing cost of computational resources, using a digital approach could help go beyond these constraints, reduce the number of expensive prototypes, accelerate the products development cycles, and bring more understanding in the noise generation mechanisms. Integrating these methods in the current development process of fan and blower systems could lead to achieving better acoustic performances and even exceeding the present targets while, at the same time, managing aerodynamic and mechanical objectives.

In a first publication [1], it has been shown how PowerFLOW, a compressible and unsteady Computational Fluid Dynamics (CFD) solver based on the Lattice-Boltzmann Method (LBM), can accurately capture the flow induced noise phenomena at the origin of the broadband contributions of a Condenser Radiator Fan Module (CRFM). It has been successfully used to rank different fan designs upon their aeroacoustics performances. A more recent study [2] presented its accuracy at predicting the tonal noise radiated by such a fan but also the effect of an upstream geometry on broadband noise. In this paper, the integration of this numerical methodology in the development process of Delphi Thermal Systems will be discussed, leading to better aeroacoustics performances and more efficient products. The use of this numerical simulation for predicting aeroacoustics phenomena can be extended to other products, which will be shown with the first validation results of HVAC blower noise predictions using PowerFLOW. Acoustic power predictions of an automotive HVAC blower freely discharging in a semi anechoic environment will be compared to experiments (Fig. 1). Transient and spectral analyses will be performed to give a better understanding of the main flow-induced noise generation mechanisms (Fig. 2).

[1] M. Piellard, B. Coutty, V. Le Goff, F. Pérot, V. Vidal, "Direct aeroacoustics simulation of automotive engine cooling fan system: an application study", Aachen Acoustics Colloquium, Aachen, Germany, November 27-29 2013.

[2] M. Piellard, B. Coutty, V. Le Goff, F. Pérot, V. Vidal, "Direct aeroacoustics simulation of automotive engine cooling fan system: effect of upstream geometry on broadband noise", 20th AIAA/CEAS Aeroacoustics Conference, No. AIAA Paper 2014-2455, Atlanta, GA, June 16-20 2014.

IMPACT OF A SKEWED INLET BOUNDARY LAYER ON THE AERODYNAMIC PERFORMANCE OF A STATOR-HUB EQUIVALENT HIGH-TURNING COMPRESSOR CASCADE

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The paper reports on numerical investigations into the effects of inlet boundary layer skew on the aerodynamic performance of high turning, 2D compressor cascades. Cascades of this type are representative of the stator hub sections in highly loaded single-stage axial-flow low-speed compressors. All simulations were done with the commercially available, steady three-dimensional RANS solver CFX 14.5 of ANSYS. Preliminary simulations were performed with different turbulence and transition models, along with a grid sensitivity analysis. The shear stress transport (SST) k-w turbulence model of Menter turned out to be best suited for the present investigation with a focus on turbulent endwall and secondary flows. The stator-hub equivalent high-turning compressor cascade consists of 2D blades with 8% standard NACA 65 thickness distribution on 64.5° circular arc camber lines. The blade aspect ratio is h/l=1.0, the space/chord ratio t/l=0.5 and the stagger angle lambda=25°. The midspan inlet angle was varied between beta1=50° and 58°. Reynolds number and endwall boundary layer thickness at inlet were hold constant, Re1=5*10^5 and d/l=0.1 respectively.

In axial turbomachines, for example axial flow compressors, the relative motion between adjacent blade rows (rotor/stator, stator/rotor) causes the endwall boundary layers to be skewed and reenergized. This phenomenon has been picked up in the present paper for the particular case of a compressor hub flow at rotor exit and stator inlet. A boundary layer leaving a rotor hub with large velocity deficiencies is reenergized and has a new start as it enters the stator hub. This phenomenon has been investigated in a simplified manner using a linear cascade model with skewed boundary layers at the inlet of the cascade. The more important results of the investigation may be summarized as follows: i) no leading edge separations were found in spite of very high incidence angles next to the endwalls, ii) the overturning of the endwall flow was much less with inlet skew than without thus indicating a passage vortex of considerably reduced strength, iii) due to ii) the interaction between the endwall flow and the blade suction surface flow was less with inlet skew than without resulting in lower net total pressure losses (without inlet losses), iv) the performance improvements caused by a skewed inlet boundary layer decreased with increasing inlet angle.

Influence of Compressibility on Incidence Losses of Turbomachinery at Subsonic Operation

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Acceptance tests on large fans to prove the performance (efficiency and total pressure rise) are sophisticated and expensive. One way to reduce costs and efforts are a better prediction of fan performance at the design point as well as at off-design conditions. The commonly used scaling-up methods are working quite well near the design point and right now none of them are taking the compressible effects into account, which are getting more and more important at higher flow velocities. The need of highly loaded radial fans make it necessary to run fans at higher rotational speed and therefore at higher flow velocities. At part- or overload conditions inertia losses are important. Other authors showed that compressible effects are becoming highly relevant for radial fans and turbocharger compressors due to a shift of the peak efficiency to other flow coefficients, which occur at high flow velocities.

This paper begins with the physically based description of a two-dimensional flow through a blade cascade (without curvature) with variable incidence angle and incoming flow velocity. The incompressible case is now complemented with the common formulas for the compressible flow. If the friction along the blades is neglected and the blades are infinitesimal thin the analytical solution of the equation of continuity and the balance of momentum and energy exist. As well is the loss coefficient of the compressible incidence loss proportional to the square of the incoming Mach number. A comparison with fundamental experimental investigations of blade cascades shows a very similar behavior of the variation of the incidence angle and the incoming Mach number. A further correction is taking the compressible Borda-Carnot loss into account to include the fact that the blades in the investigated cascade have a nonzero height. This correction shows good results in a Mach number range from zero to 0.7 and is also good up to incidence angles at which flow separations appear. These separations are the limits of the theoretical model. Additional corrections can be included for the friction along the blade or further separation models can be added.

HUMAN PERCEPTION AND FAN NOISES

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Human interactions with external environment need to be very efficient in a survival mode and there is a very good match between sound perception and external stimuli such as speech, which is a key communication skill. But global perception is related to all senses.

New technologies products are created to enhance human comfort. They produce sounds and can be evaluated in a human perception point of view. Different perceptive quotation scales are discussed. An overview of Psychoacoustics tools applied to fan noises is presented.

Comfort enhancement strategy for Automotive Heating Ventilation and Air Conditioning systems consists in a first step in a classification into different noises characteristics and presence conditions. In a second step, optimisation of the main perceptive characters of each pre-classified noise is proposed, generally involving other comfort parameters. Concerning Automotive Cooling Fan systems, Loudness criterion is the main characteristic of the acoustic annoyance.

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