Recent Research Activities of DLR Engine Acoustics

Dr. Robert Meyer

German Aerospace Center (DLR)
Institute of Propulsion Technology
Engine Acoustics, Berlin
DLR
German Aerospace Center

Research Areas
- Aeronautics
- Space Research and Technology
- Transport
- Energy
- Space Administration
- Project Management Agency
DLR: Sites and employees

7,400 employees working in 32 research institutes and facilities at 16 Sites.


Sites of the Institute of Propulsion Technologies

Engine Acoustics is located in Berlin:
DLR Site
Cologne (DLR Headquarter)

Employees: 1400
Size of site: 550 000 m²
Research institutes and facilities:

- Institute of Materials Physics in Space
- Institute of Aerospace Medicine
- **Institute of Propulsion Technology**
- Institute of Materials Research
- Institute of Air Transport and Airport Research
- Institute of Solar Research
- Institute of Technical Thermodynamics
- High-flux-density solar furnace
- Simulation- and Software Technology
- Quality and Product Assurance
- European Astronaut Center
- Supersonic and Hypersonic Technologies
- European Transonic Wind Tunnel
- Microgravity User Support Center (MUSC)
- DLR Project Management Agency
DLR Site
Berlin-Charlottenburg

Employees: 31
Scientist: 25
Infrastructure: 6
+ Students

Research institutes and facilities:
Institute of Propulsion Technology
Department of Engine Acoustics

Location:
Downtown of the Berlin City –West
on Campus of the Technical University of Berlin
Organisation of the Institute of Propulsion Technologie

Institute of Propulsion Technique
Prof. Dr.-Ing. Reinhard Mönig

Components
- Fan and Compressor
  Dr.-Ing. Eberhard Nicke
- Combustor
  Dr.-Ing. Christoph Hassa
- Turbine
  Prof. Dr.-Ing. Ingo Röhle
- Combustion Test
  Dipl.-Ing. Christian Fleing

General Methods
- Engine
  Dr.-Ing. Andreas Döpelheuer
- Engine Acoustics
  Prof. Dr. rer. nat. Lars Enghardt
- Engine Measurement Systems
  Dr.-Ing. Christian Willert
- Numerical Methods
  Dr.-Ing. Edmund Kügeler

Center for Combustion Technique
Engine Acoustics

Analysis of

- Engine Noise
- Turbine Noise
- Combustion Noise
- Jet Noise
- Fan- and Compressor Noise

Reduction by

- Innovative Noise Abatement Methods
- Noise Control Liners
- Design-to-noise Pre-design

Methods:
- numerical
- experimental
- analytical
Main Work Topics/Structure
Department of Engine Acoustics in Berlin

Lead: Lars Enghardt

Turbo machinery Acoustics
- Acoustic Data- and Mode analysis
- Source localization
- Indoor-, Inflight- and Flyover-Measurements
  - Jet Noise
  - Active Noise Control
- 9 Researcher
  - U. Tapken

Numerics/Modelling
- Numerical Acoustic
- Software Development
  - Source modeling and directivity
  - Design to noise
- 6 Researcher
  - S. Guerin

Combustion Acoustics
- Combustor sound fields
- Optical measurement technique
- Entropy- and vortex noise
  - Liner (hot and cold)
- Combustor instabilities
- 5 Researcher
  - F. Bake

Turbo machinery Aerodynamics
- Flow control
- Turbulence research
- Hot wire measurements
  - Secondary flows
  - Drag reduction
  - Efficiency improvements
- 5 Researcher
  - R. Meyer

Infrastructure: 6 Employees
Overall: 31 Employees
Research on Open Rotors

Sebastien Guerin, Christian Weckmüller, Antoine Moreau, Henri Siller, Rainer Schnell, Richard Becker

- Engine performance and mission analysis (AT-TWK, Cologne)
- Aerodynamics (AT-FUV, Cologne)
- Acoustics (AT-TRA, Berlin)
  - Acoustic prediction with a RANS-informed analytical method
    - Tonal and broadband noise
  - Design-to-noise (blade design)
    - trailing-edge serrations
    - Reduction of interaction tones
  - Improved use of Ffowcs Williams Hawkings (FW-H)
    - Spurious noise induced by vortices cutting
    - Split between acoustic and aerodynamic contributions (in progress)

Publication: Chr. Weckmüller, S. Guerin AIAA-2012-2124
Design capabilities: trailing-edge serrations

- Broadening of the wake
- Reduction of interaction tones

C. Weckmüller, S. Guérin; *On the influence of trailing-edge serrations on open-rotor tonal noise*, AIAA 2012-2124.
Focus: Experimental identification of the contributions of each of the engine modules to exhaust broadband noise

Turbo shaft exhaust noise:
a mix of combustion and turbine noise, with very little jet noise representative for “core noise”

TEENI work program is divided in 3 interdependent Work packages (WP)

• WP1 : Innovative sensors development – to provide reference measurements of fluctuating quantities within the engine under harsh operating conditions.

• WP2 : Noise Sources Breakdown Techniques to determine the dominant emission location/s from external measurements (taking the internal measurements into account)

• WP3 : Turboshaft engine full-scale test apply WP1 and WP2 developments
**New probes for high pressure applications**

**Microphone probes**
- Mean pressure up to 20bar (during test 12bar)
- Temperature up to 1200°C
- Fluctuations <1bar (194dB)
- 6 specific length probes, 30 standard probes at the nozzle

**Twin Thermocouples**
- Thermocouples Type R, Pt/Rh (87/13%) / Pt
  - Tmax≈1600°C, short time Tmax≈1700°C
- Temp fluctuations up to at least 800Hz
- Two thermocouples of different diameter (and different time constant) allow for correction of time signal by iterative post-processing

Publication: K. Knobloch et al GT2011-45705
Full-scale test - Installation with DLR Sensors

Installation zones internal sensors
- 2x Mic probes in CC2, HPT, TL1
- 4x TwinTC in CC2, 2x in HPT
- 36x Mic probes at nozzle

External instrumentation (TM): 17 microphones on a semicircle … @ about 19m distance

Synchronized measurement of internal sources, exhaust noise (mode analysis) and far-field radiation
Mode analysis using internal reference sensors / Separation of different noise source contributions

- FB1 and FB2:
  - all sources strongly contribute to dominant mode \( m=0 \)
- FB3:
  - all sources contribute to dominant mode \( m=+1 \)
  - HPT and TL contribute to \( m=0 \)
  - only HPT contributes to \( m=-1 \)
- FB4:
  - combustor and HPT contribute more to \( m=-2 \)
  - TL contributes more to \( m=0 \) and \( m=+2 \)
- FB5:
  - HPT and TL contribute mainly to \( m=-2 \), \( m=-1 \) and \( m=+3 \)

Analysis of data base is still on-going!
Impact of bypass-duct bifurcations on fan noise

Axel Holewa, Christian Weckmüller, Sébastien Guérin

- Focus:
  - tonal fan noise, flow interaction with bypass-duct components
  - Slow decay of potential field of the bifurcations
  - interaction with the rotor \( \rightarrow \) source of sound?

- Method:
  - unsteady RANS, DLR in-house code: TRACE

- Challenge:
  - proper resolution of aerodynamic and acoustic flow features over a large and complex domain
  - Full-3D domain: >160 millions cells (URANS analysis in progress)
  - Quasi-3D domain: 1.8 millions cells, thin stream tube, annulus shaped, single cell in radial direction
    (Presented at AIAA 2012)

- Quasi-3D flow path

Publication: Axel Holewa et al.: ISABE-2009-1152
Quasi-3D results

Instantaneous pressure field

Axial decay of the potential field

Isolated fan stage

Fan stage with bifurcations
Rotor—blade forces in the rotating frame

Forces on the stator vanes

Time domain

Acoustic mode decomposition in the bypass duct

- TS modes less strong
- Additional broadband mode spectra
- Total sound power increases by 2-3 dB at 1 BPF and 2 BPF
Reduction of subsonic jet noise by passive flow control devices
(Joint PSU & DLR experiments)
Robert Meyer, Ching-Wen Kuo, Dennis K. McLaughlin

- Enhancement of turbulent mixing
- Experiments at high subsonic Mach numbers (0.5-1.0)
- Variation of Zigzag shape
  - Thickness, jag width,..
- Microphone measurements with
- Near field ring array
- Fare field arc array

Publication: Robert Meyer; Ching-Wen Kuo; Dennis K. McLaughlin: AIAA-Aero acoustics Berlin 2013
Results of the *near field ring array*; Comparison of baseline, rough surface and zigzag nozzle

![Graph showing comparison of noise levels for different nozzle conditions](image)

- **Reference Nozzle / Zigzag tape/ rough surface**
  - Ref; Ma=0.9
  - Ref; Ma=0.5
  - Ref; Ma=0.8
  - ZigZag; Ma=0.5
  - ZigZag; Ma=0.8
  - ZigZag; Ma=0.9
  - Rough surface, Grain 100; Ma=0.5
  - Rough surface, Grain 100; Ma=0.8
  - Rough surface, Grain 100; Ma=0.9

![Baseline nozzle](image)

![Rough surface nozzle](image)

![Zigzag nozzle](image)
Variation of zigzag height:
Nozzle with zigzag tape; Ma = 1.0

<table>
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<th>Zigzag type</th>
<th>h [mm]</th>
<th>a [mm]</th>
<th>B [mm]</th>
<th>t [mm]</th>
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Thank you for your attention