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**Application of a hybrid
Computational Aeroacoustics method
to an automotive blower**

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Mélanie Piellard & Bruno Coutty
Delphi Thermal Systems, Bascharage (Luxembourg)

Outline

- ◆ Introduction
- ◆ Simulation method
- ◆ HVAC blower study
- ◆ Conclusions & Future work



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Simulation of aeroacoustic noise

- ◆ Objective: predict the aeroacoustic noise in an industrial context
 - Reasonable simulation time and computing resources
 - Use commercial or free computing codes
- ◆ Target applications
 - Internal flows
 - Low Mach numbers
 - Complex geometries
 - Fans involving rotating parts
- ◆ Simulation strategy applicable to complex geometries
 - Two steps hybrid method of Computational AeroAcoustics: CFD + acoustic
 - Full scale incompressible unsteady Large Eddy Simulation
 - Spectral finite element formulation for acoustic propagation

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Variational formulation of Lighthill's Acoustic Analogy

- ◆ Starting point: Lighthill's equation (Lighthill, 1952)

$$\frac{\partial^2 \rho_a}{\partial t^2} - c_0^2 \frac{\partial^2 \rho_a}{\partial x_i \partial x_i} = \frac{\partial^2 T_{ij}}{\partial x_i \partial x_j} \quad \text{with} \quad T_{ij} = \rho u_i u_j + \delta_{ij} \left((p - p_0) - c_0^2 (\rho - \rho_0) \right) - \tau_{ij}$$

- ◆ Finite Element implementation (Oberai *et al* & Caro *et al*)
 - Generalized functions + variational spectral formulation applied to Lighthill's equation

$$\int_{\Omega} \left(\frac{\partial^2 \rho_a}{\partial t^2} \delta \rho + c_0^2 \frac{\partial \rho_a}{\partial x_i} \frac{\partial \delta \rho}{\partial x_i} \right) d\mathbf{x} = - \int_{\Omega} \frac{\partial T_{ij}}{\partial x_j} \frac{\partial \delta \rho}{\partial x_i} d\mathbf{x} + \int_{\Gamma} \frac{\partial \Sigma_{ij}}{\partial x_j} n_i \delta \rho d\Gamma(\mathbf{x}) \nabla \delta \rho$$

volume source term

surface source term defined on a porous control surface

$$n_i \frac{\partial \Sigma_{ij}}{\partial x_j} = -n_i \frac{\partial}{\partial t} (\rho u_i)$$

References

- ◆ Lighthill, M. J. Proc. Roy. Soc. London, A211, 1952.
- ◆ Oberai, A. A. et al. Comput. Meth. in Appl. Mech. Eng., 190, 2000.
- ◆ Caro, S. et al. AIAA Paper 2004-2891, 2004.

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Practical application: 5 steps

1. Preliminary CFD computation: Fluent
 - Unsteady LES until reaching of a statistical convergence
 - Flow field analysis: determination of acoustic source region(s)
2. Acoustic mesh design
 - Might be refined in source region(s) & on porous surface
3. Unsteady LES & record of aerodynamic quantities (velocity vector)
4. Computation of source terms and interpolation on the acoustic mesh
5. Acoustic computation: Actran/LA
 - Fast Fourier Transform of unsteady source terms
 - Spectral acoustic propagation in the finite elements domain, with
 - » Volume source terms in the fluid domain
 - » Surface source terms as boundary condition to account for the fan
 - » Spatial filter to damp out sources before boundaries

References

- ♦ ANSYS, Inc. ANSYS FLUENT 12.0 User's Guide, 2009.
- ♦ Free Field Technologies. Actran 11.1 User's Guide, URL: www.fft.be, 2010.

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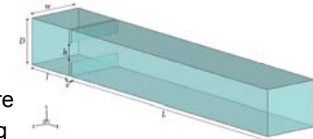
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Validation of the method (background)

- ♦ Theoretical validation
 - Already performed on the two corotating vortices case
 - Successful comparison with the analytical formulation of Lighthill's Acoustic Analogy

- ♦ Validation on a real case

- The ducted diaphragm at low Mach number
- Comparison with available data in the literature
- Influence of the interpolation method → strong
- Influence of the acoustic finite element order → weak
- Influence of the CFD solution (and of the CFD code) → weak



> *Good correlation obtained on a simple fixed geometry*

References

- ♦ Piellard, M. A hybrid method for Computational AeroAcoustics applied to confined geometries, Ph.D. thesis, Ecole Centrale de Lyon, 2008.
- ♦ Piellard, M. et al. AIAA paper 2010-3996, 2010.

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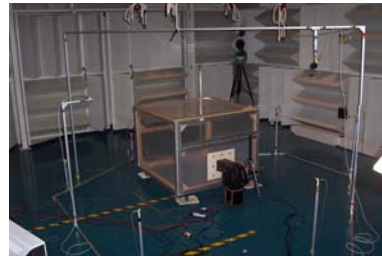
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Application to an automotive centrifugal blower Experimental setup

- ◆ ISO 10302: experimental method for sound power measurement of fan systems

- ◆ Mylar plenum setup

- Outlet size variation to simulate a restriction/blower operating point
- Acoustically transparent material
- 10 microphones installed on a 2 meter radius half-sphere centered on plenum inlet



Mylar setup

References

- ◆ ISO 10302:1996. Acoustics – Method for the measurement of airborne noise emitted by small air-moving devices.

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Application to an automotive centrifugal blower Blower under study

- ◆ Blower taken from production HVAC

- 39 forward-skewed blades
- Electrical motor with plastic cover
- Straight duct length: 20cm
- All walls are covered by foam and heavy material to avoid sound transmission through walls

- ◆ Operating point chosen

- 3000rpm
- 438m³/h
- 562Pa



Automotive blower

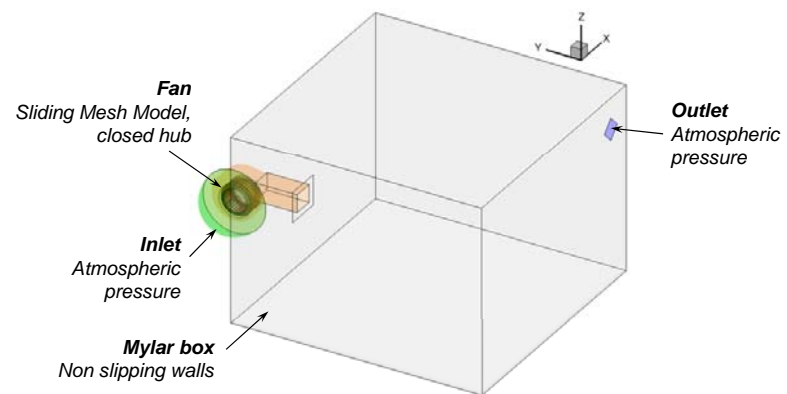
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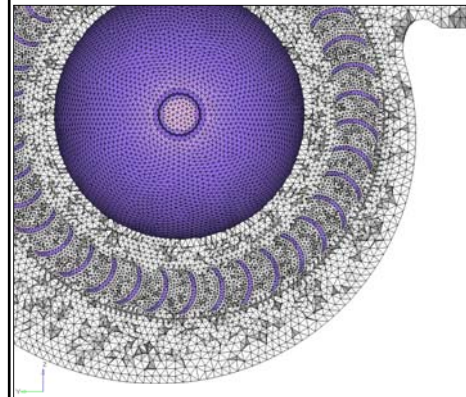
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CFD simulation setup

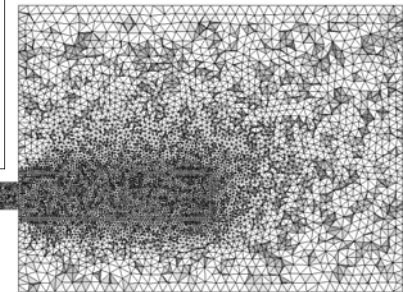


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CFD tetrahedral mesh



- ◆ Total mesh size: $4 \cdot 10^6$ cells
- ◆ Refinement
 - Fan: 1.5mm (no BLs)
 - Scroll: 3mm
 - Duct & jet: 7mm
 - Mylar box: 20mm



CFD parameters

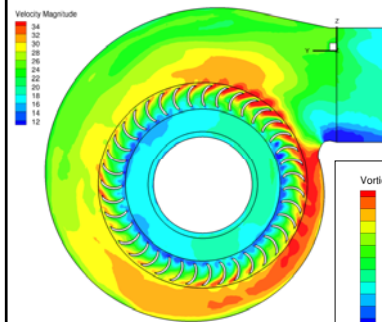
- ◆ Sliding Mesh Model to account for fan rotation
- ◆ Detached Eddy Simulation
 - Incompressible
 - Blending of LES and Spalart-Allmaras RANS model
 - Second order transient formulation
 - Time step $5 \cdot 10^{-5}$ s
 - » 400 time steps/cycle
 - » 10 time steps/blade passage
 - Momentum & turbulent viscosity equations: central differencing scheme
 - Pressure equation: second order scheme
- ◆ 14 cycles run to reach flow convergence
- ◆ Velocity vector recorded during 4.25 cycles (85ms)
 - Will allow a frequency resolution of ~ 12 Hz in the acoustic simulation
- ◆ Load point obtained in simulation vs. experiment

	Airflow (m ³ /h)	Pressure (Pa)
Simulation	442	480
Experiment	438	562

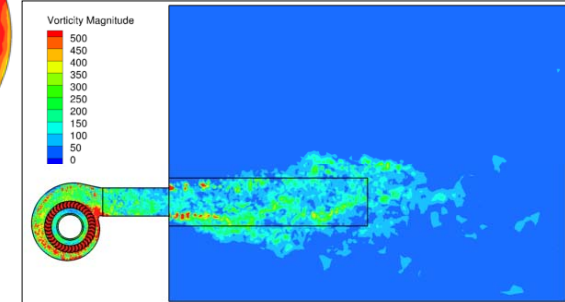
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CFD instantaneous results

Velocity magnitude

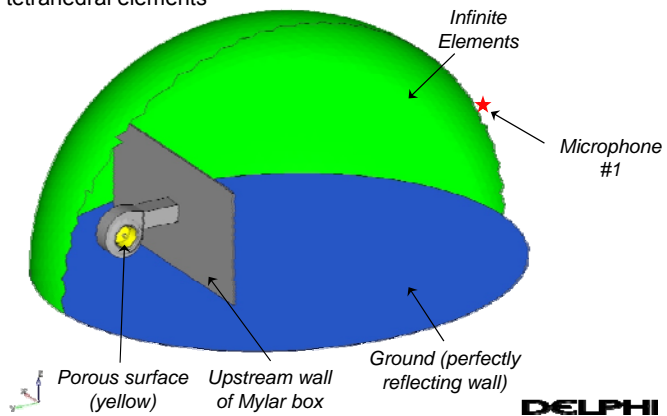


Vorticity magnitude



Acoustic simulation setup

- ◆ Quadratic mesh
 - 308,000 nodes
 - 217,000 tetrahedral elements

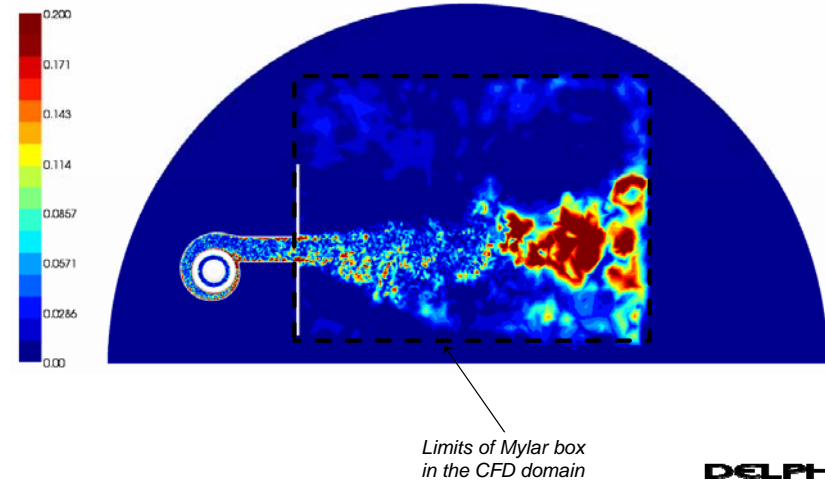


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Map of instantaneous volume source terms



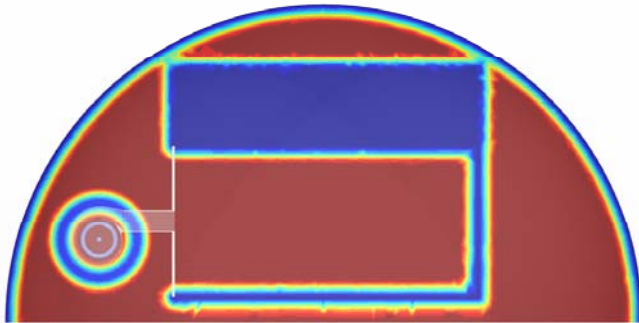
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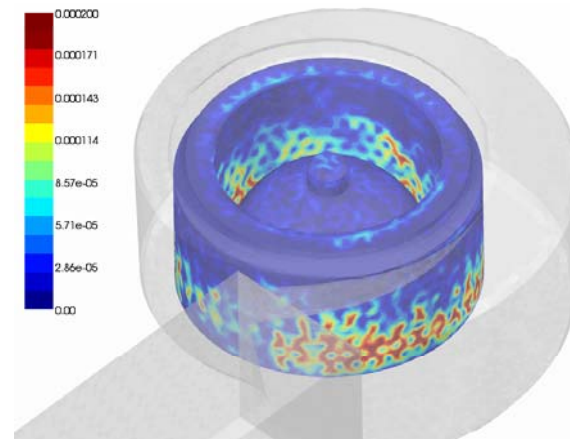
Filtering of volume source terms

- ◆ Volume source terms need to be filtered before boundaries to avoid spurious noise radiation
- ◆ Spatial filter defined as a cosine type weight ($0 \leq \text{weight} \leq 1$)



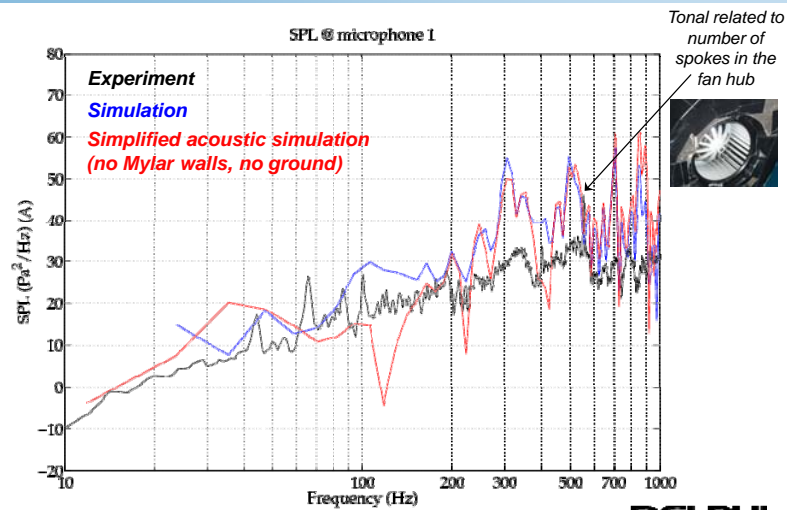
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Map of instantaneous surface source terms



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Acoustic results obtained @ microphone #1

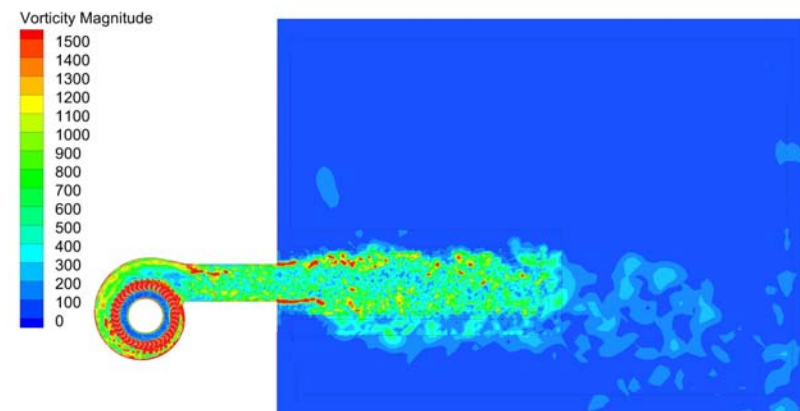


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CFD mesh refinement: $8 \cdot 10^6$ cells

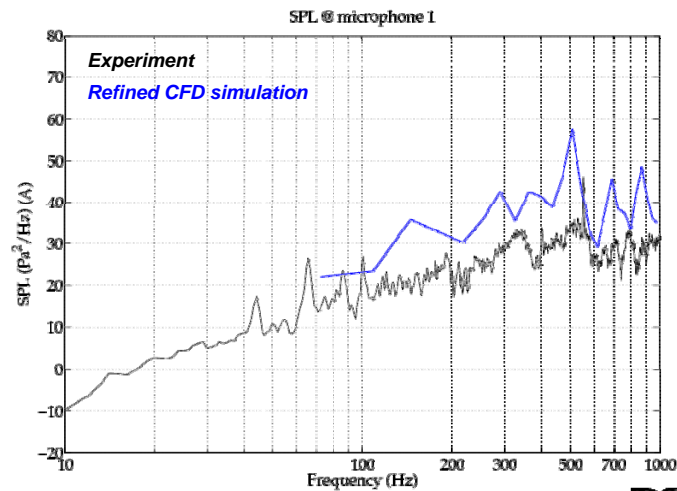


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Improvement after CFD mesh refinement



Conclusions & Future work

◆ Conclusions

- Use of a hybrid CAA method on a real case involving turbomachinery
- Compliance of setup between experimental and simulation is of primary importance, probably the cause of discrepancies

◆ Future work

- Perform a simulation in a simpler setup, without Mylar box to remove questions about boundary conditions
- Make sure that the blower/duct CAD model reproduces reality
- Improve the CFD accuracy through mesh refinement
- Increase the simulation time
 - » Improve the frequency resolution
 - » Allow averaging
- Axial fan simulation ongoing