



Prediction of Noise in HVAC Ducts

Dr Karamjit Sandhu

**Climate Control Systems
Jaguar Land Rover**

Open Source CFD International Conference 2008

Summary



- Introduction
- Benchmark LES Flow Verification
- HVAC Aero-Acoustic Noise Source Calculations
- HVAC Aero-Acoustic Noise Propagation Prediction
- Conclusions
- Acknowledgements

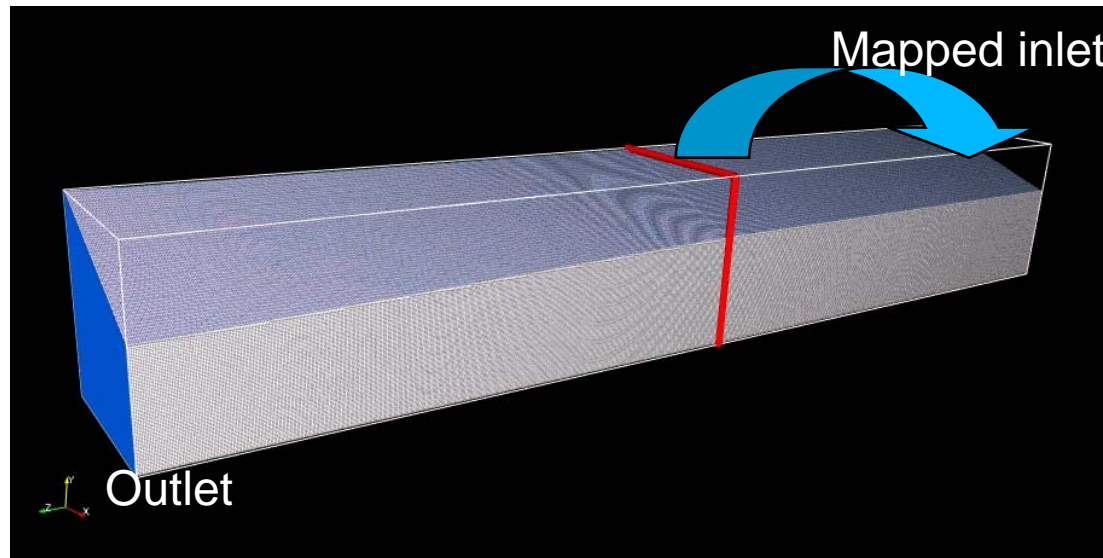
- Current CAE methods are not mature enough to predict noise in ducts and propagated into the interior vehicle cabin
- Eliminate late changes and costs in vehicle programmes to reduce HVAC noise
- Complex problem and methods required to predict noise in simple ducts
- Method needed to identify potential noise sources early
- Aim is to develop a CAE method to predict far field noise in a HVAC duct
- Advanced CFD and CAA methods will be introduced to tackle the problem

The work was performed in conjunction with ICON

Benchmark LES Flow Verification

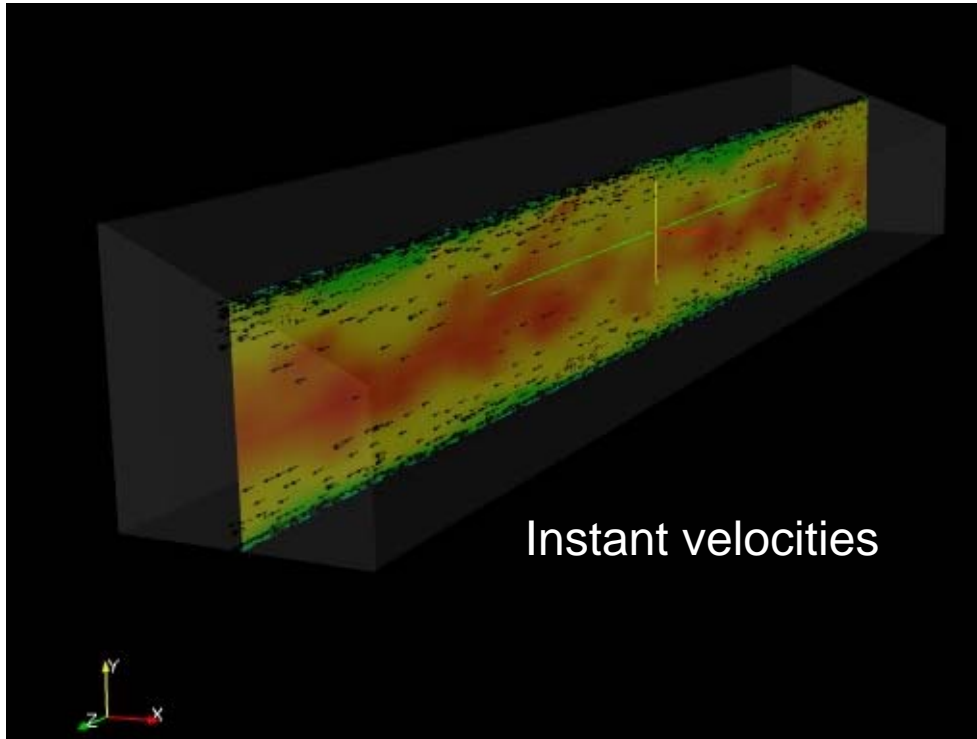


- For the initial studies a mapped inlet duct LES flow solution was obtained to establish a fully turbulent inlet starting condition for the full configuration
- Validation using experimental outlet velocity profiles
- Verification of the basic meshing and flow solution methodology

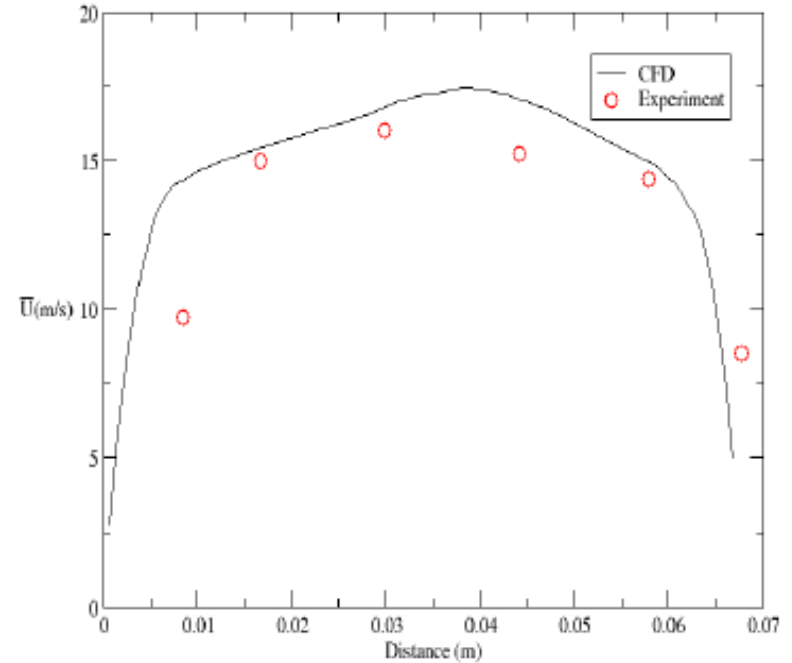


Inlet Mapped Boundary Condition

Benchmark LES Flow Verification

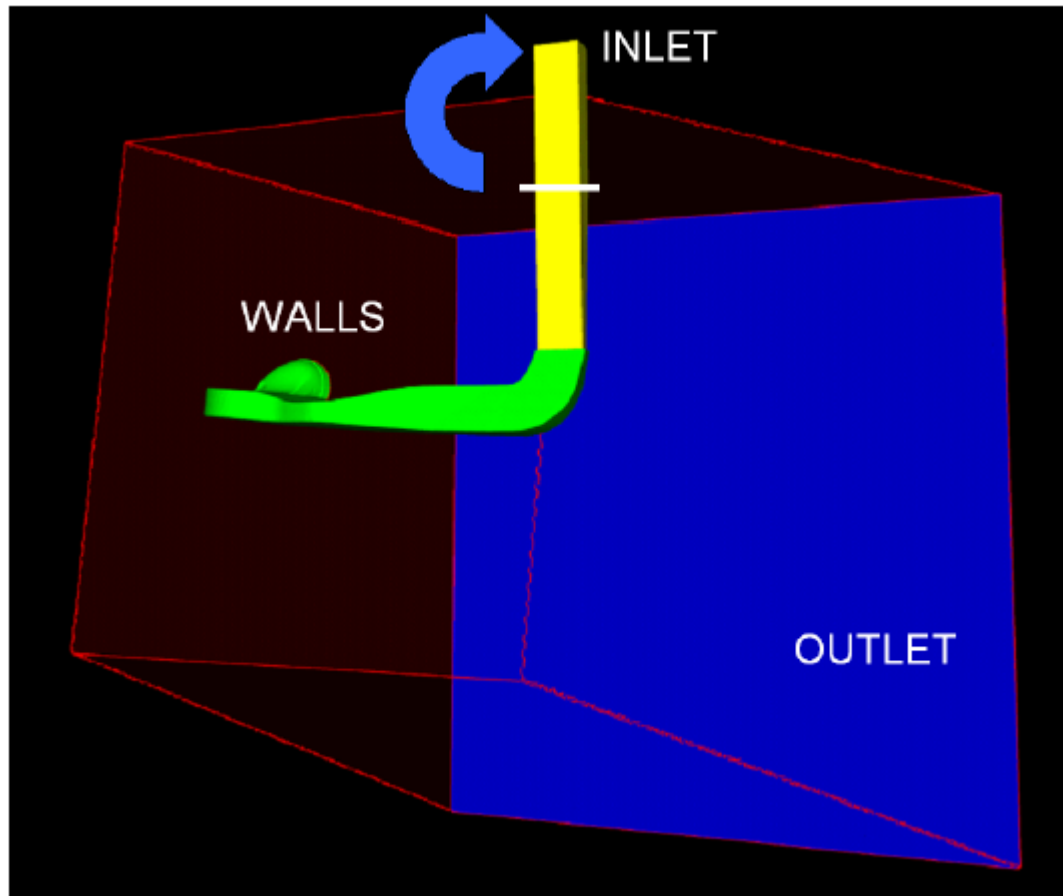


Shaded contours of the instantaneous velocities in the inlet section



Comparison of mean velocities across the outlet

HVAC Aero-Acoustic Noise Source Calculations

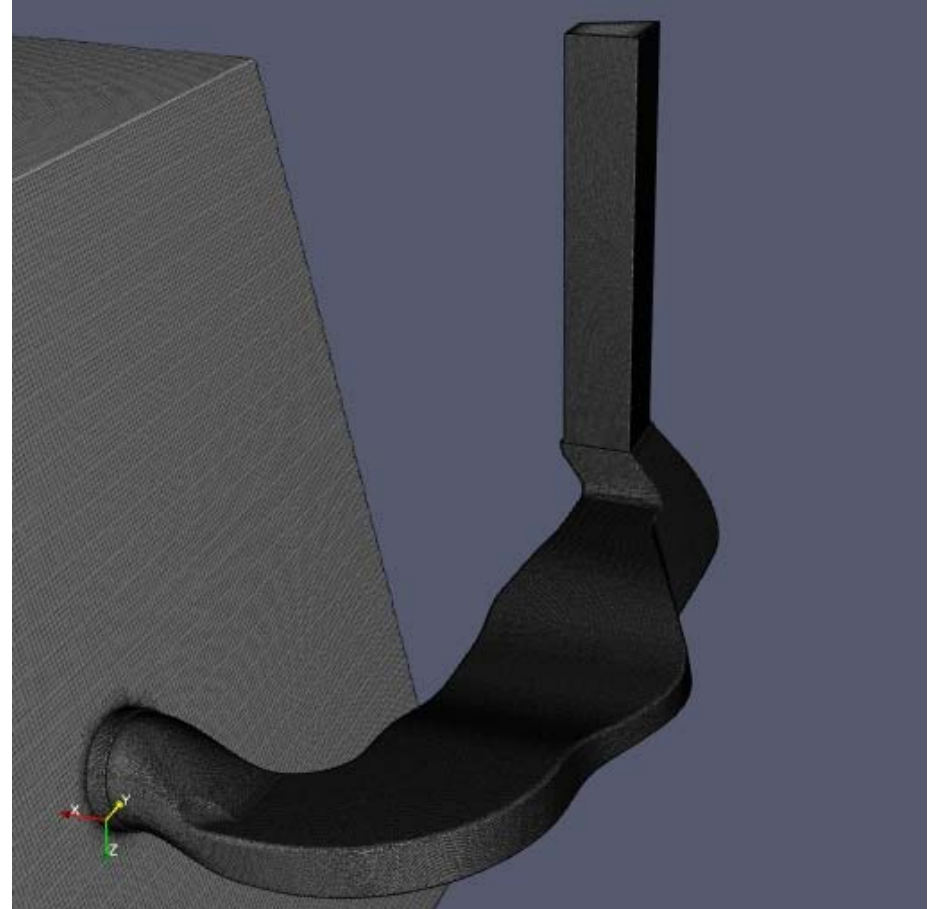


Geometry used to calculate the flow through the duct

HVAC Aero-Acoustic Noise Source Calculations

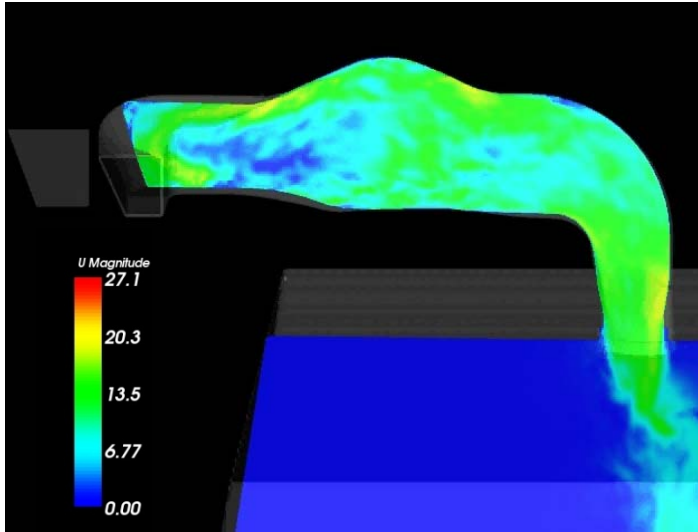


- Auto-Hex Mesh (AHM) for rapid high quality mesh generation
 - Hex dominant
 - Surface layers
 - 6 million Cells
- Inlet mapping – based on the a fixed total pressure inlet
- Advanced LES solver
- OpenFOAM LES solver, oodles
- Discretisation using the Crank-Nicholson for time and central-differencing

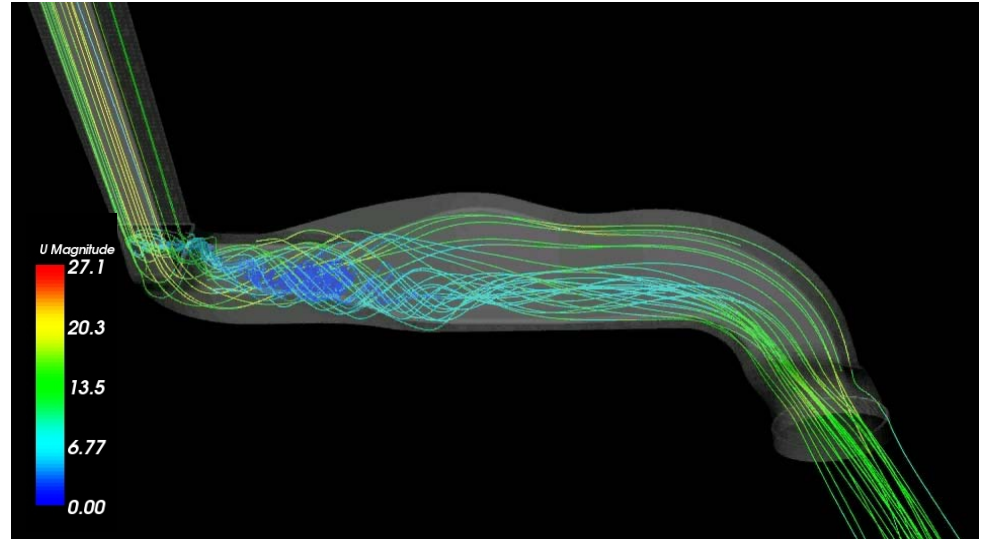


Surface Mesh of the Duct

HVAC Aero-Acoustic Noise Source Calculations



Instantaneous velocity at 0.2s

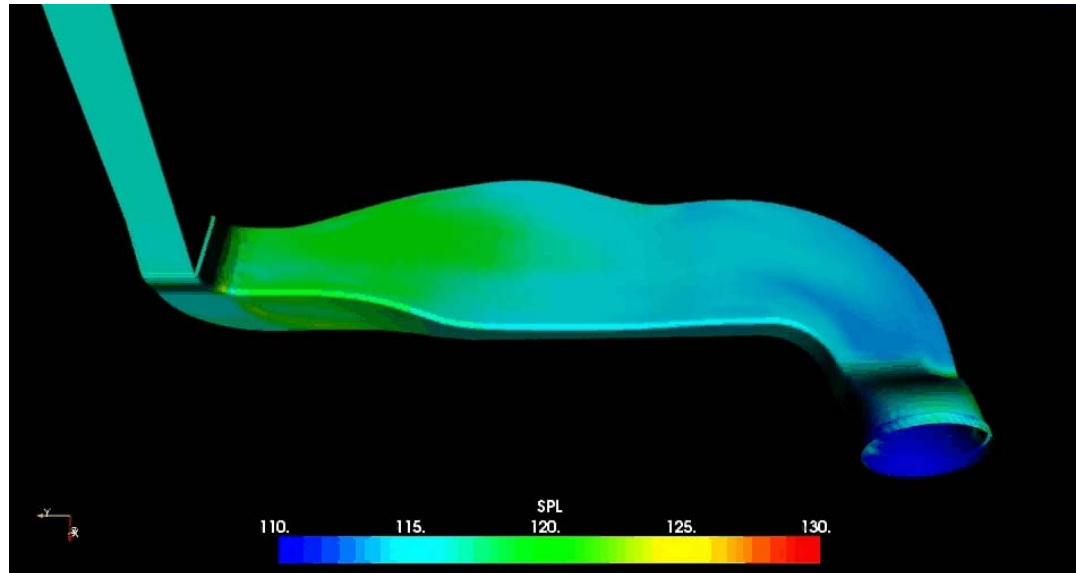


Mean Streamlines at 0.4s

HVAC Aero-Acoustic Noise Source Calculations



- Results show a re-circulation at the entry of the duct
- Major source of the noise generated
- Air borne noise is mainly caused by pressure fluctuations at the wall
- This is illustrated in the SPL values below

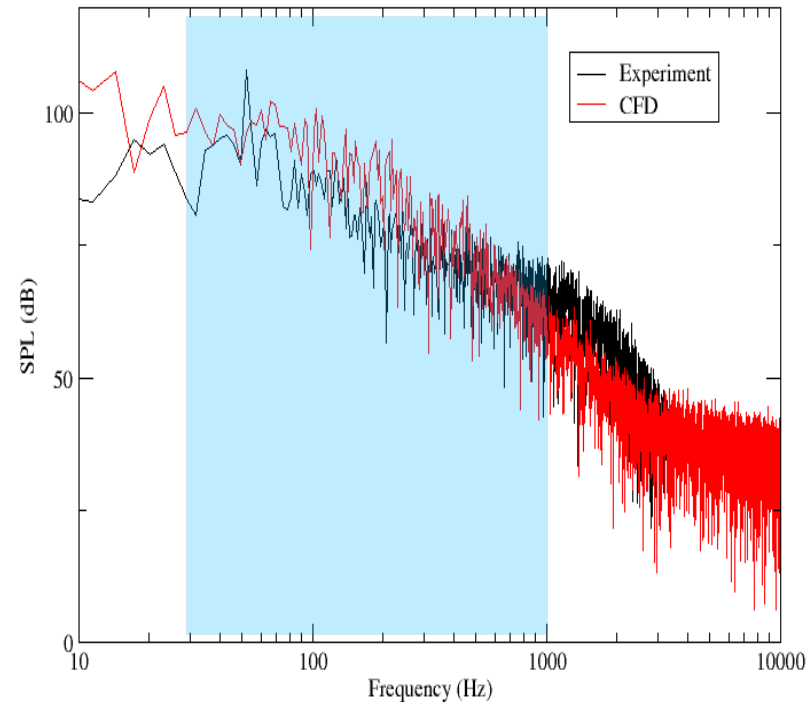
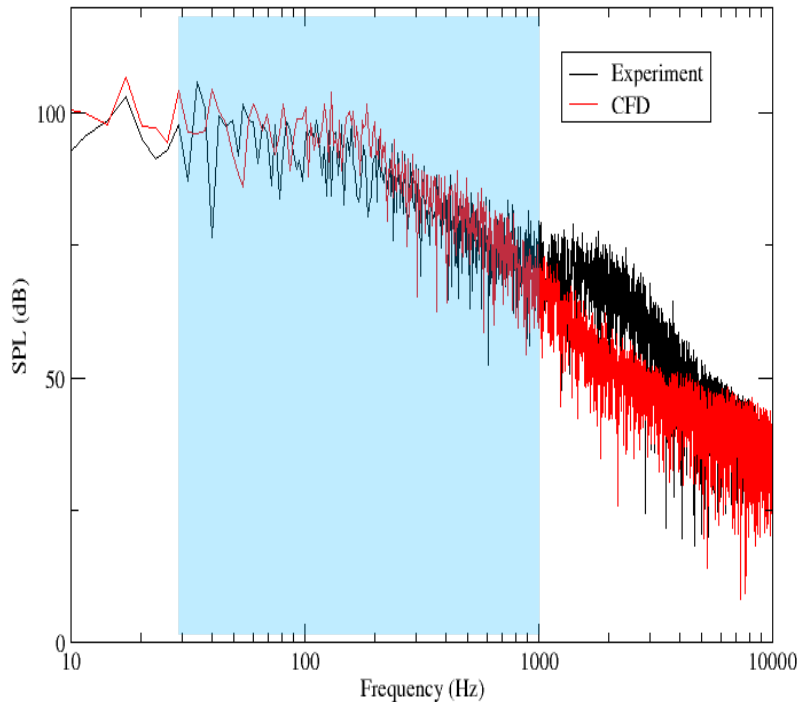


Mean Surface Sound Pressure Level(SPL)

HVAC Aero-Acoustic Noise Source Calculations



- To validate the results a comparison was made with test data
- Fourier transforms(FFT) were employed to convert the time dependent pressure to frequency dependent domain

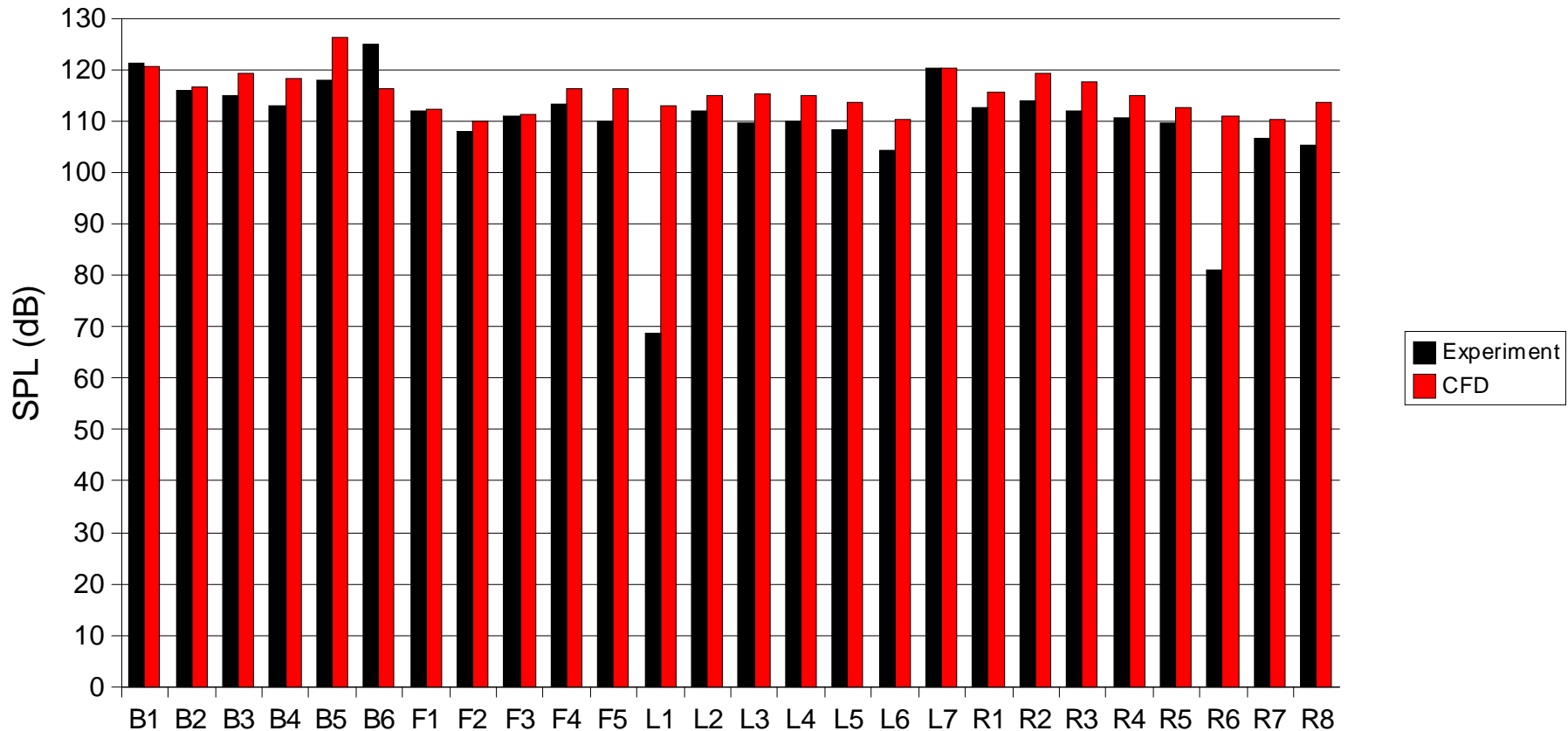


Comparison of Simulation and Test Data

HVAC Aero-Acoustic Noise Source Calculations



- Overall comparison of the CFD Equivalent SPL was good
- There were a couple of large discrepancies (due to experimental error)
- SPL mean error of 3.9dB over all sampling points



HVAC Aero-Acoustic Noise Propagation Prediction



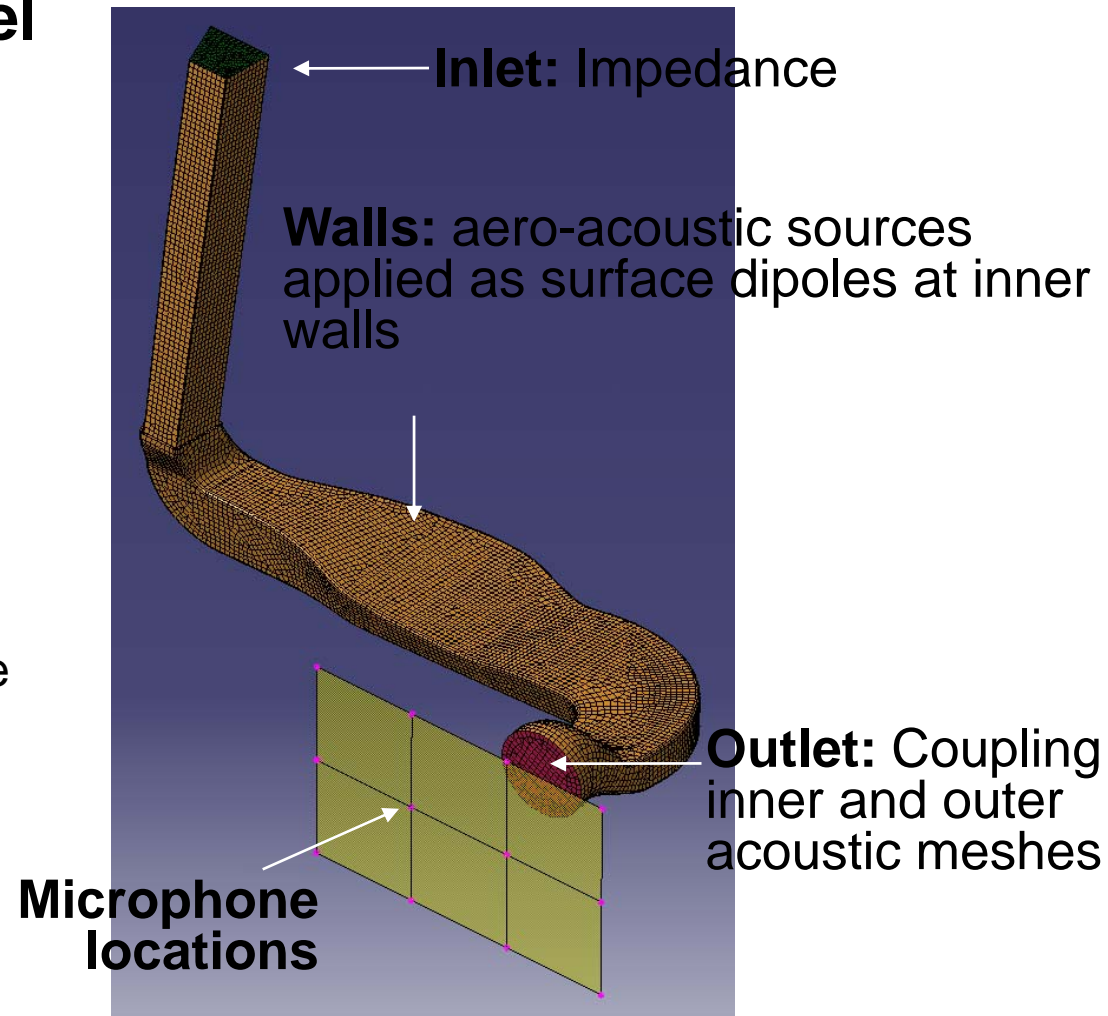
- Two approaches tested for CAA computations:
 - Multi Domain Direct Boundary Element Method (MDDBEM) using LMS Virtual Lab
 - Simplified form of the Ffowcs Williams-Hawkings (FW-H) equation for line-of-sight noise propagation using OpenFOAM
- LES results for instantaneous pressure were used as source of aero-acoustic noise (surface dipoles)
- The two approaches were compared against experimental measurements

HVAC Aero-Acoustic Noise Propagation Prediction



LMS.VL MDDBEM Model

- MDDBEM solves two simultaneous problems:
 - interior problem with surface dipoles as acoustic sources (from LES calculation) is coupled to external far field noise propagation problem at outlet
- The solution was solved in the range 20Hz to 2kHz



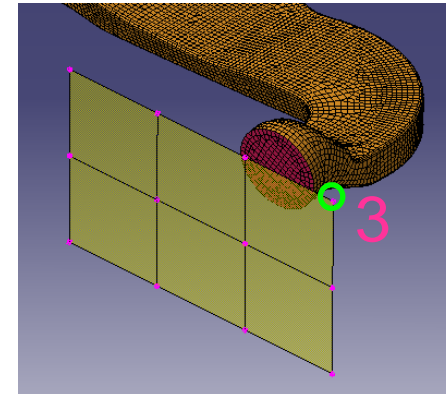
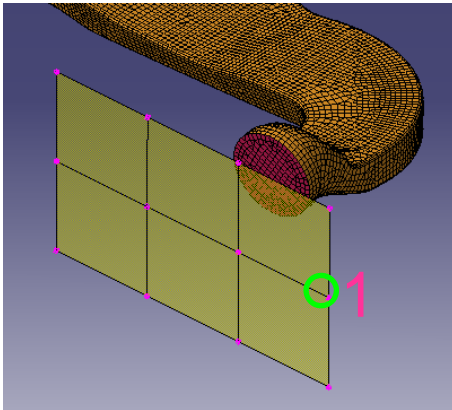
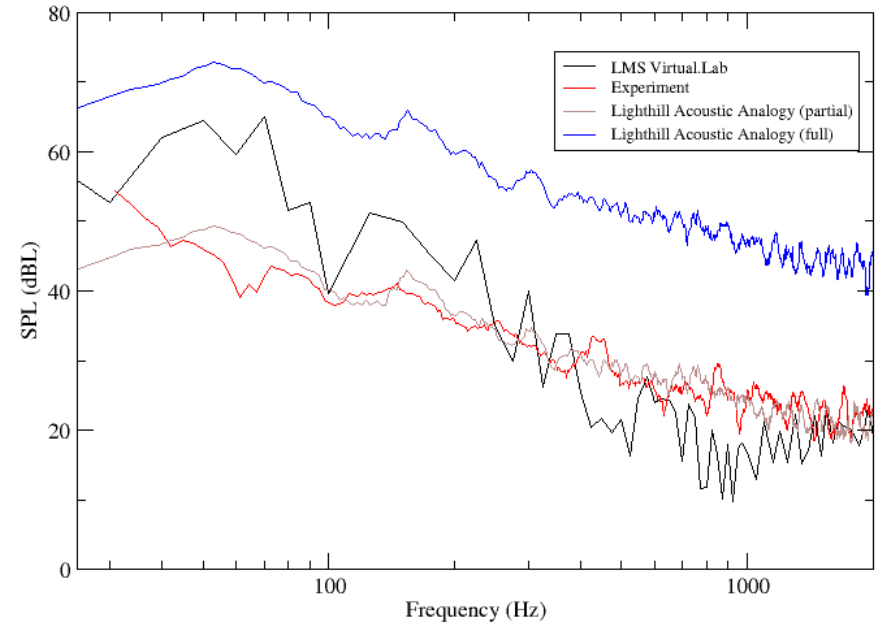
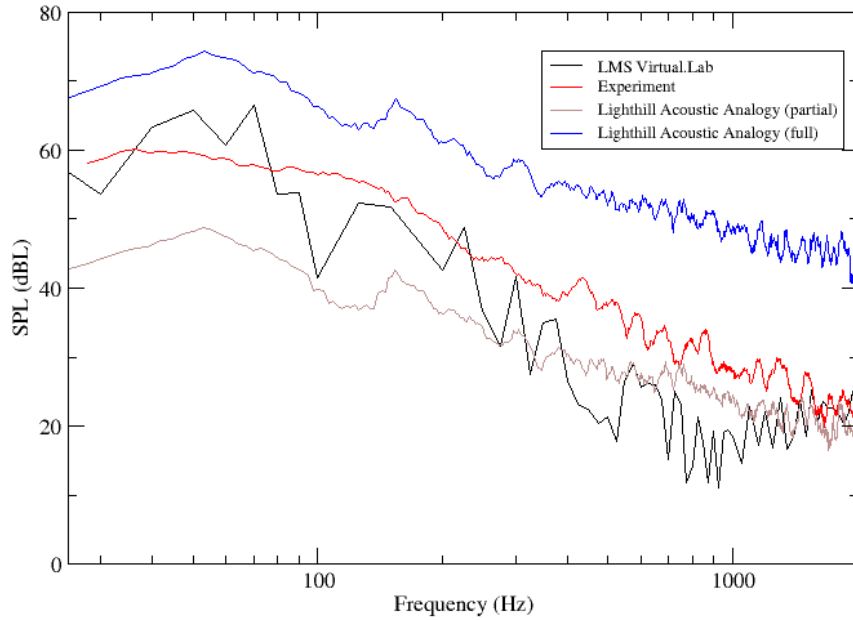
HVAC Aero-Acoustic Noise Propagation Prediction



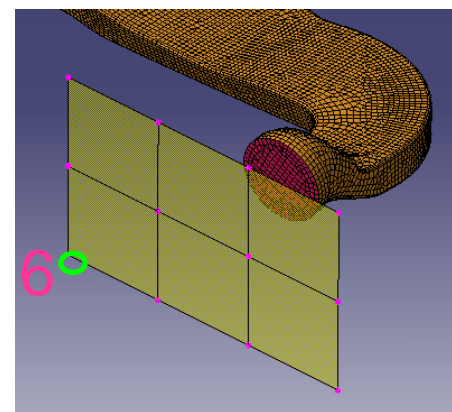
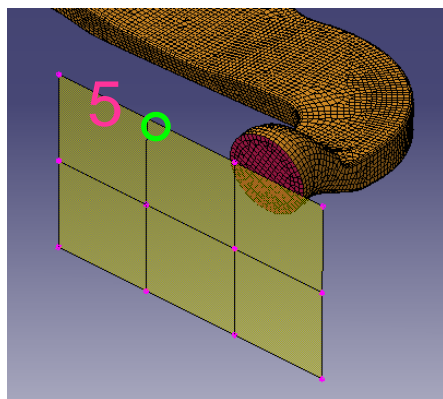
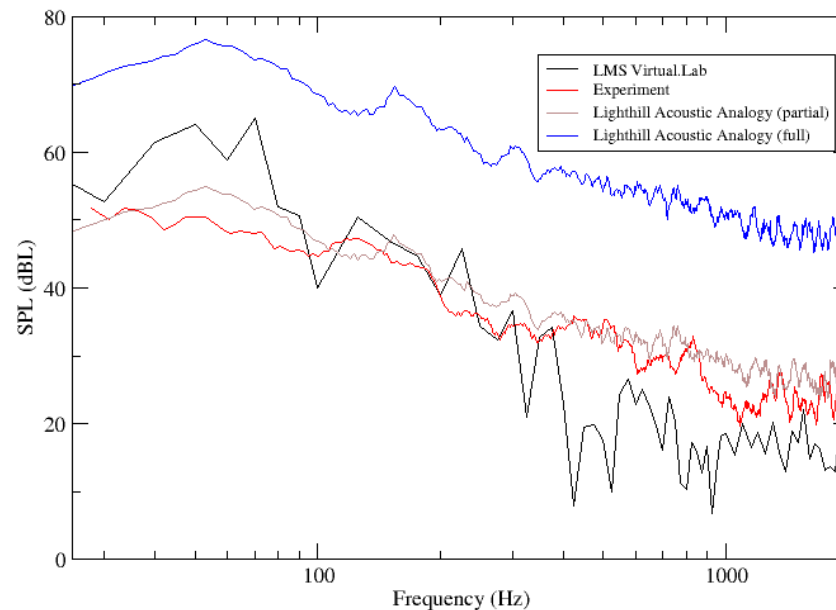
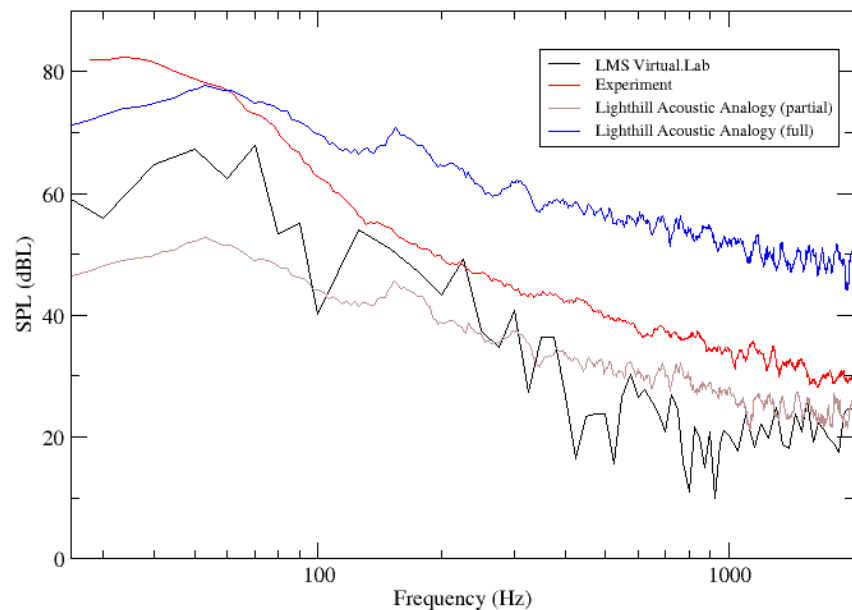
OpenFOAM FWH Model

- Simplified form of the Ffowcs Williams-Hawkings (FW-H) equation implemented in OpenFOAM
- Propagation method along line of sight provides estimates of upper and lower bounds on noise propagation results
- Sound reflection, deflection or transmission are not considered as with BEM/FEM
- Results are obtained as part of the CFD calculation and are only of qualitative value

HVAC Aero-Acoustic Noise Propagation Prediction



HVAC Aero-Acoustic Noise Propagation Prediction



HVAC Aero-Acoustic Noise Propagation Prediction



- LMS Virtual Lab results highly oscillatory: 15dB jumps between neighbouring frequencies
- Lighthill's acoustic analogy provides upper and lower bounds on noise propagation results
- Level of background noise at low frequency comparable with experimental noise
- Microphone 5 has SPL higher by $O(20\text{dB})$ than surrounding microphone location, probably located in exit stream
- Variation of up to 3dB between microphones over the frequency space using Virtual Lab. Up to 15dB variation in experimental results (excluding Mic 5).

Conclusions



- CFD method to calculate aero acoustic noise based on LES methods has been successfully employed using OpenFOAM
- LES results showed good agreement with experimental data. Mean error in SPL was 3.9dB
- LES solutions can be used to perform SPL calculations to identify high SPL regions and compare alternative duct designs
- Two methods were compared to predict noise propagation based on acoustic sources from LES solutions
- The MDDBEM in LMS Virtual Lab was the more accurate method and showed relatively good agreement in terms of trends
- The Ffowcs William-Hawkings method is limited since no reflection, deflection or transmission is considered. It does provide upper and lower bounds which could be employed for engineering design purposes
- Further work is required in this area to provide more accurate solutions

Acknowledgments



The following should be thanked for their effort in producing this piece of research

Tayeb Zegeur

Neil Beloe



Francisco Campos

Andrew Jackson

Eugene de Villiers

