TU-Delft/3DS Workshop on PowerFLOW simulations of aircraft noise

Direct CFD/CAA simulation of acoustic liners

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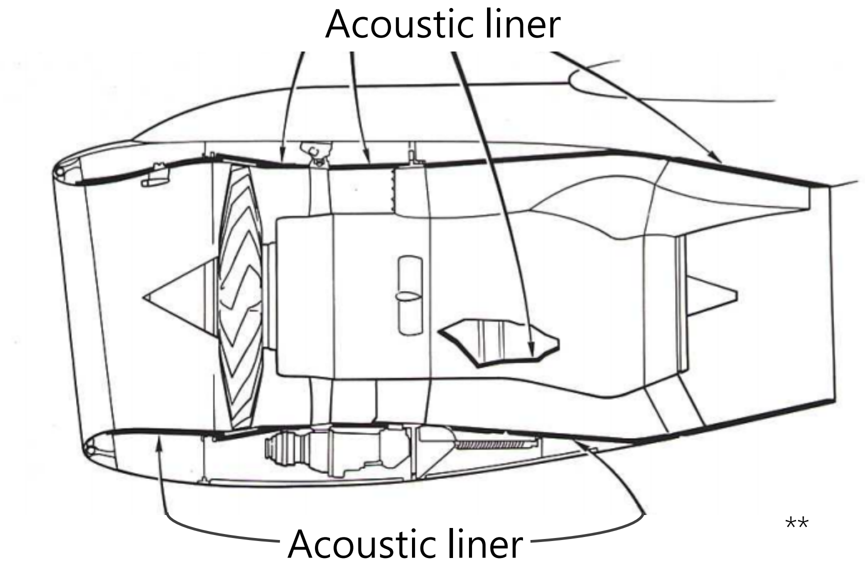
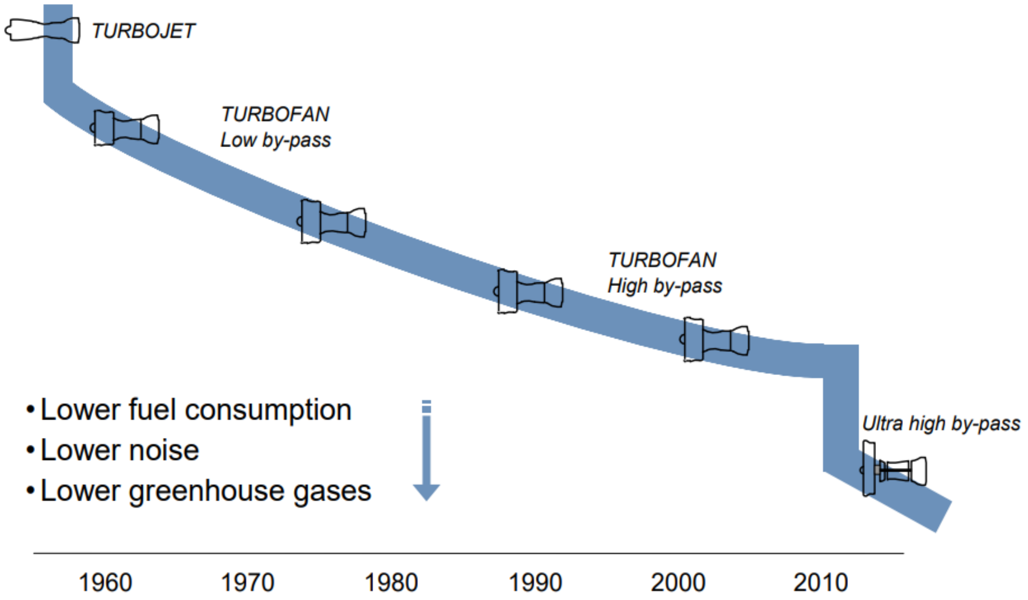


**Rolls Royce, plc. *The jet engine*. John Wiley & Sons, 2015.

Introduction



[1] Collaborative Research on the Ultra High Bypass Ratio Engine Cycle to Reduce Noise, Emissions and Fuel Consumption – https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080047444.pdf

Introduction

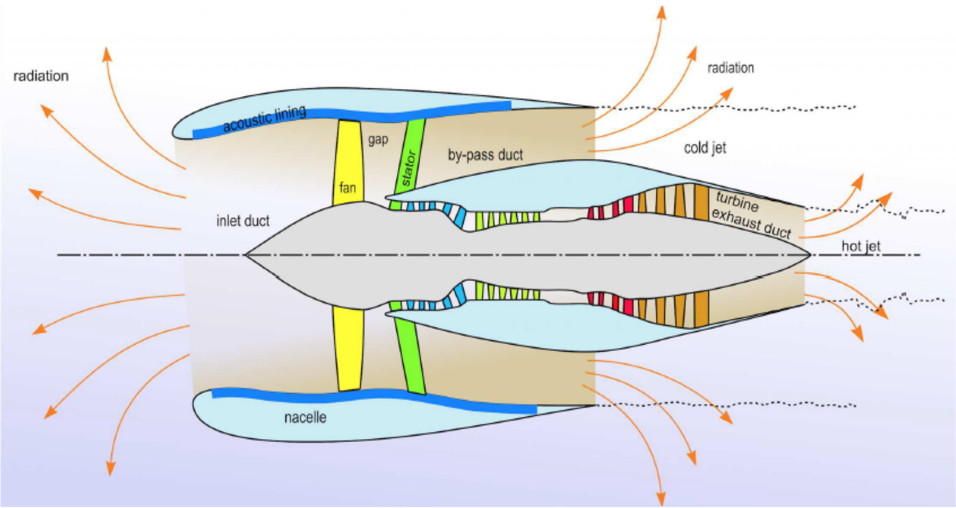
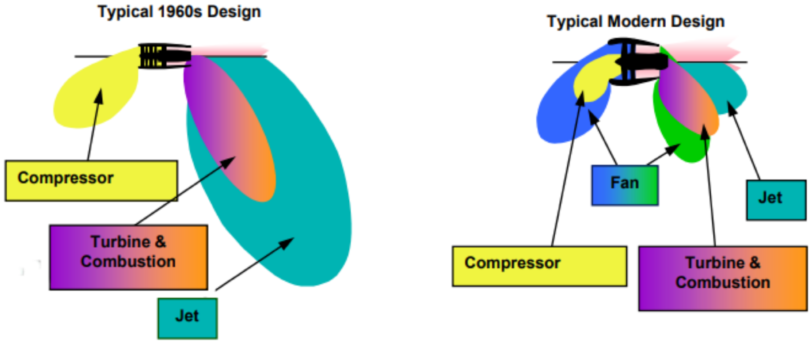


Illustration of modern turbofan engine [2].

- In modern high bypass ratio turbofan engines, fan noise is a dominant source.
- Generally, surface treatment devices known as **acoustic liners** are used to suppress the fan noise.



Noise sources in low (left) and high bypass ratio (right) engines [3].

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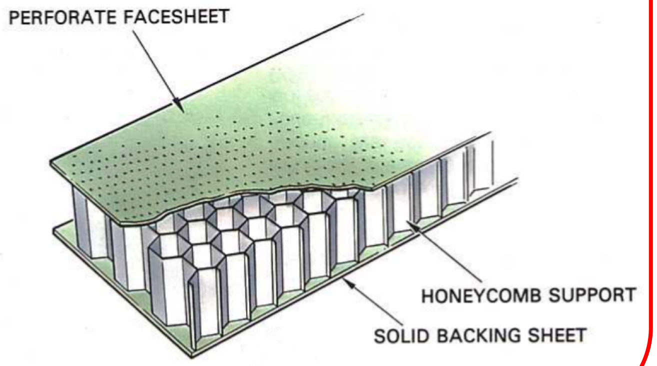
[2] S. W. Rienstra and A. Hirschberg. An Introduction to Acoustics. Technical report, Technische Universiteit Eindhoven, 2012. revised and updated version of IWDE 92-06, http://www.win.tue.nl/ sjoerdr/papers/boek.pdf.
[3] https://www.win.tue.nl/ceas-asc/Workshop15/CEAS-ASC_XNoise-EV_K1_Kempton.pdf

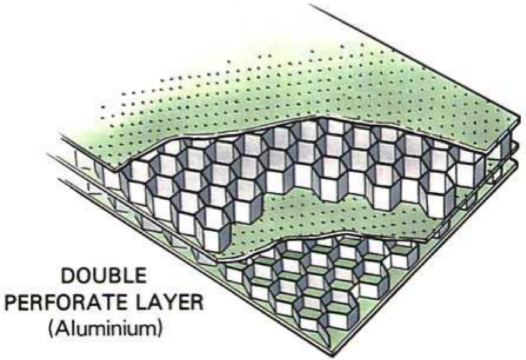
Introduction

- Based on the effective frequency range of the noise suppression, liners are classified as:

Single degree of freedom (SDOF)*



Double degree of freedom (DDOF)*



Bulk Absorbing material

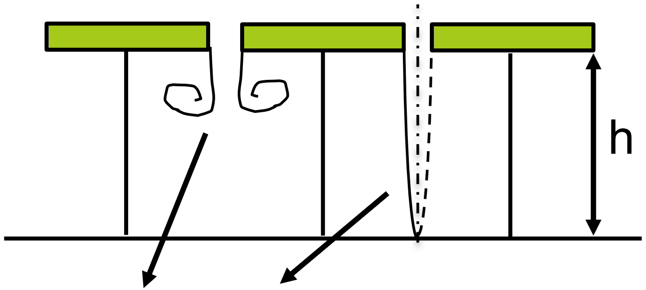
Ceramic foam

*[4] https://www.win.tue.nl/ceas-asc/Workshop15/CEAS-ASC_XNoise-EV_K1_Kempton.pdf

Introduction

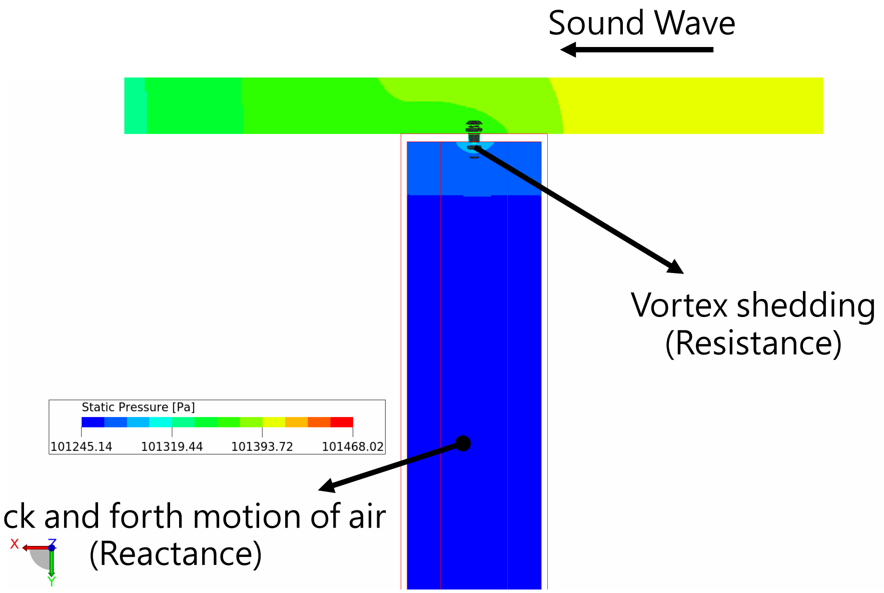
- A liner is characterised by its impedance (Z):

$$Z = \frac{\hat{p}}{\hat{\boldsymbol{v}} \cdot \boldsymbol{n}}$$



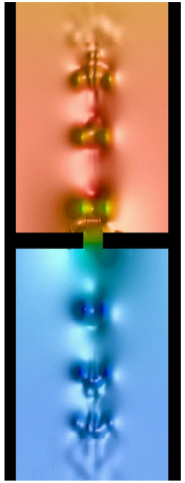
$$\frac{Z}{\rho c} = \underbrace{\frac{R}{\rho c}}_{\text{Resistance}} + i \underbrace{\frac{X}{\rho c}}_{\text{Reactance}} = \theta + i\chi$$

Illustration of sound attenuation by liner



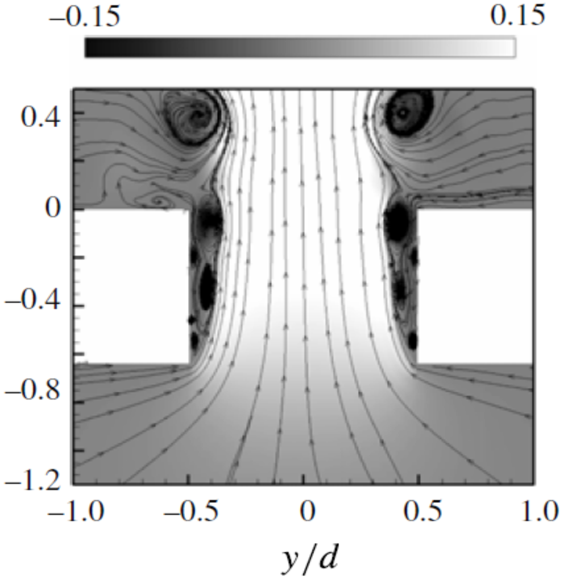
Introduction

- Previous DNS studies have highlighted some important aspects of the flow field influencing the attenuation of noise by liners.



Instantaneous density distribution showing vortex trains shed from a resonator opening [5].

Streamlines superimposed on the phase averaged velocity showing secondary vorticity along orifice walls [6].



[5] Tam, Christopher KW, et al. "A computational and experimental study of resonators in three dimensions." Journal of Sound and Vibration 329.24 (2010): 5164-5193.
[6] Zhang, Q., and Bodony, D. J., "Numerical investigation and modelling of acoustically excited flow through a circular orifice backed by a hexagonal cavity," Journal of Fluid Mechanics, Vol. 693, 2012, pp. 367–401

Introduction

- Although a good understanding of the physics associated with the orifice flow is available, a unified theory in understanding the various fluid dynamic aspects of the liners is still lacking.

Solution

Experiments

- Non-intrusive techniques such as PIV is best suited to capture the flow-field.
- However, measurements are very difficult because of the small dimensions of the geometry and limited optical access.

Simulations

- DNS
  - Exact flow-field captured.
  - Geometrical and flow (Re) simplifications required.
- LES
  - Geometrical simplifications are minimised and no flow (Re) simplifications are required.
  - Flow-field influenced by the turbulence model.

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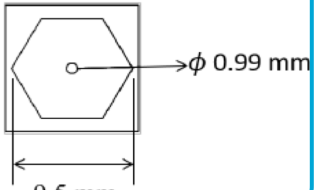
Computational Setup

- Geometrical Models:

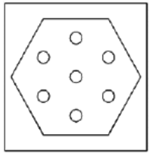
- Config.1
  - Identical to the one studied by Zhang et al [6].
  - Porosity: 0.99%
  - Facesheet thickness: 0.64 mm

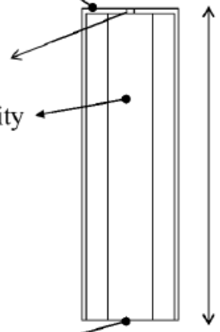
Top View



- Config.2
  - Porosity: 6.89%
  - Facesheet thickness: 0.64mm

Top View

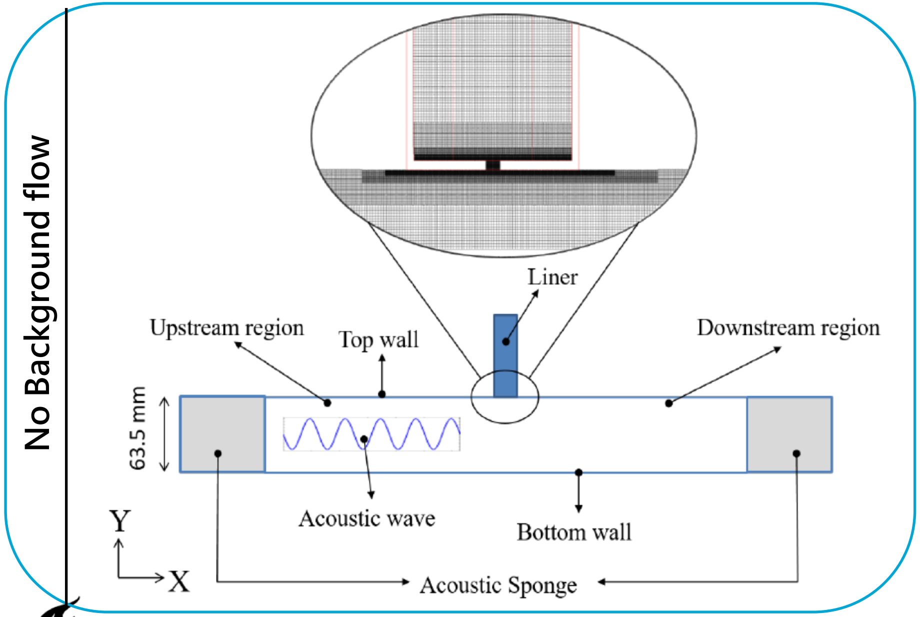


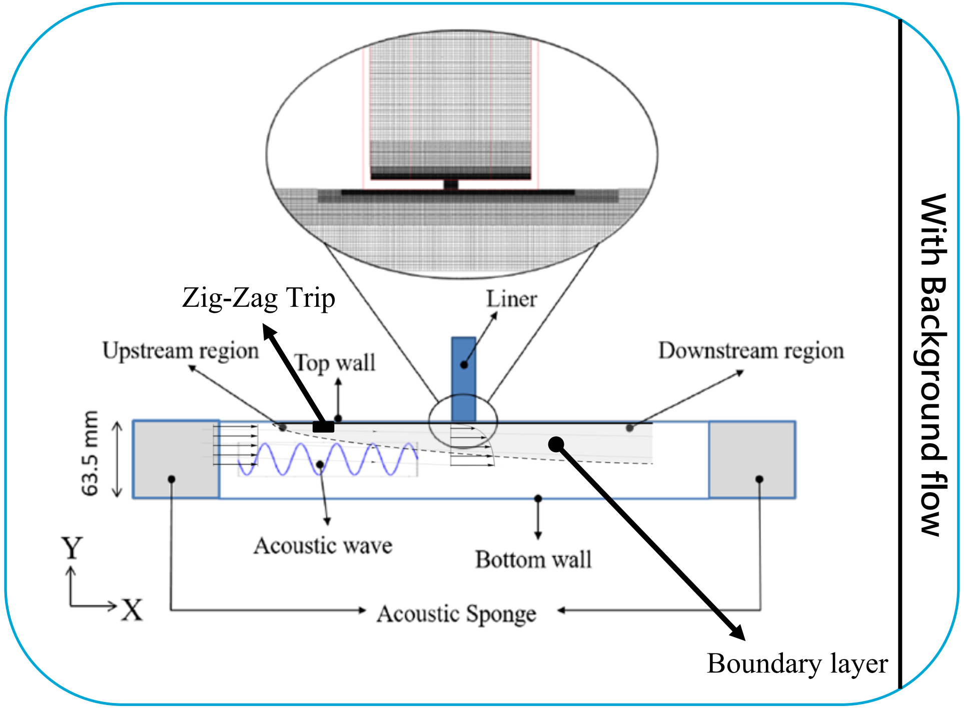


[6] Zhang, Q., and Bodony, D. J., "Numerical investigation and modelling of acoustically excited flow through a circular orifice backed by a hexagonal cavity," Journal of Fluid Mechanics, Vol. 693, 2012, pp. 367–401

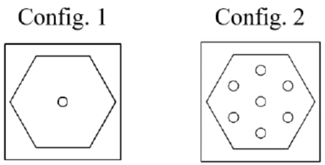
Computational Setup

- Computational Domain
  - 20 cycles/wavelengths of a plane wave initialised in the upstream region.





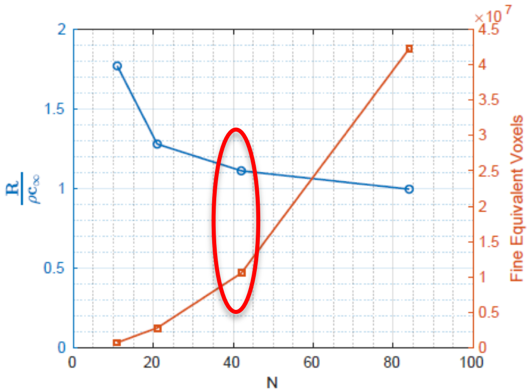
Results – No Background Flow

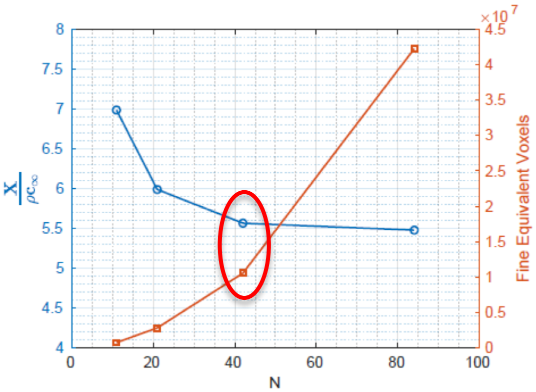


- Grid refinement study
  - **Config1.** at **SPL = 130 dB** and frequency, **f = 2 kHz**.

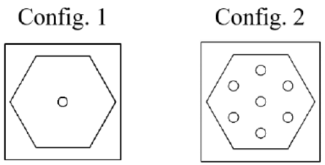
Grid	Smallest Voxel	N (voxels)	FEV (voxels)	Total CPU-hours: Processor
Coarse	0.093 mm	11 voxels	0.723 million	13.07: Xeon X5680 3.3 GHz
Medium	0.046 mm	21 voxels	2.8 million	112.06: Xeon E5-2690 2.9 GHz
Fine	0.023 mm	42 voxels	10.538 million	466.93: Xeon E5-2697 2.6 GHz
Very Fine	0.011 mm	84 voxels	42.282 million	4632: Xeon X5680 3.3 GHz

- N – number of voxels per orifice diameter.
- FEV – Fine equivalent voxels

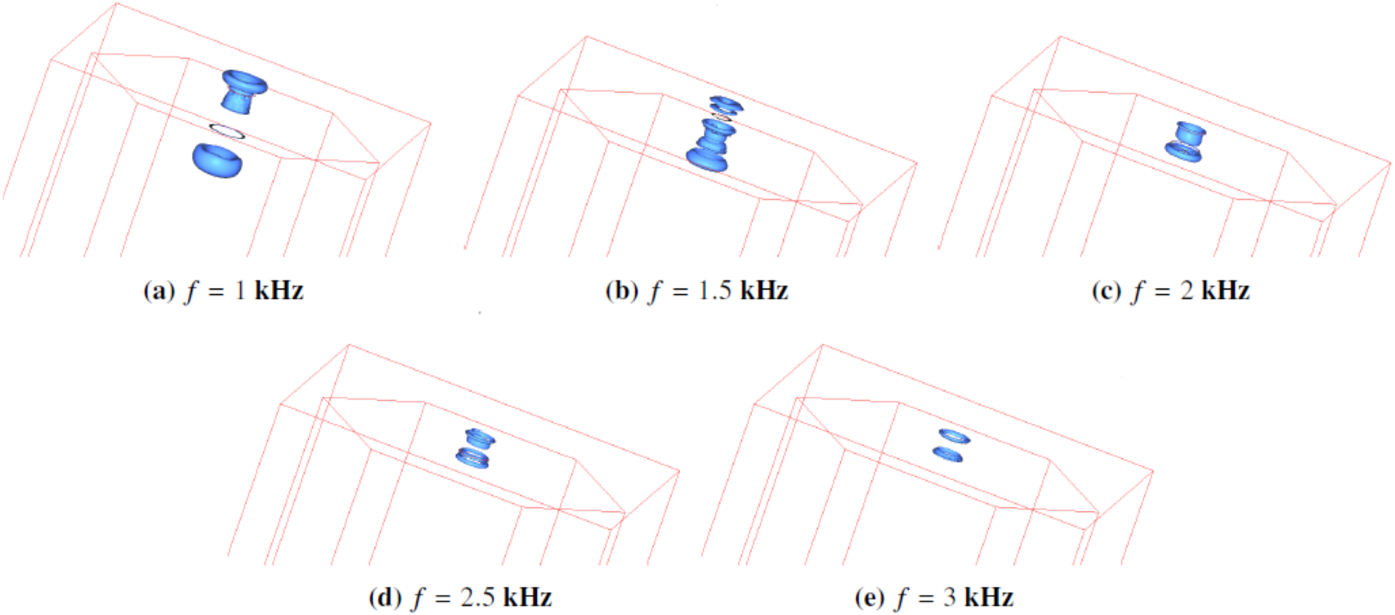




Results – No Background Flow

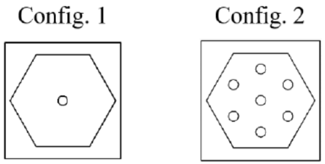


- **Config.1** with incident sound waves at **SPL = 130 dB**.

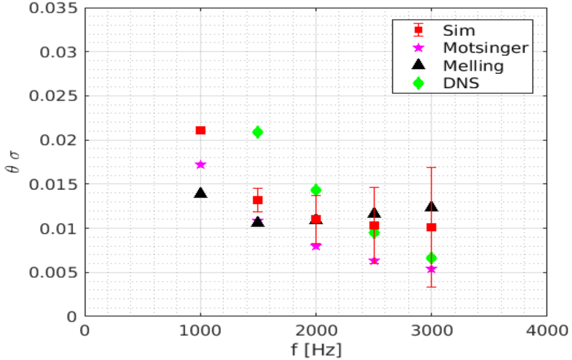


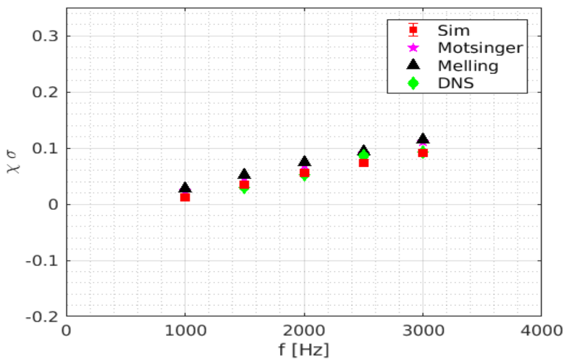
λ_2 iso-surfaces of the sound induced flow-field at different frequencies (f) of the incident sound.

Results – No Background Flow



- **Config.1** with incident sound waves at **SPL = 130 dB**.
  - Impedance computed using the in-situ technique [14].

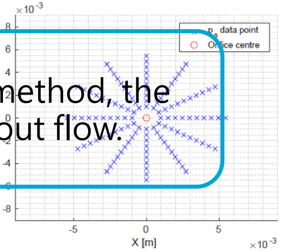




Comparison of the computed impedance with DNS results [11] and analytical models.

Results indicate that using the LBM-VLES approach in conjunction with the in-situ method, the impedance of the acoustic liner is successfully predicted for grazing sound without flow.

- The impedance value plotted above is averaged over 120 points distributed around the orifice.



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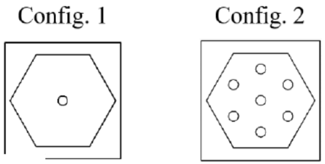
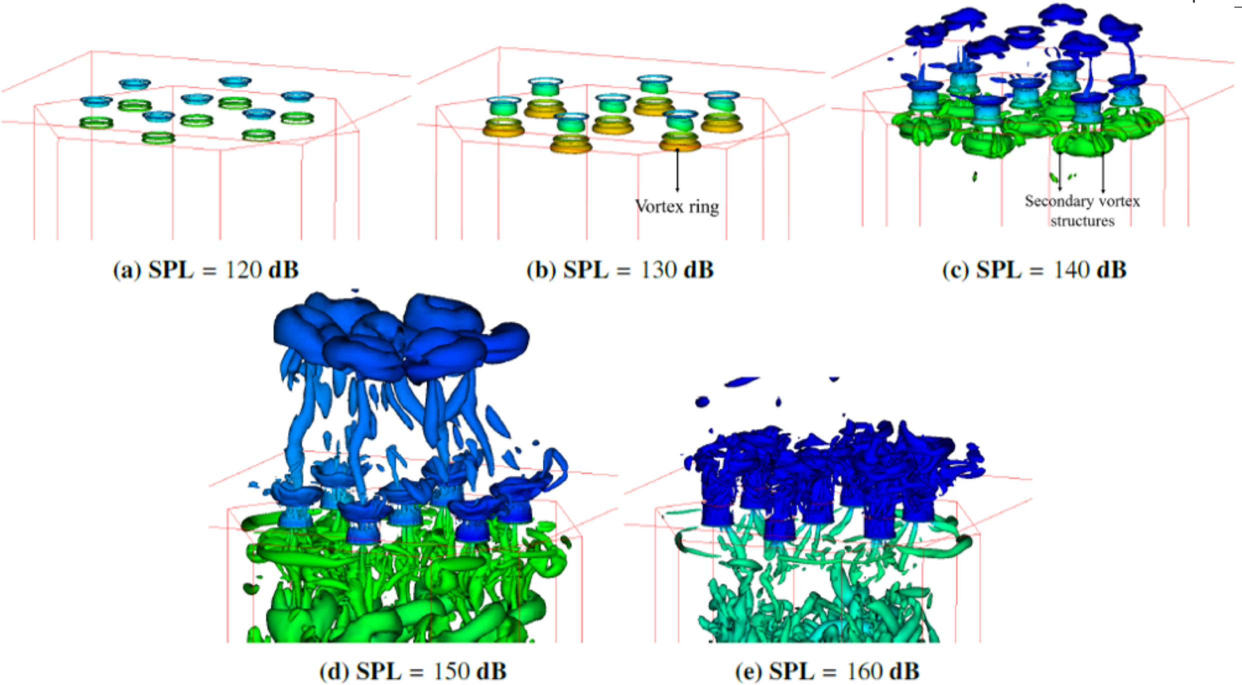
Results – No Background Flow



- **Config.2** with incident sound waves at frequency, **f = 2 kHz**.



λ_2 iso-surfaces of the sound induced flow-field

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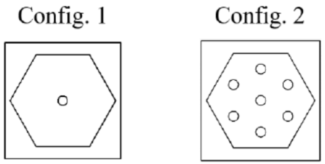
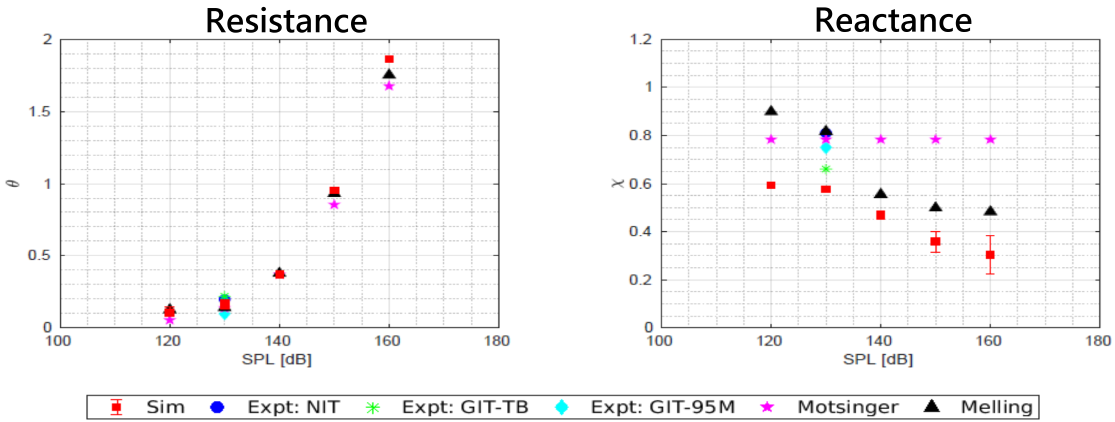
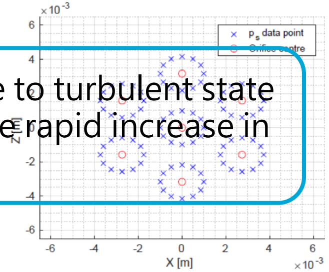
Results – No Background Flow



- **Config.** 2 with incident sound waves at frequency, **f = 2 kHz**.



Comparison of the predicted impedance with analytical models by changing the SPL of the incident sound.



With a change in SPL, the transition of the shed vortex ring from a laminar state to turbulent state with the occurrence of secondary structures is observed. This coincides with the rapid increase in resistance and a decrease in reactance.

- The impedance value plotted above is averaged over 12 points distributed around the each of the orifice.

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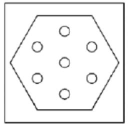
Results – With Background Flow



- Mean flow-field in the computational domain.

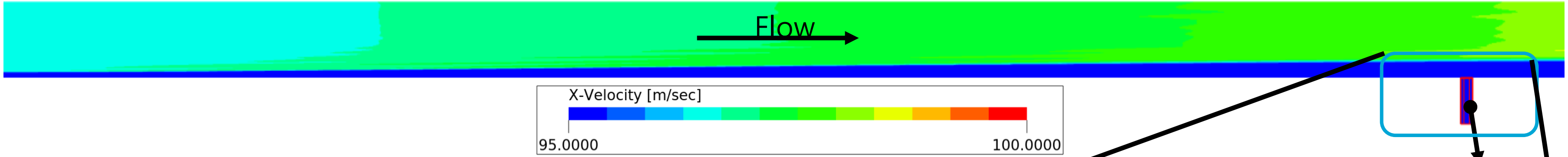
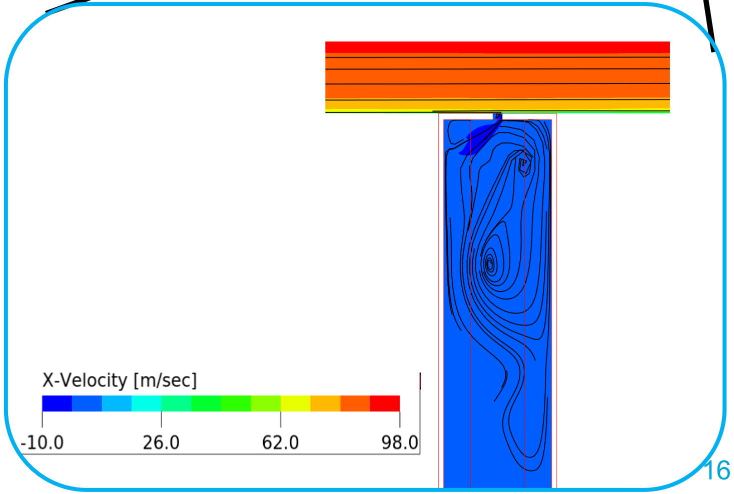
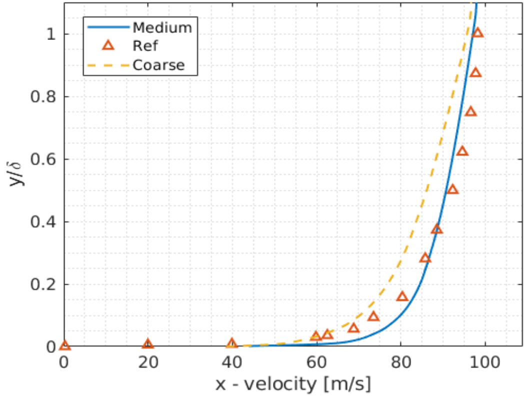


Illustration of the boundary layer development in the computational domain.



Velocity profile upstream of the liner



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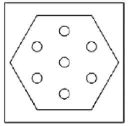
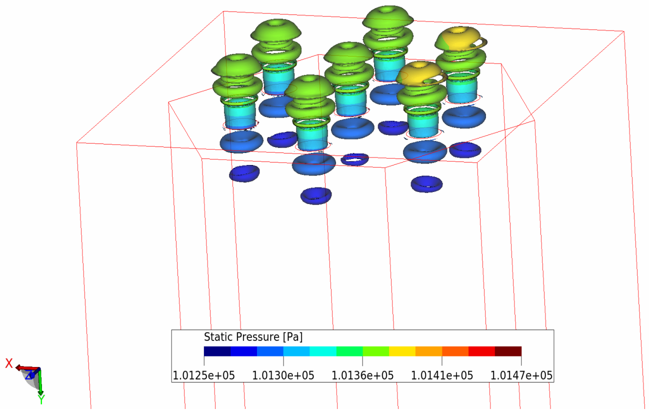
Results – With Background Flow

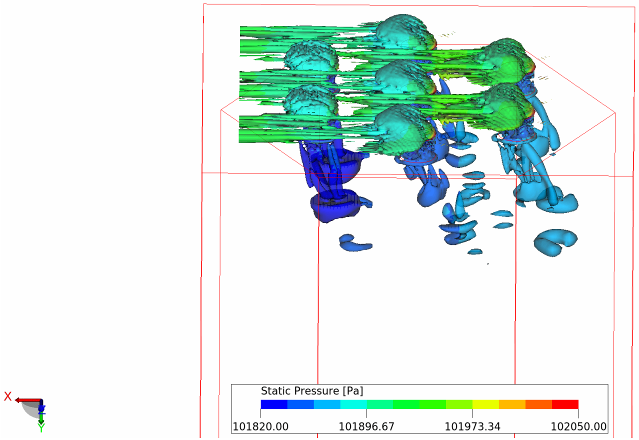
Config. 2



- Comparison of the λ_2 iso-surfaces with and without background flow at **SPL = 130 dB** and **f = 1.8 kHz.**

No Background flow

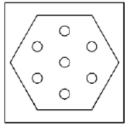




With Background flow

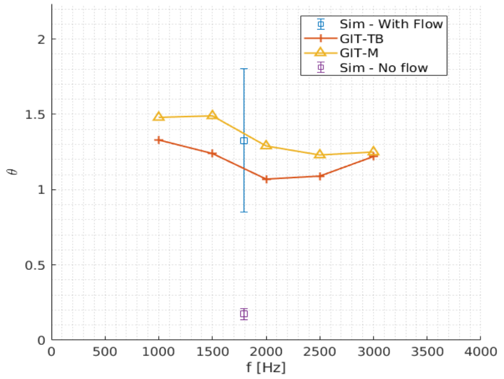
Results – With Background Flow

Config. 2

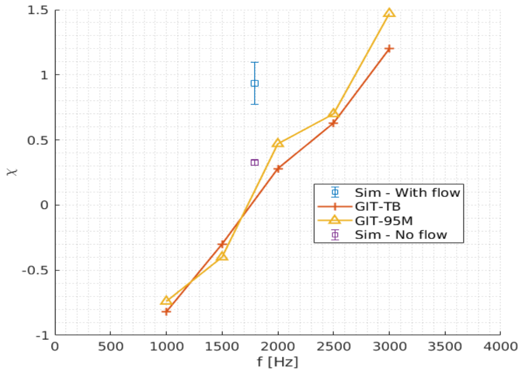


- Preliminary results (coarse sim) of the predicted impedance with flow in comparison to expts (GIT-TB and GIT-M).

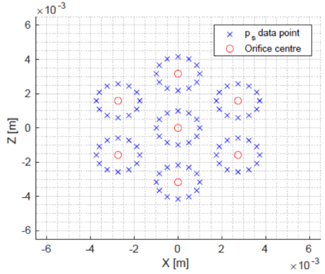
Resistance



Reactance



- The impedance value plotted above is averaged over 12 points distributed around the each of the orifice.



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Looking Ahead

- Some of the key research interests in this topic include:
  - Qualitative and quantitative understanding of the flow-field in and around the liners.
  - Understanding if impedance of the liners is dependent on the direction of the incident waves relative to mean flow.

Thank you for attention!
Questions ?

Results – No Background Flow

- Test matrix of the simulations:

SPL [dB]	Frequency [kHz]				
	1	1.5	2	2.5	3
120			Config. 2		
130	Config. 1	Config. 1	Config. 1 Config. 2	Config. 1	Config. 1
140			Config. 2		
150			Config. 2		
160			Config. 2