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Multiphysics Simulation Conference

Mesh adaptation based on Taylor micro-scale for aeroacoustics simulation

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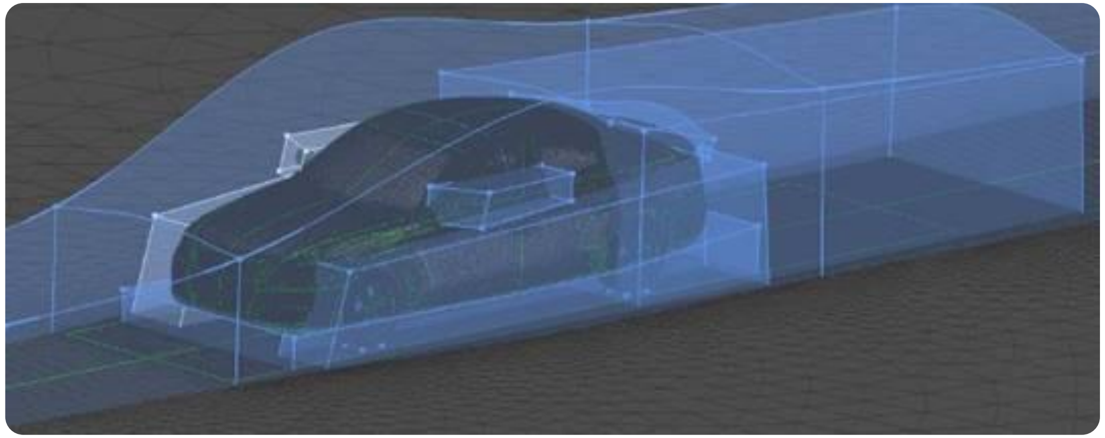
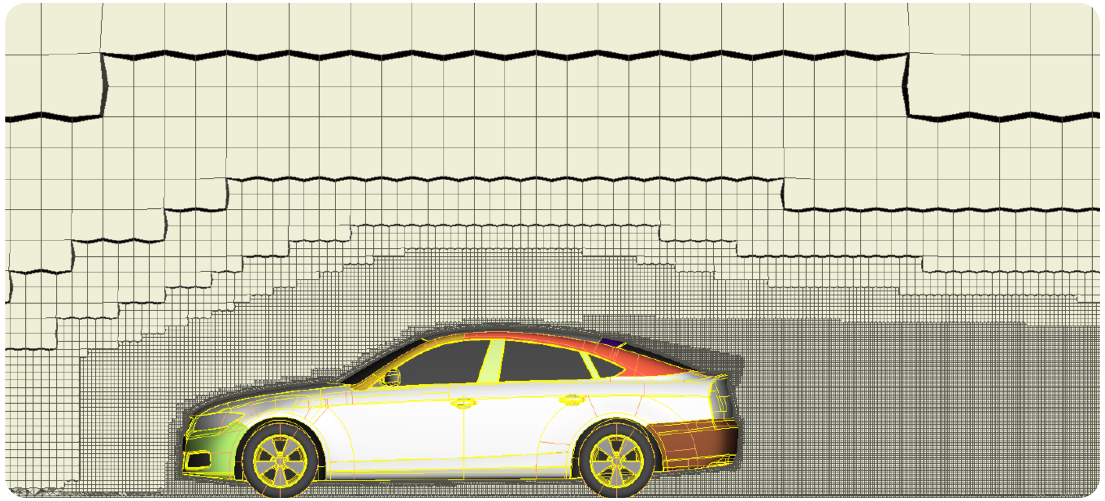
How to Setup Your Aero-acoustic model?

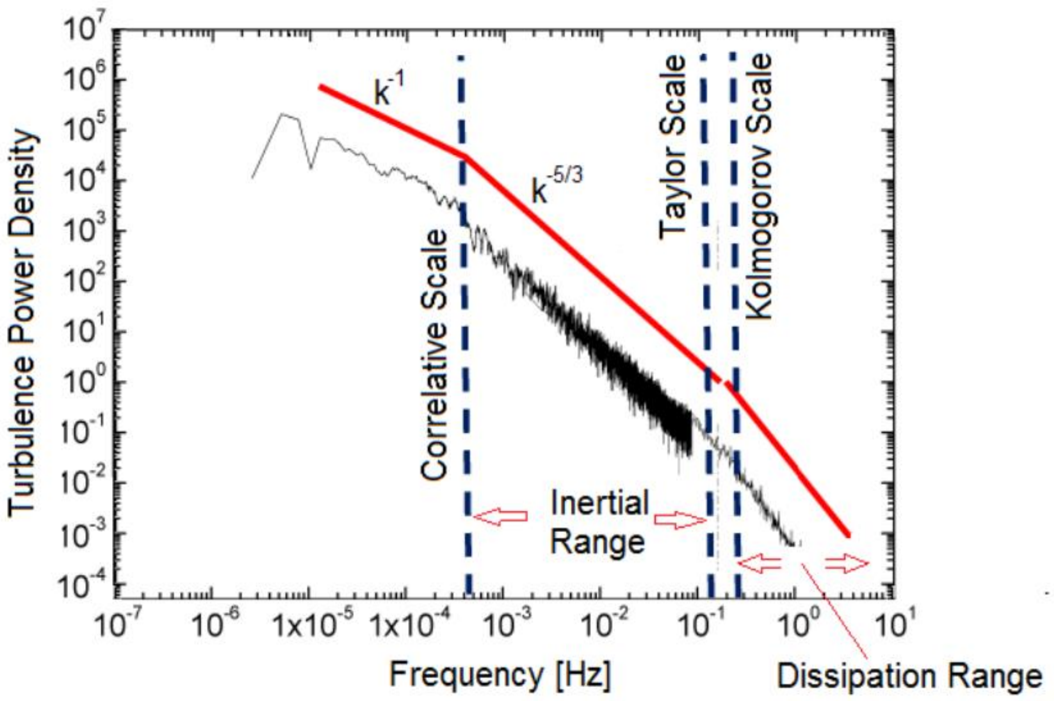




- Hard to automate with best-in-class tools
- Very manual processes for model clean-up, setup & meshing
  - Wing mirrors
  - Undercar
  - Radiator
  - Rear
  - Wheels
  - …
- Manual refinement doesn't match actual refinement needs well
- Requires expertise, knowledge & time

What is Taylor micro scale?

Taylor micro scale



Turbulence spectrum

Turbulence is one of the most complex phenomena in fluid dynamics which is characterized by chaotic changes in pressure and velocity. This turbulence phenomena, Based on Kolmogorov theory can be splitted in 3 kind of scale :

- **Integral scale**: this scale contains large eddies generated by mean flow and contains most of the energy.
- **Inertial subrange**: This scale transfer energy from integral scale to dissipation scale
- **Dissipation range**: this scale finally dissipate energy due to viscous effect

Taylor microscale is located in the inertial subrange where viscosity of the fluid started to have a significant effect on turbulent eddies.

This scale does not describe all of turbulence scale in this inertial subrange but give a good overview about which size to set up so that most of the turbulence spectrum is efficiently captured.

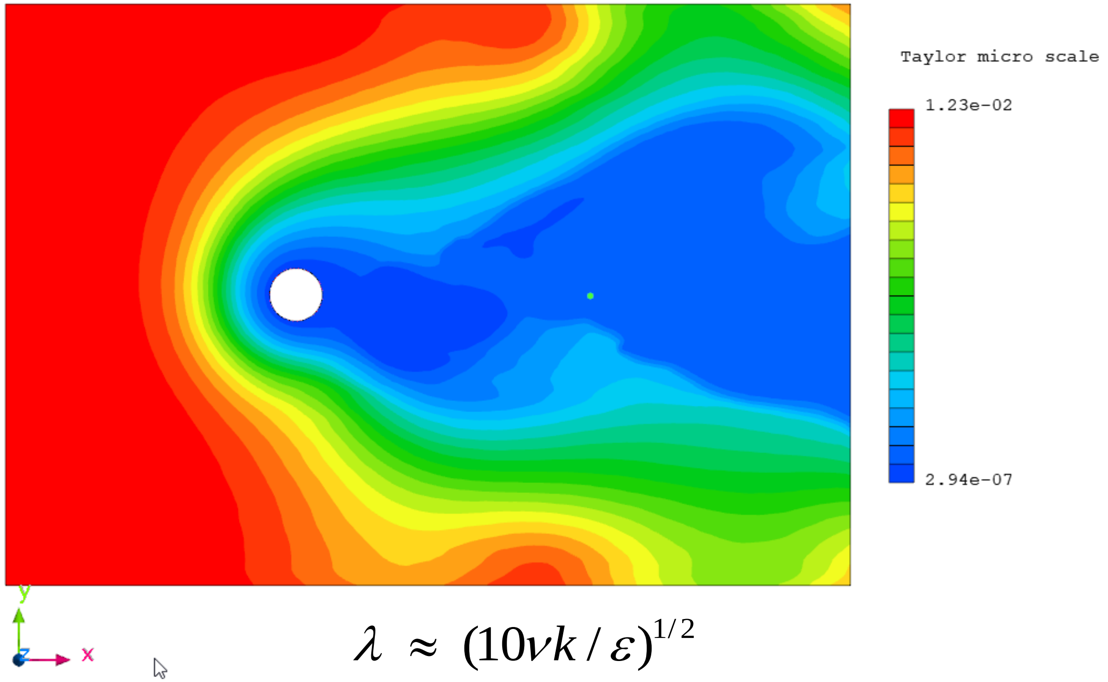
Mesh adaptivity

Purpose:
- refine the mesh based on Taylor microscale using steady state calculation

Methodology:
- Compute RANS simulation
- Extract Taylor micro scale
- Define refinement based on user defined index
- Compute DES/LES simulation based on this adapted mesh to compute aero-acoustic sources
- Propagate it using hybrid aeroacoustic approach based on the finite element method

Global approach

- TMS field value



$$\lambda \approx (10 \nu k / \varepsilon)^{1/2}$$

Mesh Metric

Proposed criteria

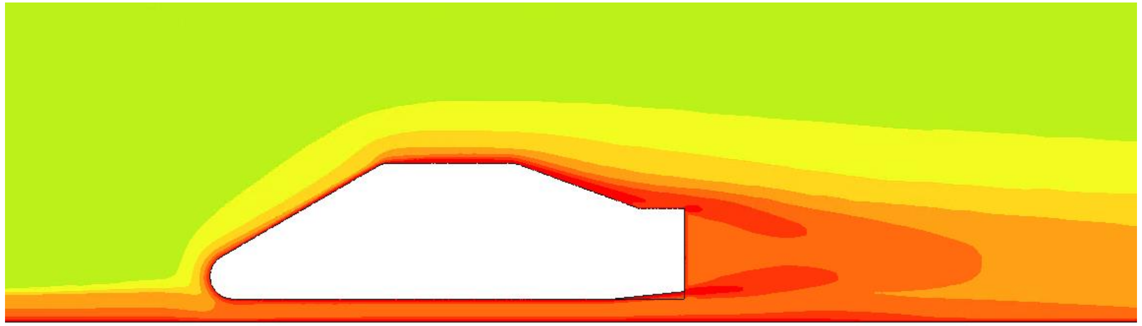
Evaluation parameter used to define mesh refinement in space is defined as follow:

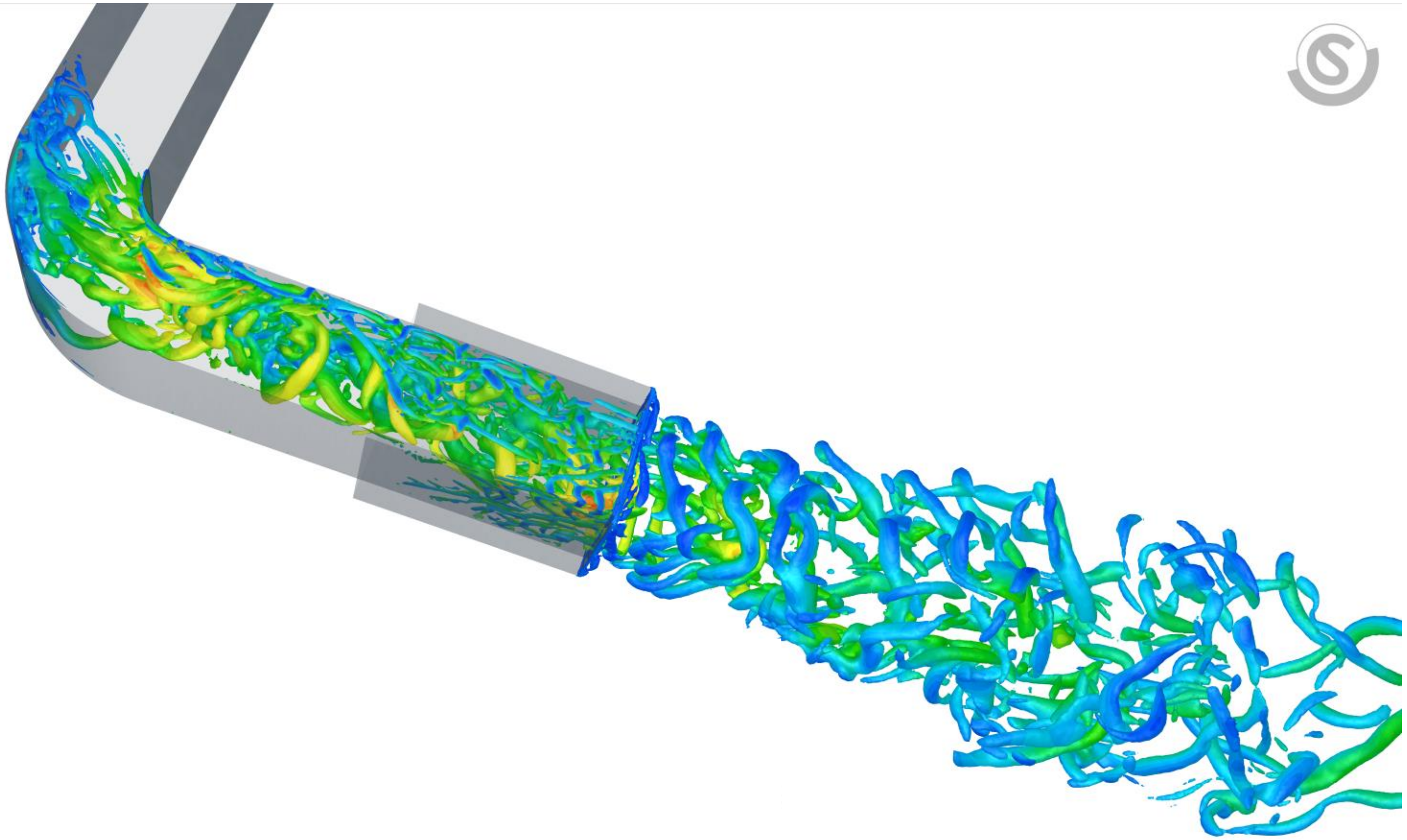
$$\Phi = \frac{1}{TMS^{\alpha}}$$

TMS: Taylor microscale value

To define such criteria, we use scripting capability provided by scFLOW from Hexagon Cradle solution

Evaluation parameter field (log scale)





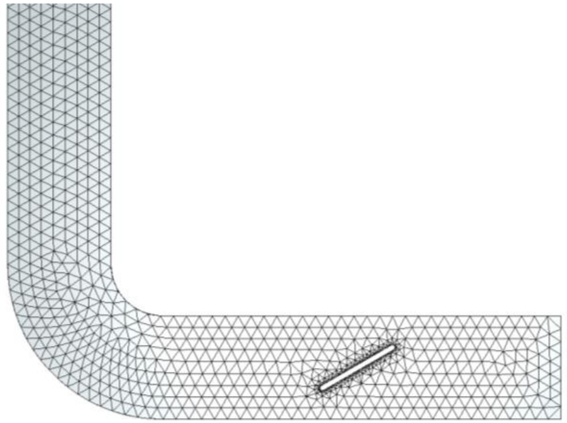
Application: HVAC system

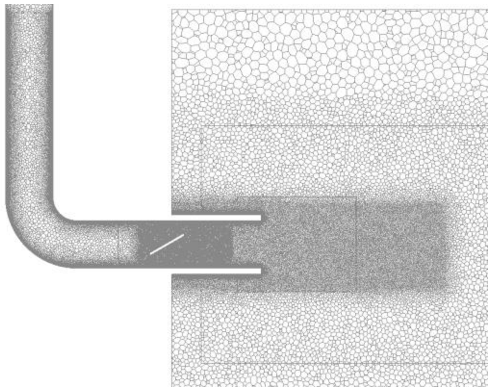
Case description

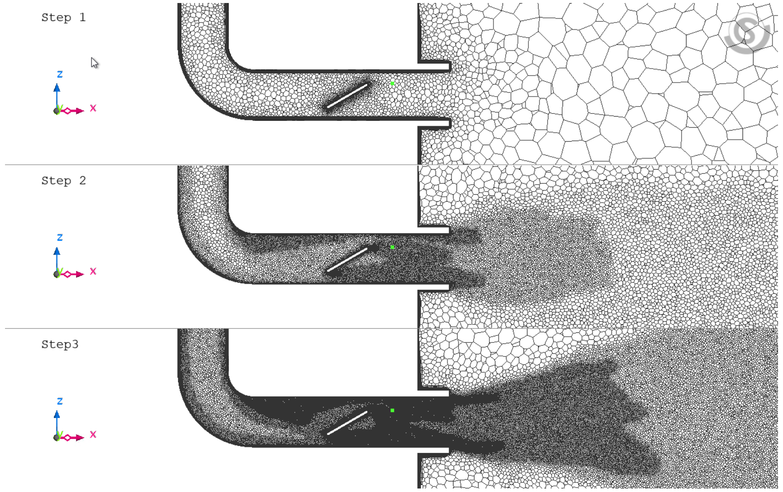
- The case used is a simplified HVAC duct that was first described in *AIAA 2008-2902**

- Two different CFD meshes will be created to showcase the effectiveness of the methodology:
  - One adapted mesh
  - One manually created mesh

- The indicators to compare will be:
  - Accuracy: the radiated power will be compared for both
  - Cost: the computational cost for the whole chain (CFD + source generation + acoustic simulation)







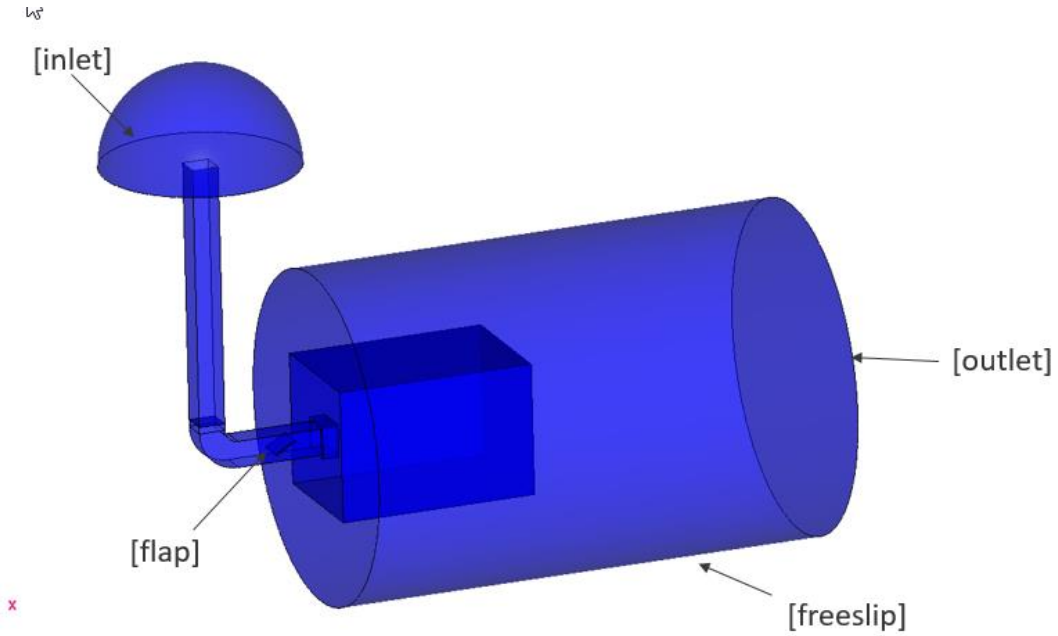
*Jäger et al, Numerical and Experimental Investigations of the Noise Generated by a Flap in a Simplified HVAC Duct, 14^{th} AIAA/CEAS Aeroacoustics Conference, 2008

First step

COMPUTE MESH ADAPTATION BASED ON TAYLOR MICRO SCALE

Geometry and boundary conditions

Steady state solution

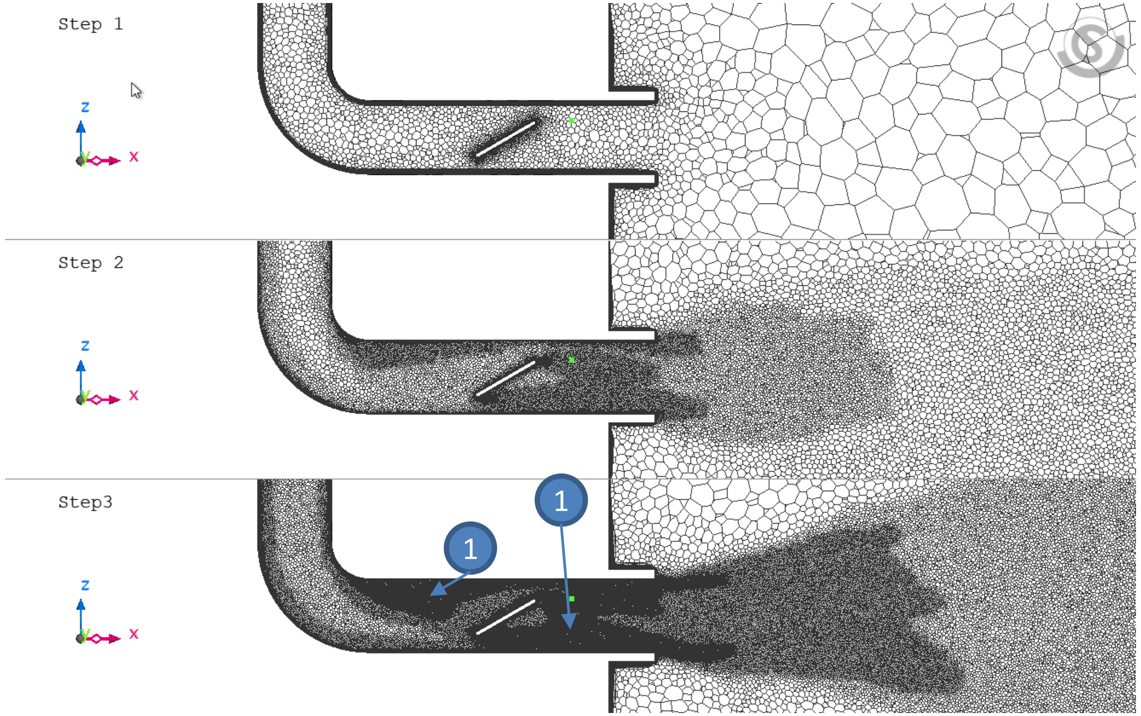


HVAC geometry

- Boundary conditions

Inlet	[inlet]	Velocity inlet	7.5 [m/s]
Outlet	**[outlet]**	Static pressure (Outflow)	0.0 [Pa]
Virtual wall	**[freeslip]**	Free slip	
[Undefined (Stress: All fluid boundary)]		No slip	

Mesh refinement for each step



Starting from a dummy mesh, this adaptation criteria show some promising key feature

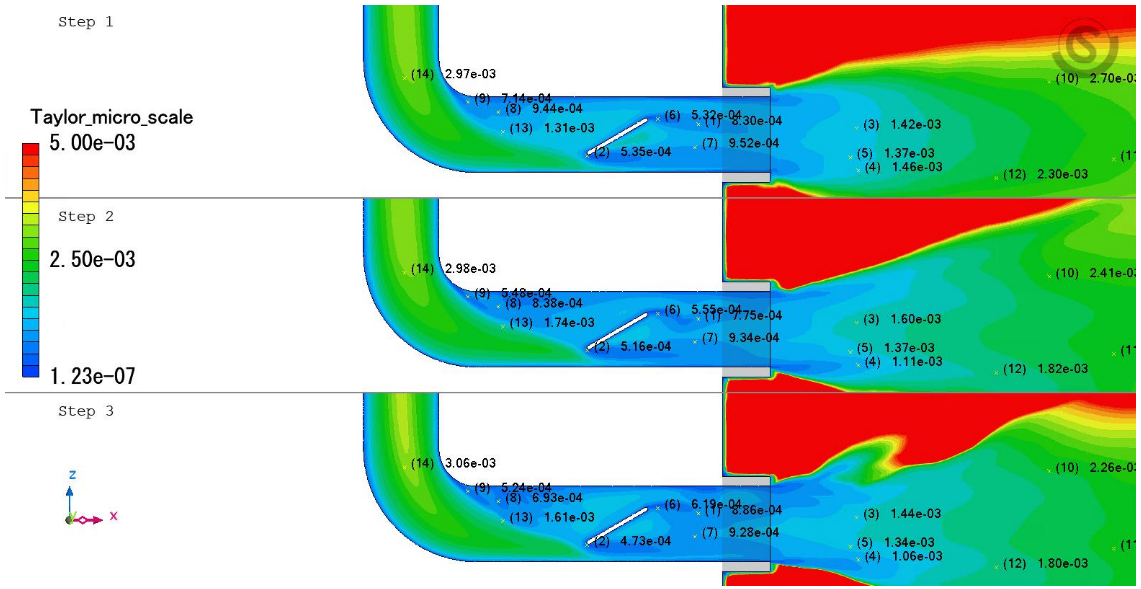
- No need for good pre-mesh refinement
- Manual wake refinement is not required

In addition, this criteria has following behavior:

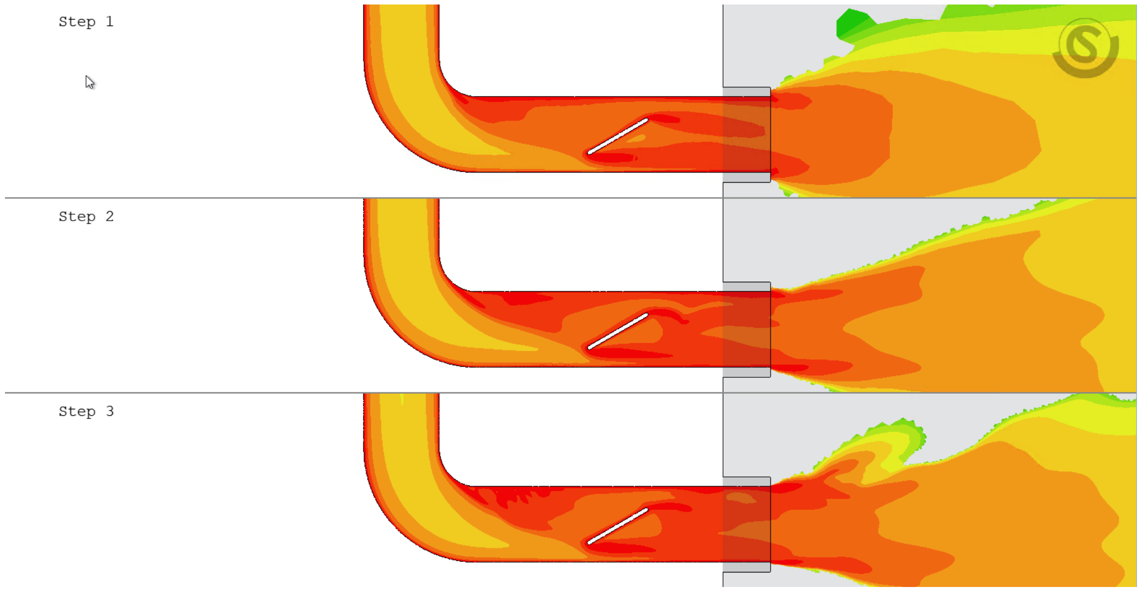
- Automatic refinement of boundary layer
- Detached boundary layer are detected and refined
- Wake behind flap

Mesh adaptation: evaluation parameter

Taylor micro scale field



Evaluation parameter for mesh adaptation in log scale

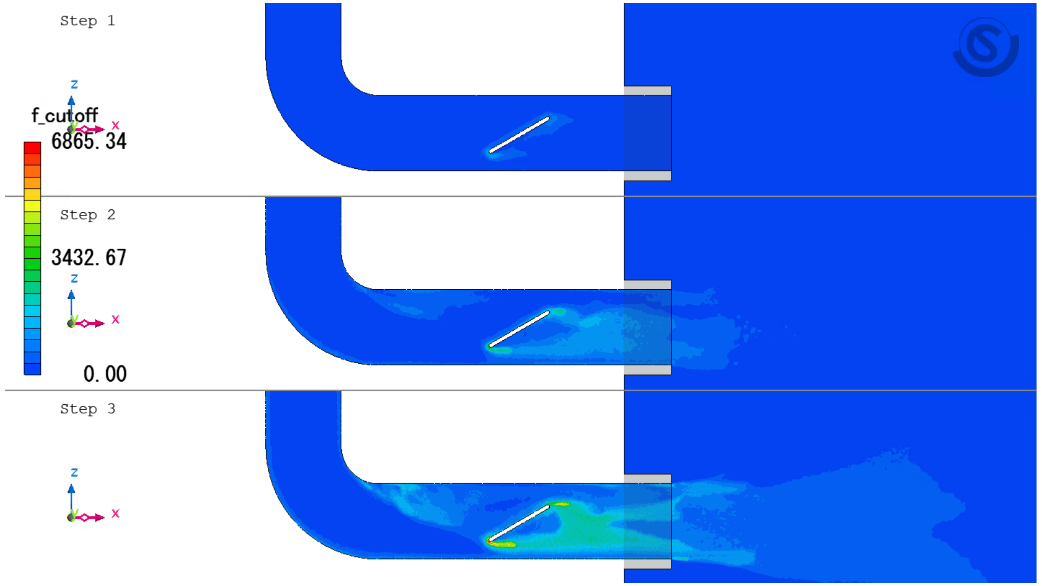


Surprisingly, Taylor micro scale field, on the left, does not show big difference between all 3 meshes, except on the shape of the wake.

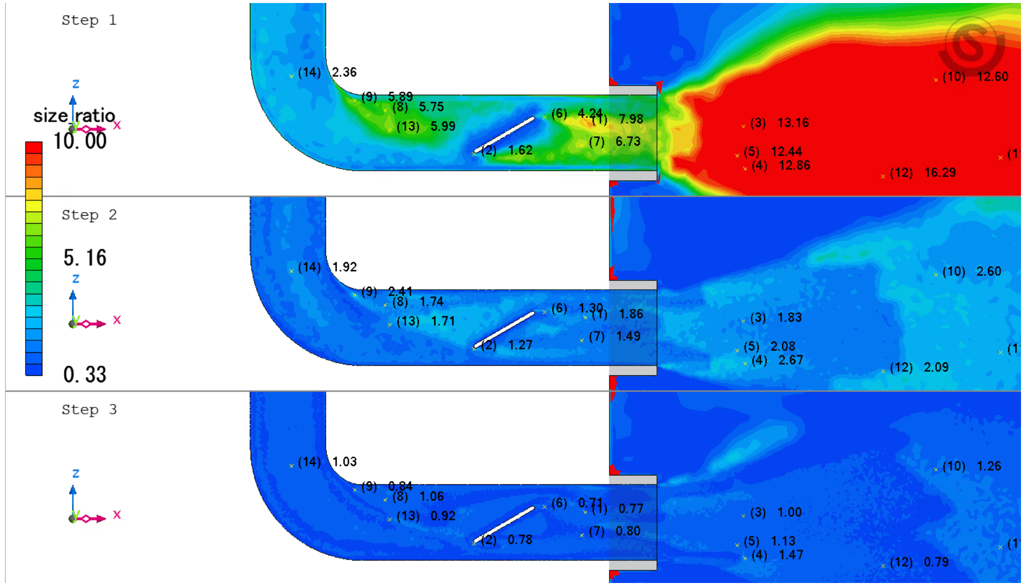
This is interesting so that initial mesh refinement does not have a big impact on final mesh

Aero and acoustic criteria

Cutoff frequency (acoustic criteria)



Size ratio (Turbulence criteria)

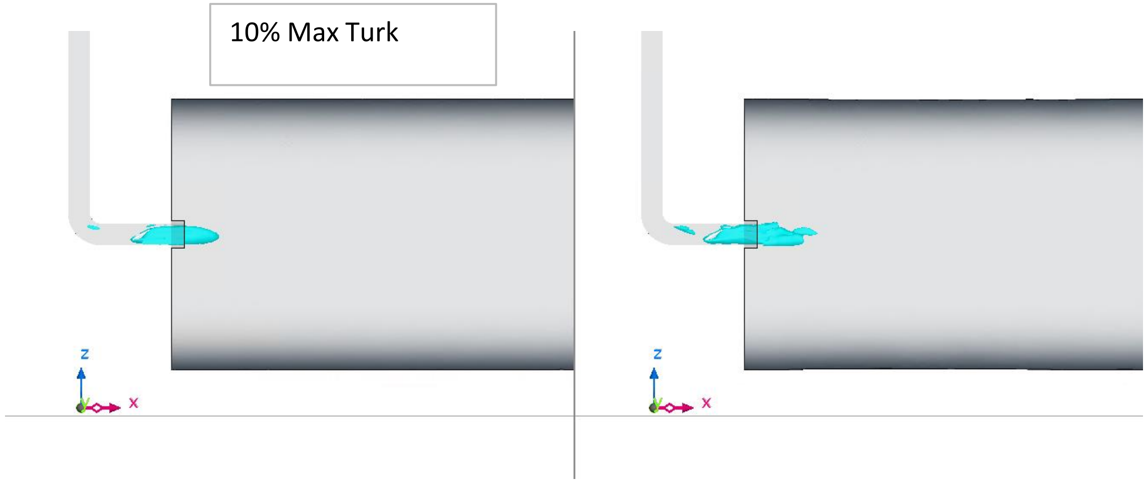


The cutoff frequency is an acoustic criterion that provides a good idea about the maximum frequency we can reach using the current mesh refinement. On the other hand, the size ratio is the ratio between mesh size and Taylor microscale values.
On the final mesh refinement, we observe that a size ratio around 1 starts to provide interesting cutoff frequency values more than 3000Hz

Integral value

Mesh convergence over adaptation

	Max Turk	Avr TURK	Max Freq	Size ratio	Avr Cutoff (Hz)
step1	21.71	5.73	2091	6.44	195.98
step2	37.76	7.38	4473	1.82	693
step3	37.49	6.52	8014	1.04	1154



Discussion

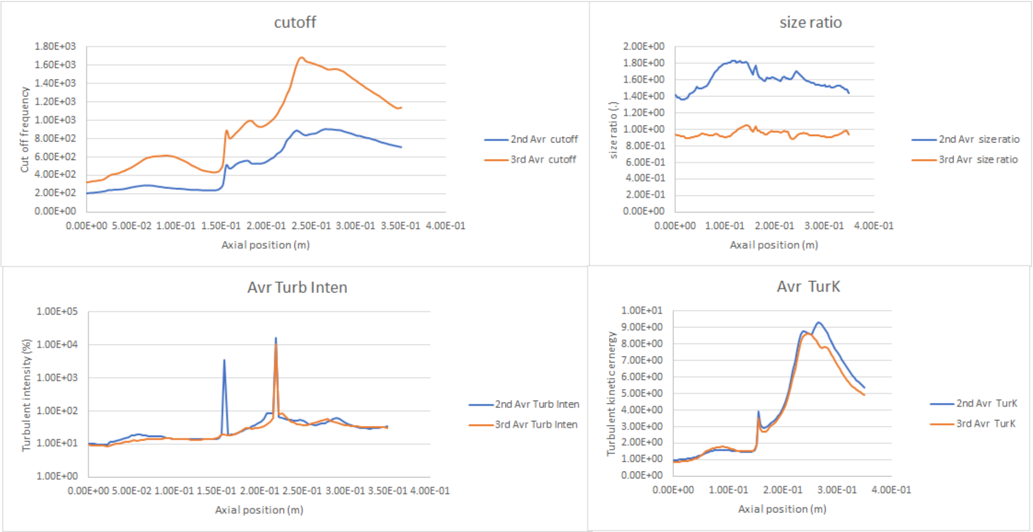
Average value are extracted within a volume defined by turbulent kinetic energy value higher than 10% of the maximum of TKE.

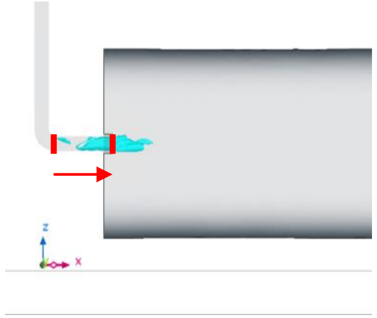
As expected average and maximum cutoff value increase due to the decrease of mesh size.

In terms of turbulence, average value are globally in the same range between 2nd and 3rd adaptation

Profile accross exhaust pipe

Integral profile over the exhaust





Discussion

Turbulence intensity and turbulent kinetic energy show very similar profile between 2nd and 3rd mesh.

As a result, mesh size decreasing cutoff value and size ratio display an expected offset

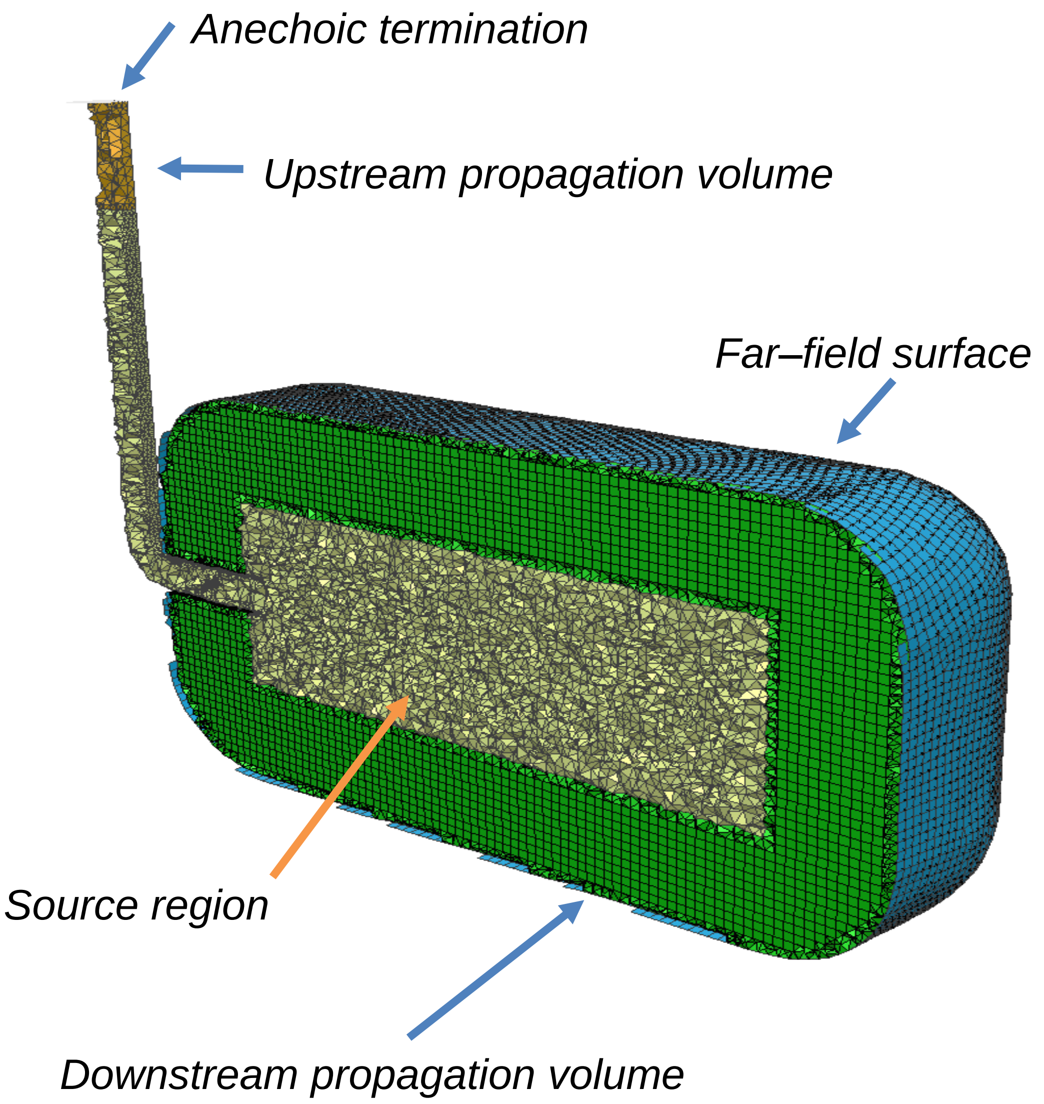
Acoustic model

- Source generation
  - A Lighthill analogy based on the finite element formulation is used for generating sources from the flow

$$\omega^2 \int_V N_a \rho dV - \int_V \frac{\partial N_a}{\partial x_i} c_0^2 \frac{\partial \rho}{\partial x_i} dV = \int_V \frac{\partial N_a}{\partial x_i} \frac{\partial \rho v_i v_j}{\partial x_j} dV + i\omega \oint_S N_a \rho v_i n_i dS$$

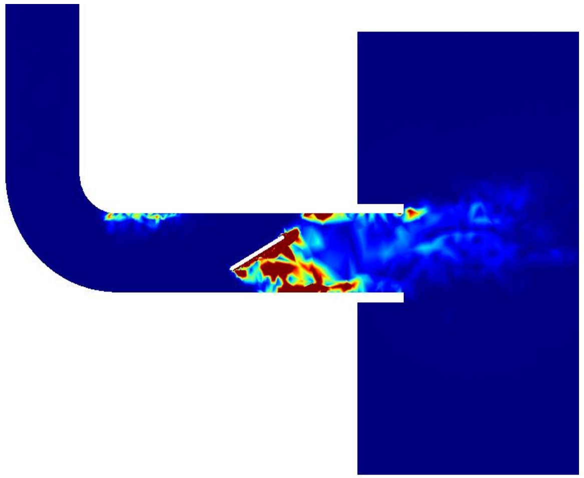
  - The sources are integrated onto the acoustic mesh

- Acoustic model
  - The acoustic model is built based on the CFD model
  - The output indicator is the radiated power in the far field surface
  - Solved by Actran

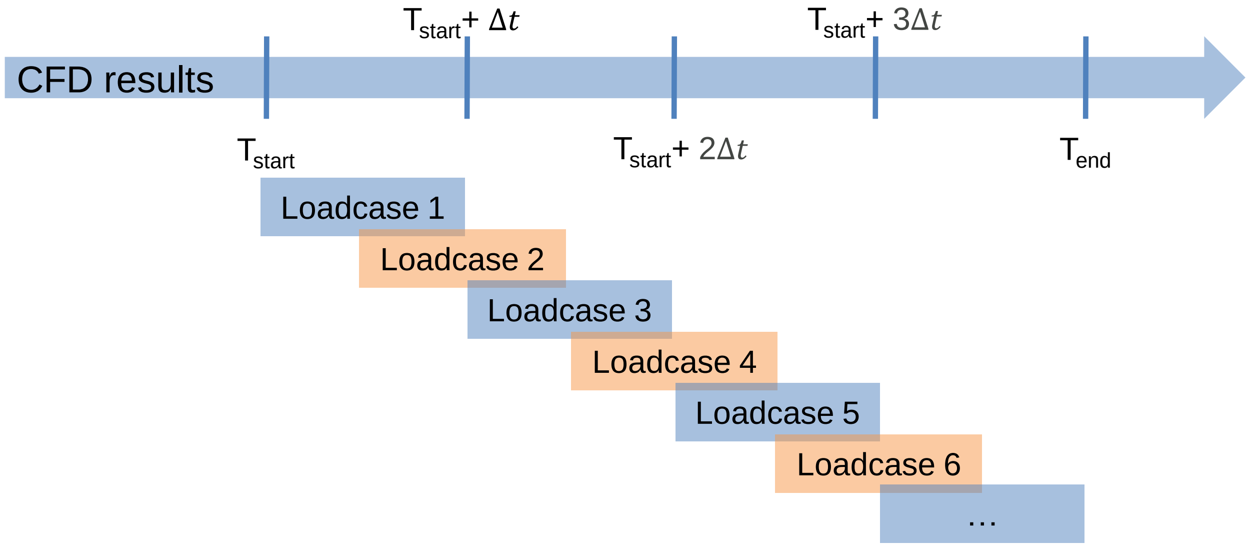


Source generation

- Aeroacoustic noise generated by turbulence which is a **stochastic process**
- In order to imitate this process, **the time signal is sampled into several time series** and a DFT is applied on each of them
- Such treatment aims at investigating the acoustic signals of the different time series and at reproducing experimental signal processing
- Properties of the Fourier Transform:
  - Frequency step : 20 Hz
  - Min frequency: 20 Hz
  - Max frequency: 2000 Hz
  - Overlap: 50%

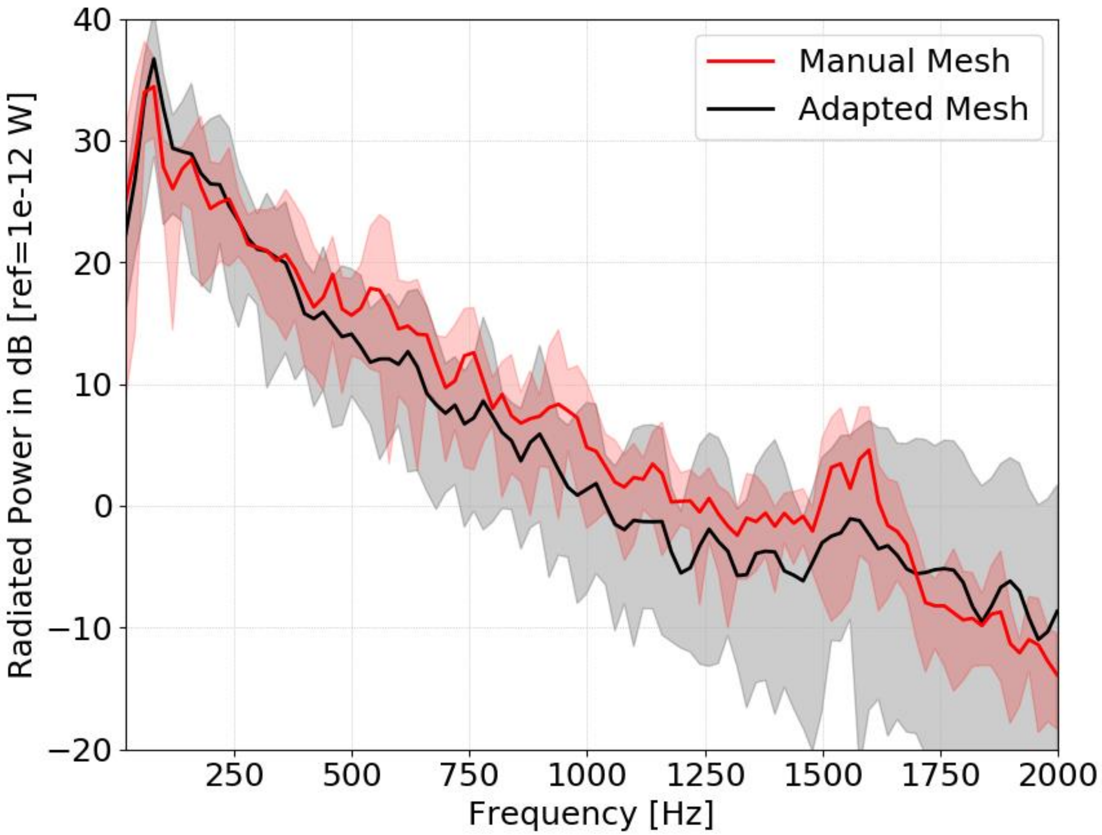


Lighthill volume density for the first loadcase



Results

- The two approaches provide similar results overall
- In the low-frequency range up to 500 Hz, no big differences are found
- From 500 Hz onwards, there is a small offset, but results remain consistent
- At 1500 Hz, there is a resonance due to the duct size, which is more pronounced for the manual mesh
- The differences in the envelopes are due to the smaller time range used in the manual mesh since the cost was much larger



Computational performance

- The table below shows the computational performance comparison between the two methods for the whole chain (CFD + source generation + acoustic propagation)

Task	Manual Mesh [CPU hours]	Adapted Mesh [CPU hours]
CFD Adaptation	-	56
CFD Settling	2	2
CFD **Acquisition**	16560	11350
Source Extraction	88	42
Acoustic Propagation	48	48

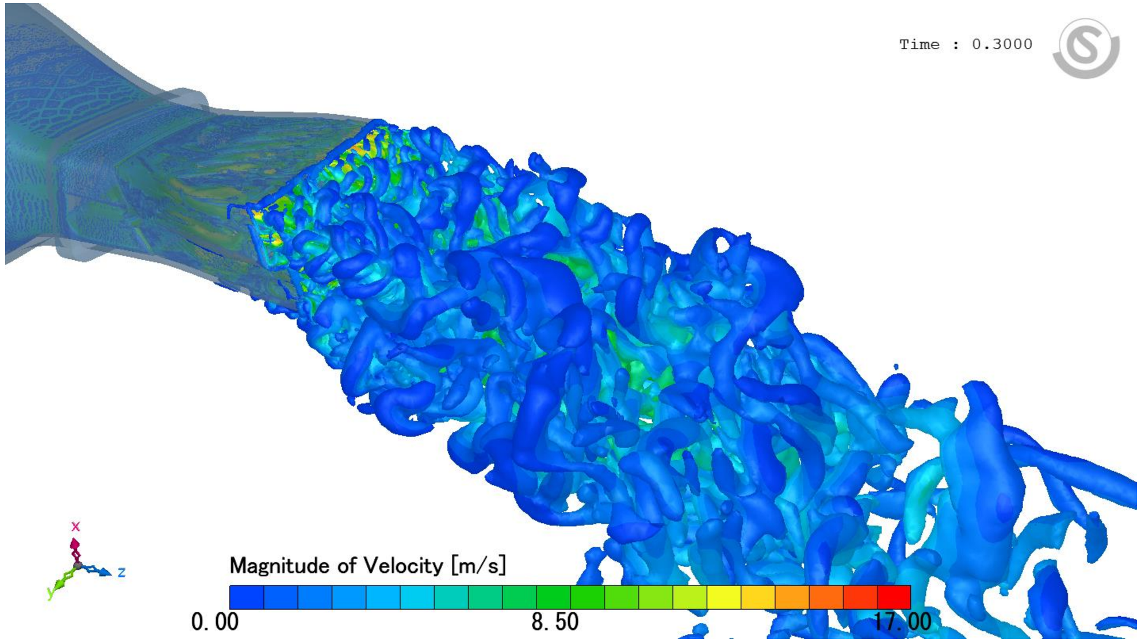
Application to an industrial case

Adaptive Mesh Refinement

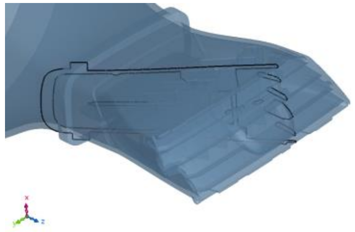
- The method was applied to an automotive HVAC duct from a well-known OEM
- A three-step adaptation process is performed where each mesh is refined further

		STEP 1	STEP 2	STEP 3
Meshing	Duration	1h 36m	3h 14m	2h 36m
	# of cores	4	4	4
# elements		7.5M	13.8M	19.9M
Running	Duration	3h14 – 750 cycles	6h17 – 750 cycles	4h48 – 750 cycles
	# of cores	36	36	36

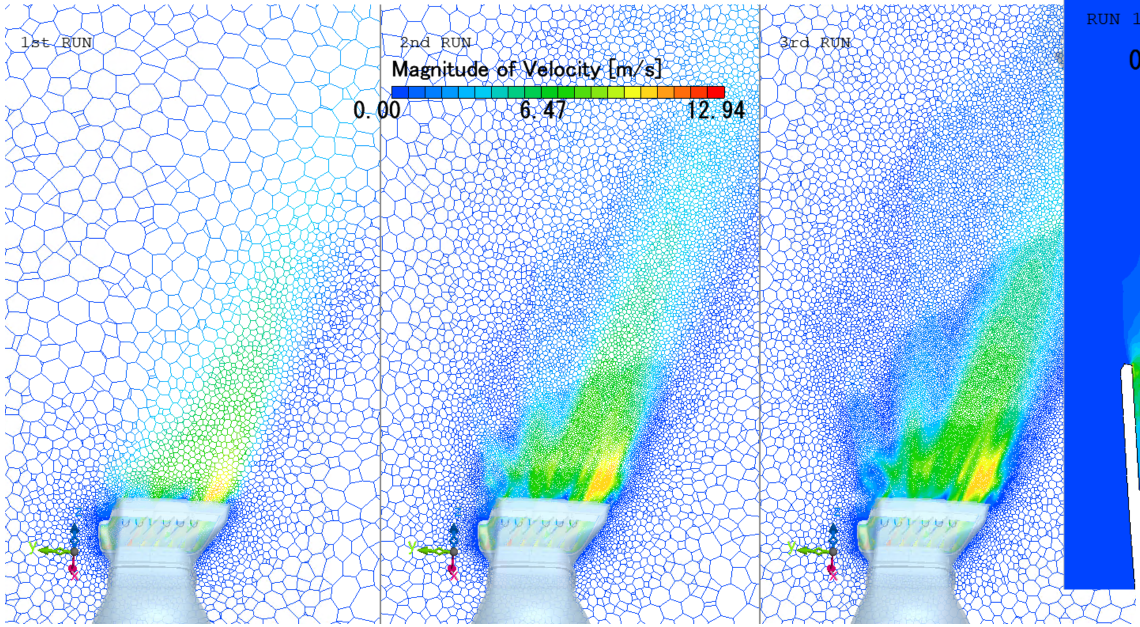
Iso-Q value colored by velocity magnitude



Application to an industrial case

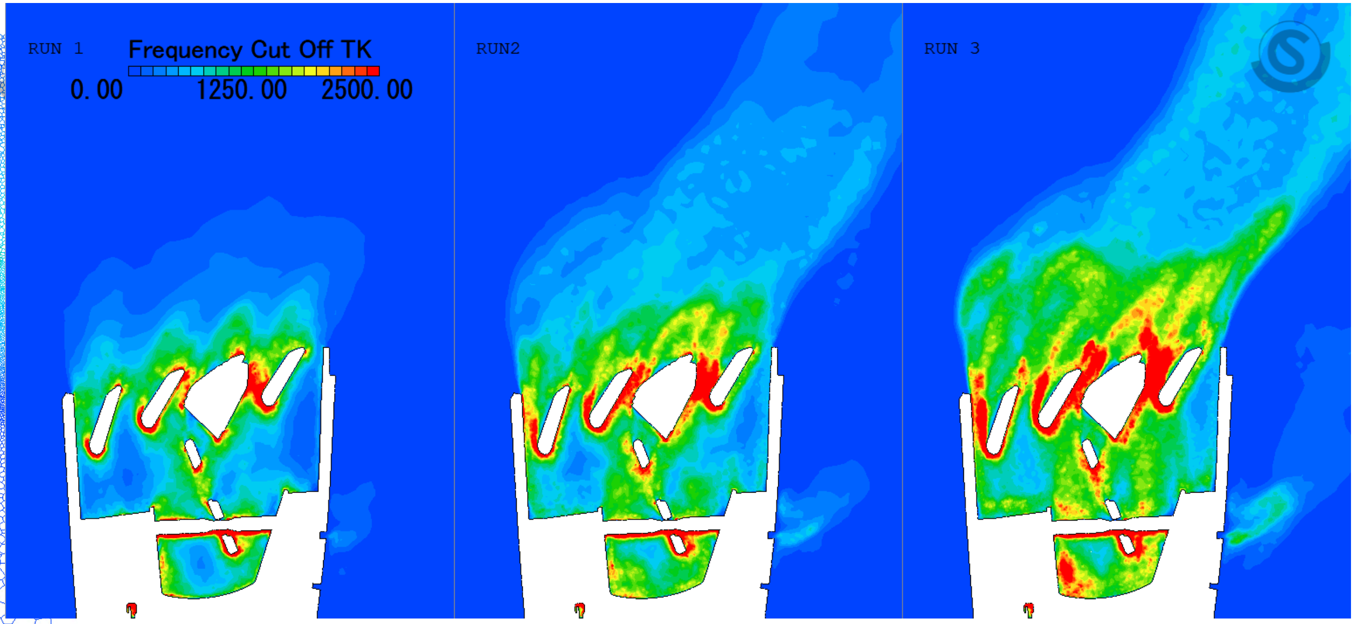


Velocity contours



Cut-off frequency

$$f_{cut-off} \approx \varepsilon^{1/3} \times \Delta x^{-2/3}$$

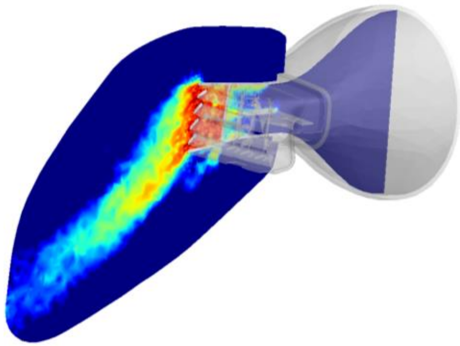


Application to an industrial case

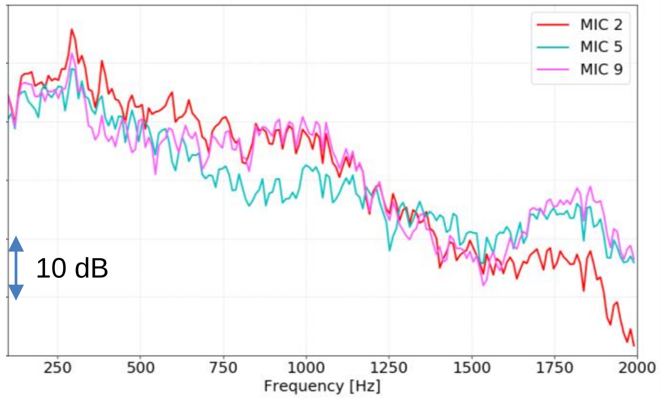
Acoustic results

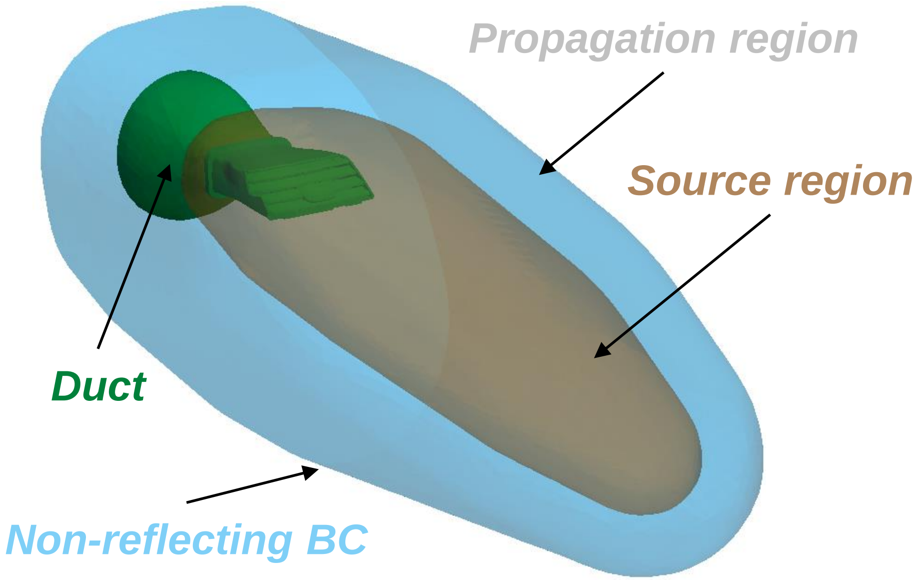
- In a process similar to the one before, the acoustic model is built:
  - Aeroacoustic sources are generated based on the CFD results
  - The sources are then propagated in semi-free field

Aeroacoustic sources at 300 Hz

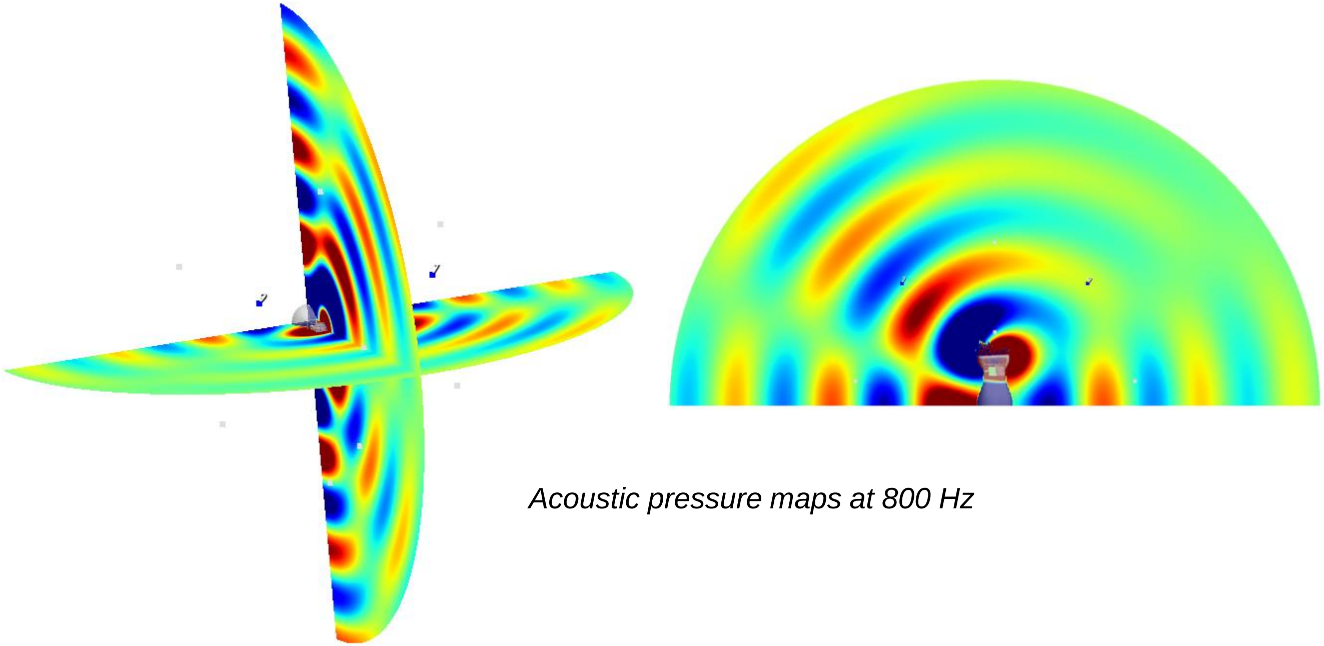


Pressure in dB on two microphones





Acoustic model definition



Acoustic pressure maps at 800 Hz

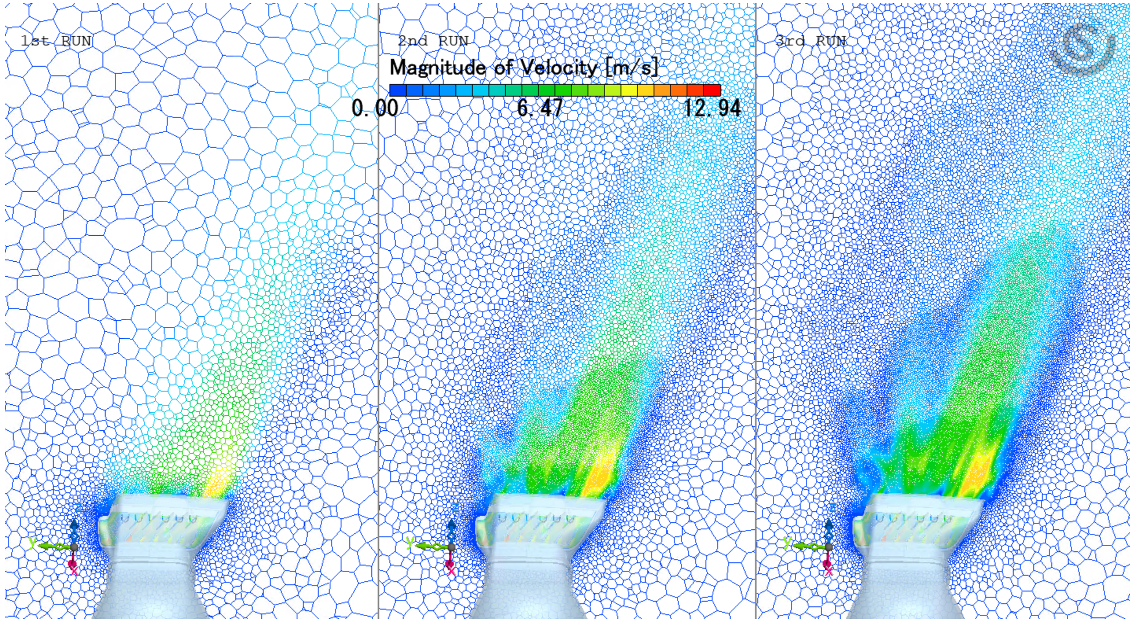
Summary

- A methodology was presented for adapting the CFD mesh based on the Taylor microscale

- The methodology is capable of refining the CFD mesh with the purpose of performing an aeroacoustic analysis

- It allows to achieve similar levels of accuracy compared to a manually created mesh while reducing the overall computational cost of the whole chain

- The method has been successfully applied in both simplified and industrial cases, proving to be a time-saving alternative to manually creating a mesh



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ANY QUESTIONS?