SIMULATION TO SUPPORT DESIGN OF COMPOSITE METAPLATE FUNCTIONALIZED WITH ACOUSTIC BLACK HOLES FOR ACOUSTIC COMFORT IN SHIP CABINS

H2020 FIBRE4YARDS

This project has received funding from European Union’s Horizon 2020 research and innovation programme under grant agreement n° 101006860.

Acoustic Black Holes for Marine Noise Abatement

- **Introduction to sound radiation – Marine example**
- **Acoustic Black Hole (ABH) – structural damping**
  - **Physical effect**
  - **ABH morphology and design parameters**
  - **Benchmark and previous Simulations**
- **ABH Simulations for Composite Panels - Functionalisation**
  - **Inputs and expected outputs**
  - **Design of Experiments**
  - **Optimised plate**
  - **Results**
- **Conclusions**

Short Remind - Noise Radiation

Acoustic radiation equation:

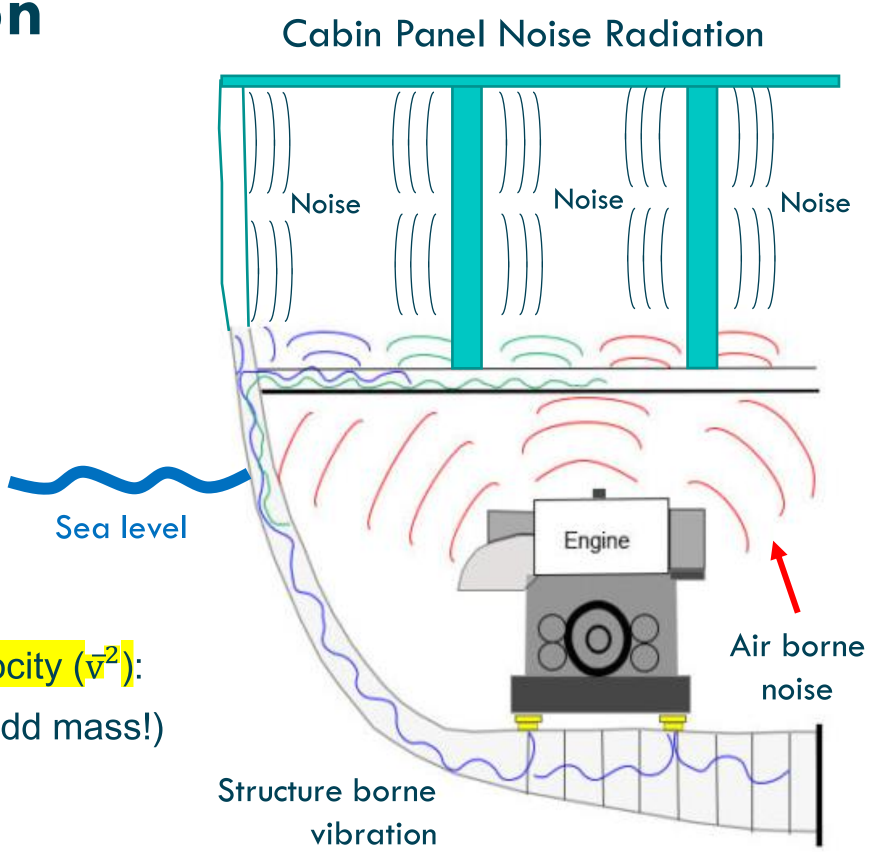
$$Pw = \sigma_{RAD} . \rho . c . S_t . \bar{v}^2 \text{ [W]}$$

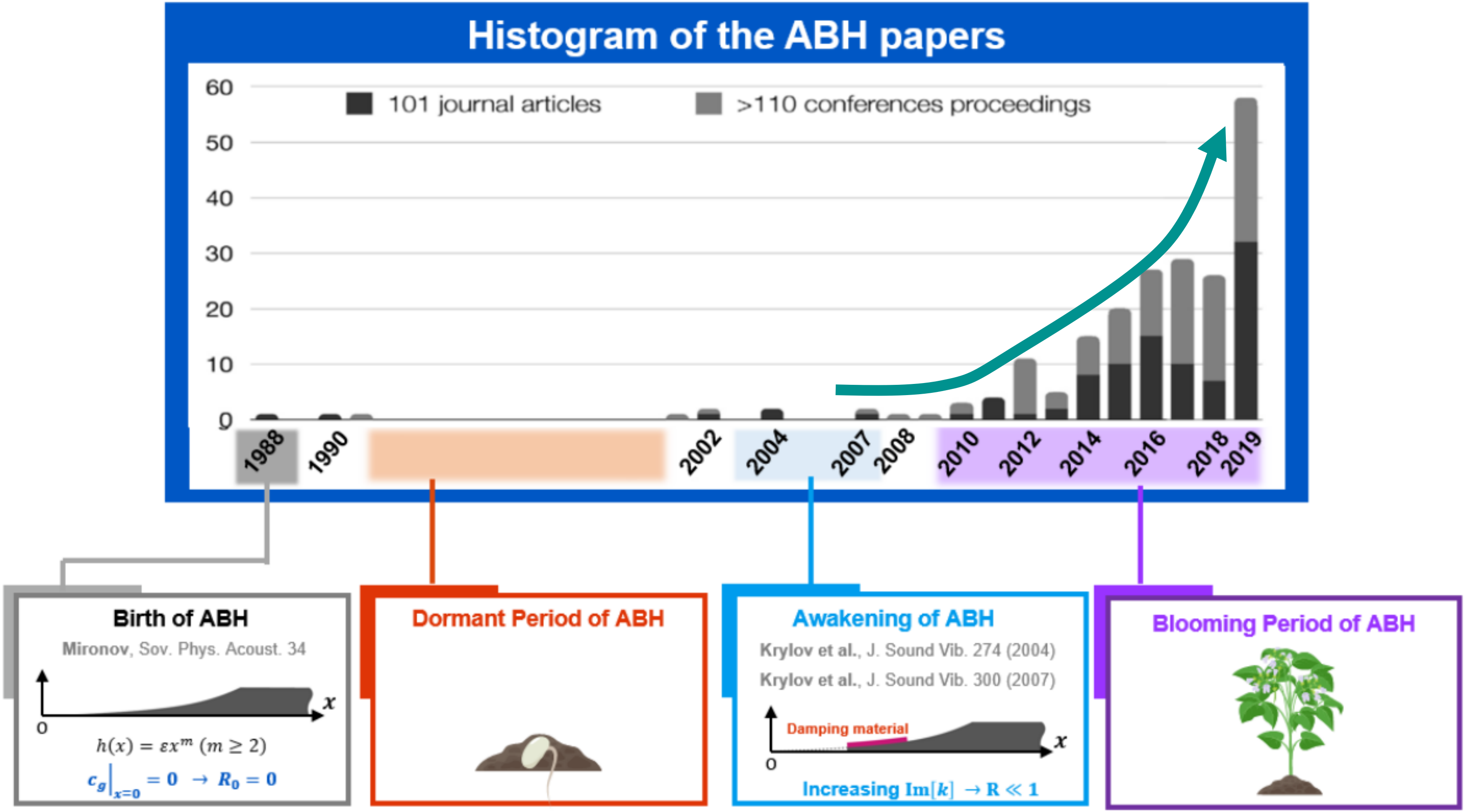
Where:

- σ_{RAD} - radiation efficience
- $\rho . c$ - medium impedance
- S_t - radiation surface
- $\bar{v}^2$ - averaged spatial/temporal squared vib. Velocity

For a given structure, the term to reduce is vibration velocity ($\bar{v}^2$):

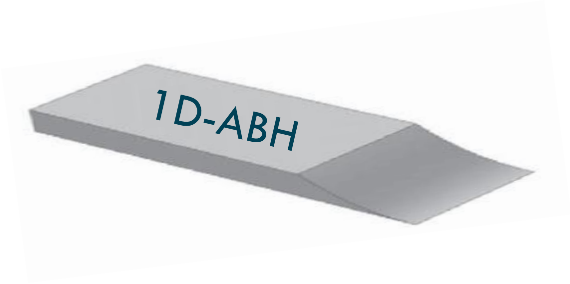
- By Increasing structural damping (add damping => add mass!)
- By tackling vibration at source (engine, others)
- By tackling vibration at its path (elastic pads, etc)

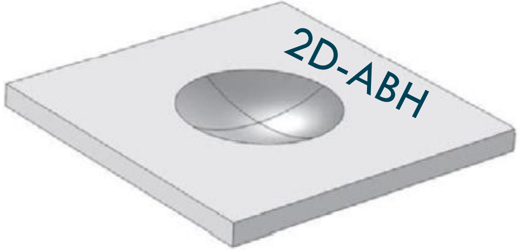




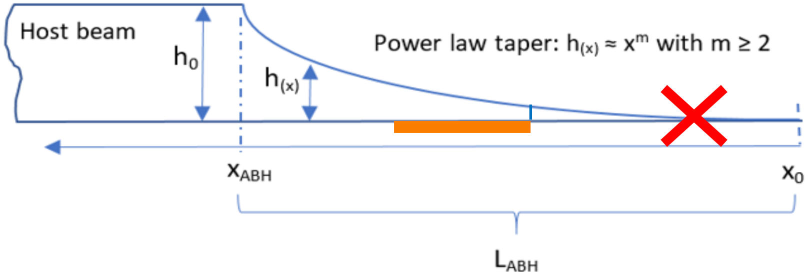
Histogram of the ABH papers
101 journal articles
>110 conferences proceedings
60
50
40
30
20
10
0
1988
1990
2002
2004
2007
2008
2010
2012
2014
2016
2018
2019
Birth of ABH
Mironov, Sov. Phys. Acoust. 34
x
0
$h(x) = \varepsilon x^m \ (m \geq 2)$
$c_g\big|_{x=0} = 0 \ \rightarrow R_0 = 0$
Dormant Period of ABH
Awakening of ABH
Krylov et al., J. Sound Vib. 274 (2004)
Krylov et al., J. Sound Vib. 300 (2007)
Damping material
x
0
Increasing $\mathrm{Im}[k] \rightarrow \mathrm{R} \ll 1$
Blooming Period of ABH

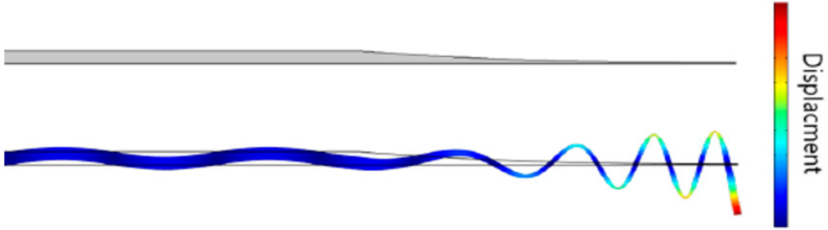
Acoustic Black Hole effect





ABH parameters



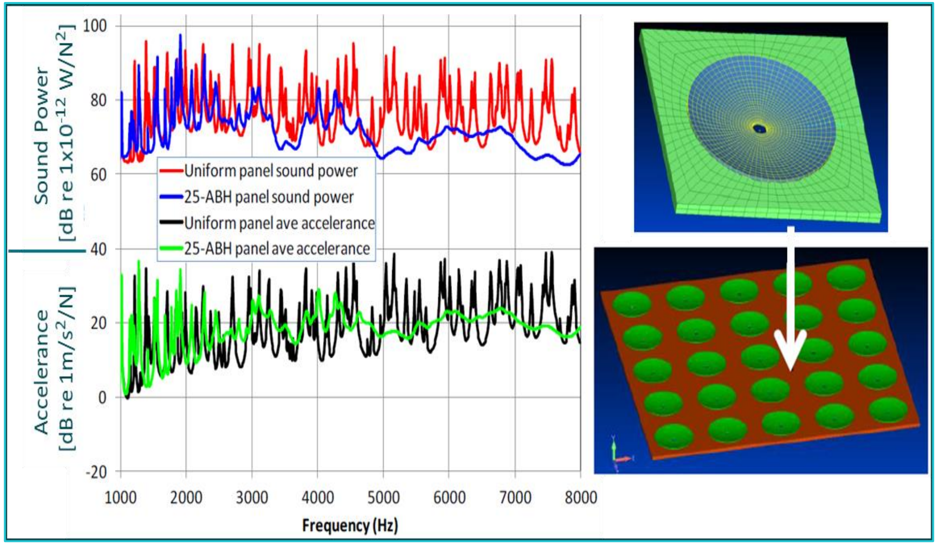


Flexural wave propagation velocity

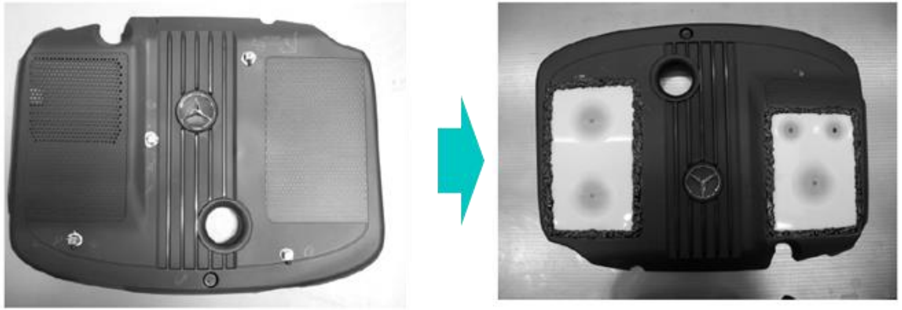
$$c(x) = \sqrt[4]{\left(\frac{E.h(x)}{12.\rho.(1-\nu^2)}\right).\omega^2}$$

Once a flexural wave gets into a tapered power-law profile (ABH), its propagation speed tends to zero towards the edge, therefore traping the wave energy and creating damping

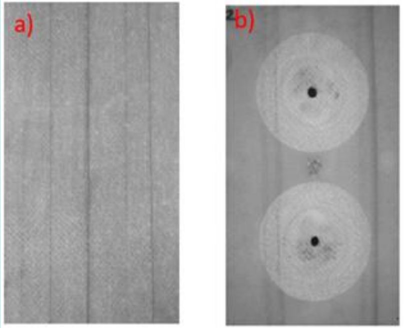
ABH – Few examples of Acoustic abatement and Applications



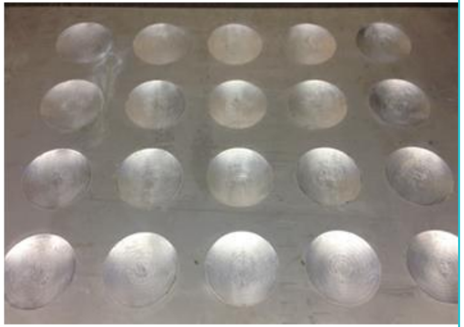
Automotive application



Composite plate



Array of ABHs



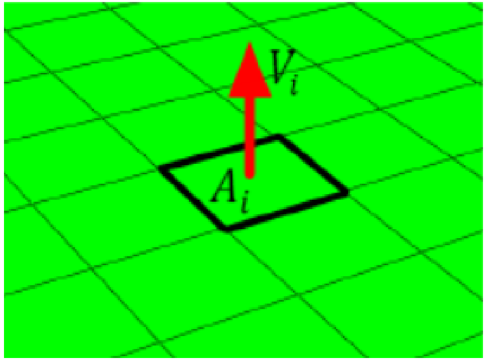
- Influence of the Number of ABHs
- High correlation between transfer function and radiation power

ABH Simulation – Composite Panel (ABAQUS)

- Objective – develop and assess a simulation tool to reduce time to design of ABH for structural damping maximisation

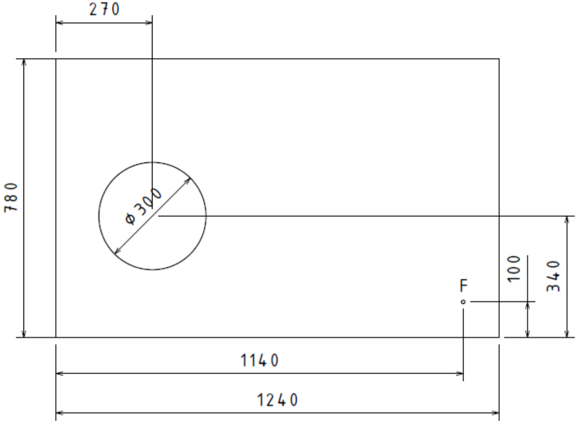
- Simulation and Optimisation of ABH design in a Composite plate, Inputs:
  - ABH parameters (*diameter, power-law coeff. and terminal thickness*)
  - ABH position and quantity
  - Visco-layer choice (*from commercial turnkey*)
  - Material properties and composite plate lay-up (GFRP)
  - Plate size and thickness
  - *Boundary conditions and excitation points*

- Parameter of assessment:
  - Equivalent Radiated Power Level (ERPL)



Design of 3x Panels with Different ABH configurations

Plate with 1x ABHs
Optimised by simu



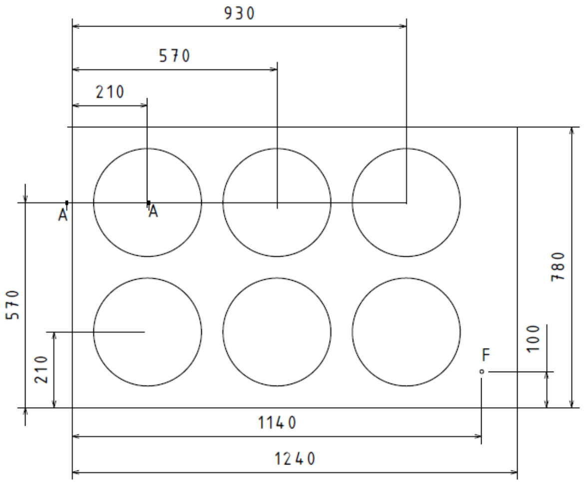
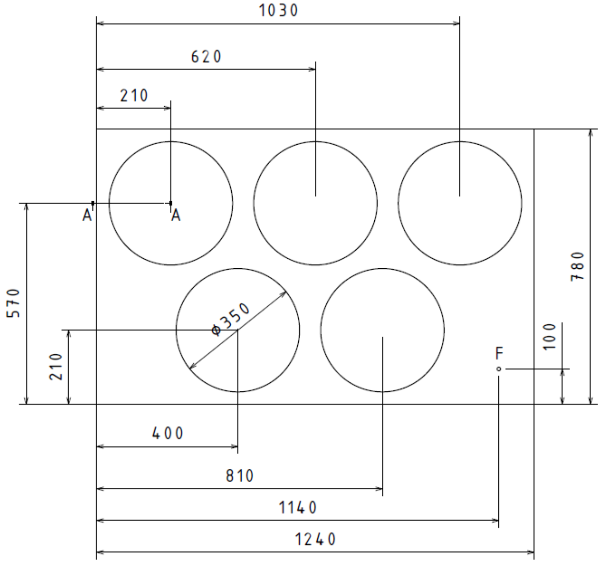


Plate with 6x ABHs
Design of Experiments

Plate with 5x ABHs



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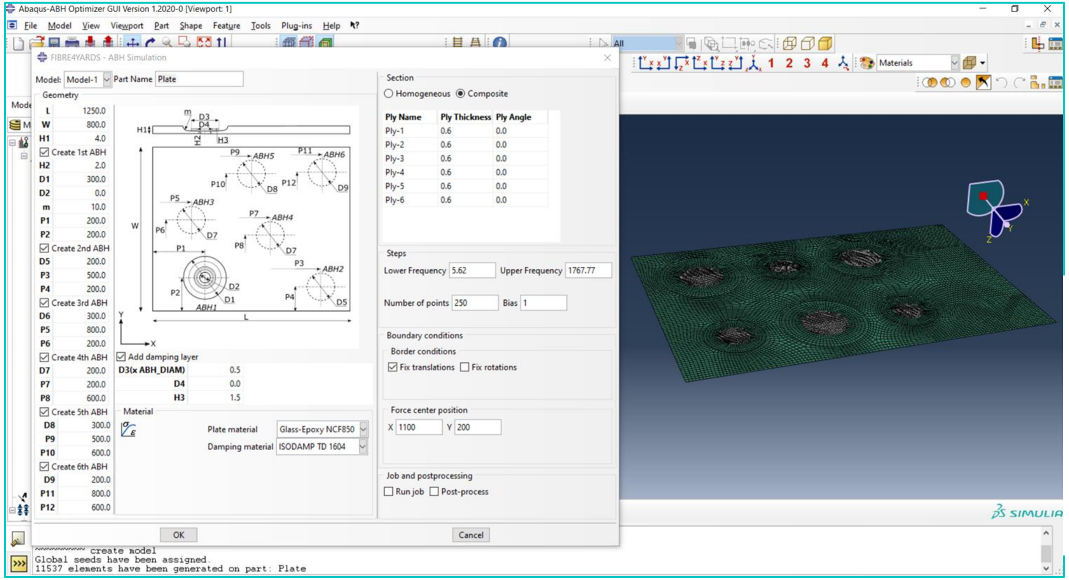
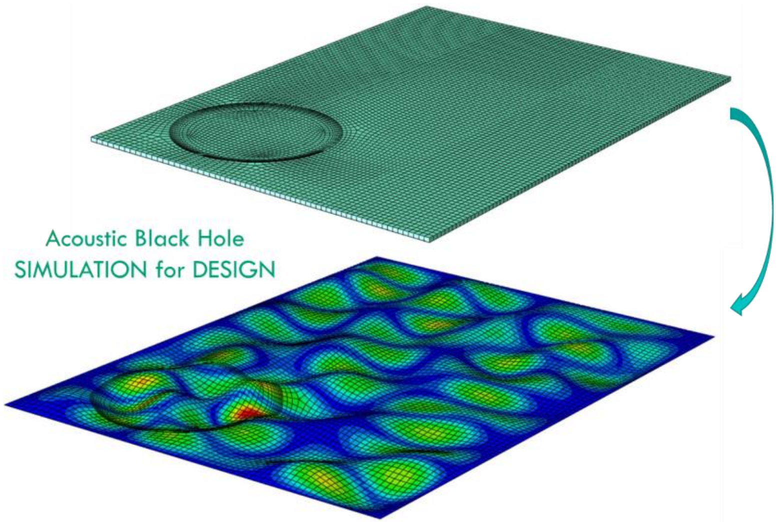
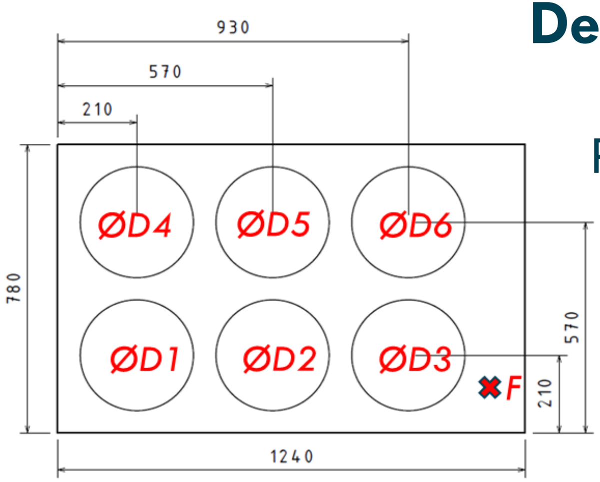
Model Builder - Graphical User Interface (GUI) – Python/Abaqus





Parametric model generation - Simulation and design of functionalised composite plates with acoustic black holes for vibro-acoustic abattement

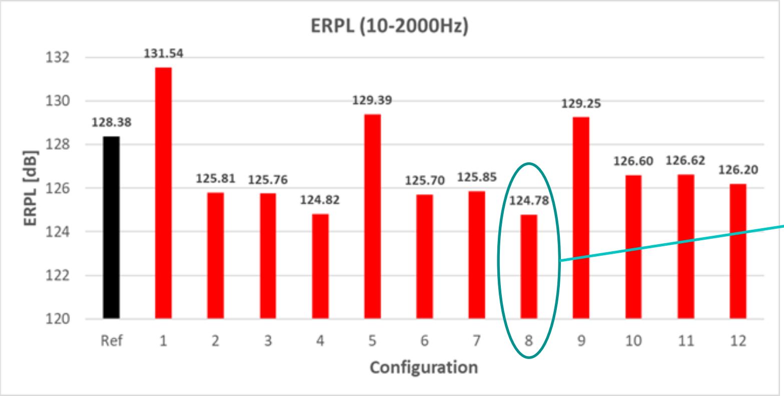
Design of Experiments panels with 6x ABHs



Panel with 6x ABHs

Power-law

Configuration	m	Diameter (mm) D1-D3-D5 [mm]	D2-D4-D6 [mm]
C1	2	200	200
C2	2	200	300
C3	2	300	200
C4	2	300	300
C5	3	200	200
C6	3	200	300
C7	3	300	200
C8	3	300	300
C9	4	200	200
C10	4	200	300
C11	4	300	200
C12	4	300	300

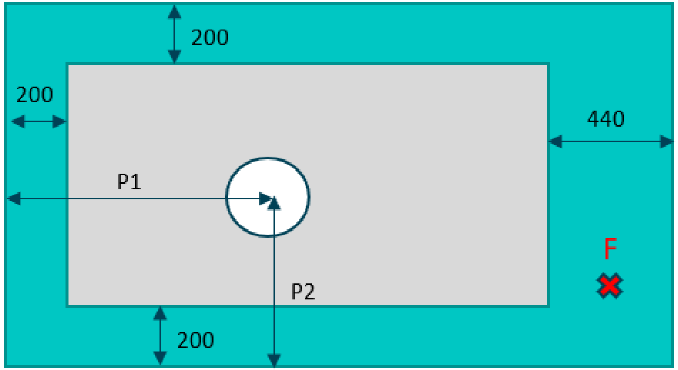


Best configuration for 6x ABHs

Optimisation for 1x ABH (method – Genetic Algorithm)

- ✓ **Utilisation of Genetic Algorithms (GA)**
- ✓ **4x different design parameters (plate functionalised with ABHs)**
  - Diameter (D) AND Power law (m) AND position#1 AND position#2
- ✓ **Parameter of decision:** minimize sound radiation – ERPL
- ✓ **4x GA parameters**

1x ABH functionalised plate Design conditions



Design parameters

Design parameter	Values range [mm]
D1	{200, 300} 2x
m	{2, 3, 4} 3x
P1	{200,210...800} 61x
P2	{200,210...580} 39x

GA parameter

GA parameter	Value
Initial population size	100
Number of generations	10
Crossover probability	0.85
Mutation probability	0.1

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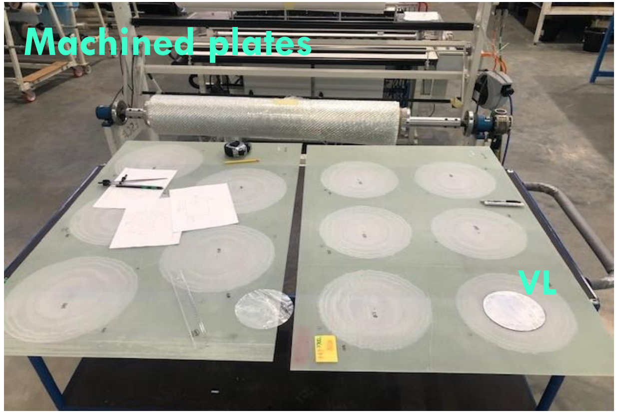
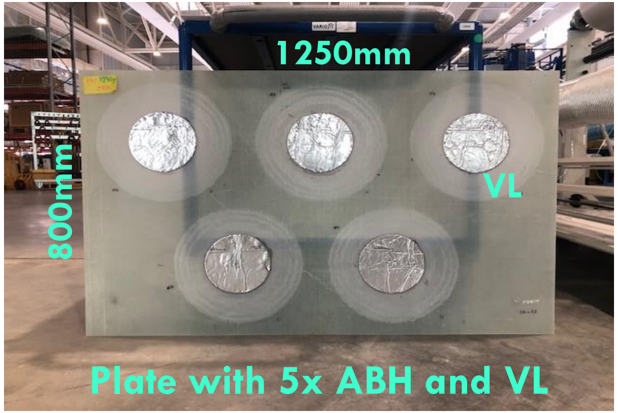
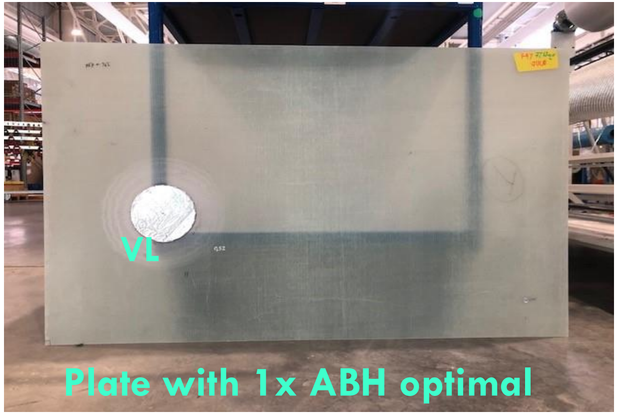
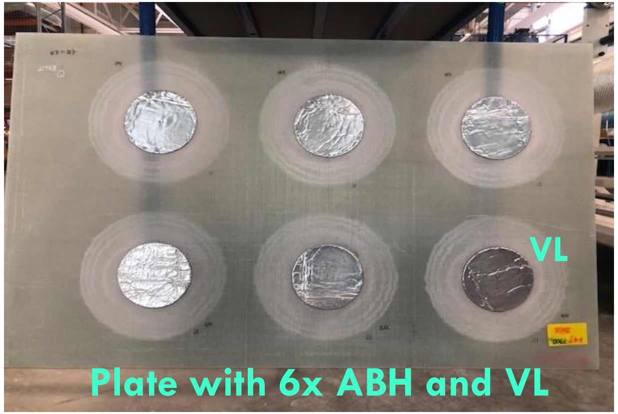
Manufacturing of Functionalised pannels

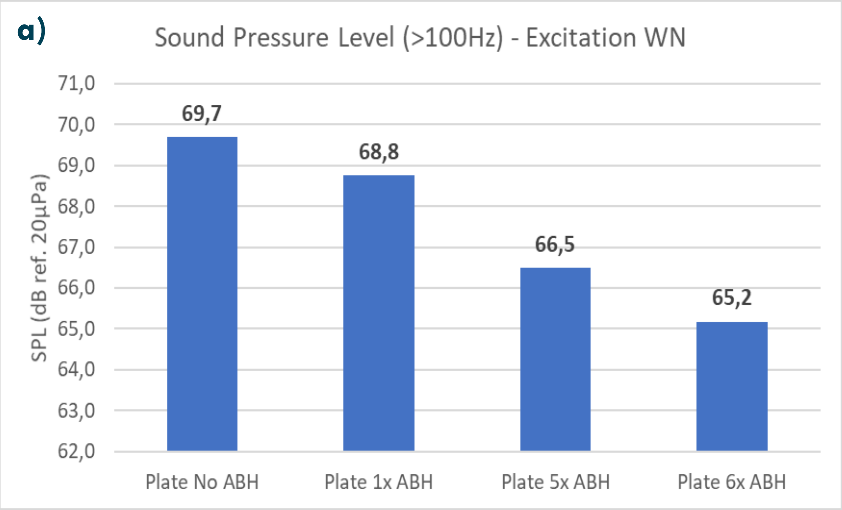


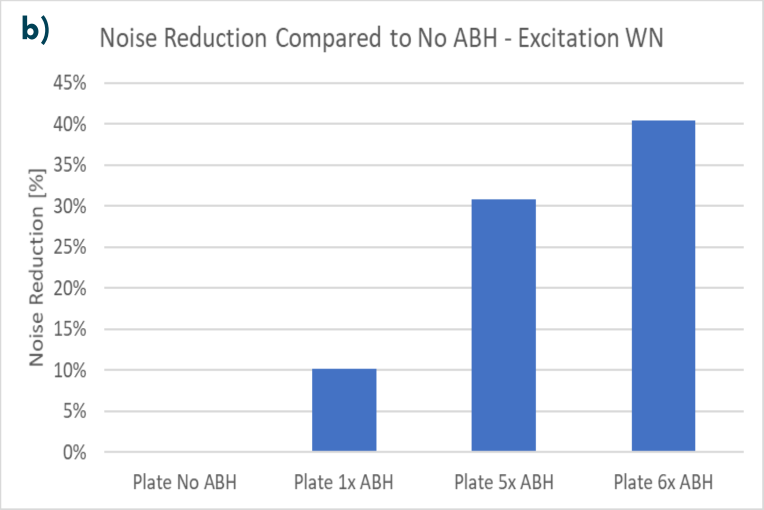






Sound Pressure Level measurements 100-8000Hz





Excitation White Noise	SPL (dB ref. 20µPa)	Measured gain (dB)	Simulation gain (dB)	Difference (calcul/test)
Plate No ABH (ref)	69,7	-	-	-
Plate 1x ABH	68,8	-0,9	-1,4	0,5
Plate 5x ABH	66,5	-3,2	-3,7	0,5
Plate 6x ABH	65,2	-4,5	-3,6	-0,9

Conclusions

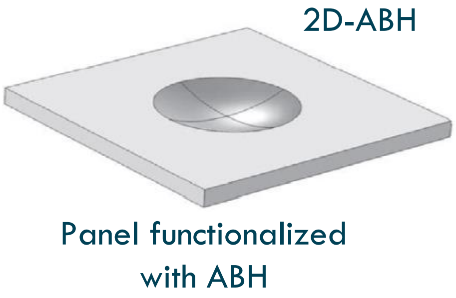
- A short introduction of using acoustic black holes (ABH) to functionalised panels for acoustic abatement was presented
- The aproach for simulating ABH in FGRP was developped with:
  - Genetic Algorithm for 1x ABH design optimisation
  - Design of experiments for finding best parameters combination for 5x and 6x ABH array
- The simulation results did present an error < 1dB (in the noise abatement) compared to measurements
- Simulation results correlates fairly well with the trends in the experimental results – further improvements would give better results
- The ABH reduced the velocity of vibration, and consequently the sound level, with a noise reduction of the order of 4.5dB (40%) for the panel with 6x ABH

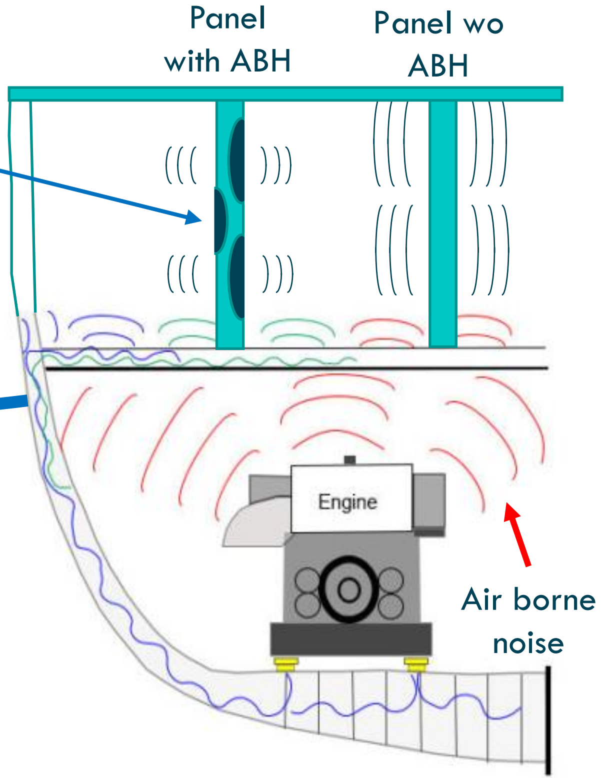
Perspectives

- The use of ABH supported by simulations is a real asset for creating smart silent structures in Naval and other types of transportation
- ABH technology is currently at TRL4-ish and has been proving its capacity of reducing vibro-acoustic, it needs now to move to higher TRLs
- Further work should be done to make it an engineering tool for optimised structures and bring it to the market at TRL higher than 7
- ABH needs further practical applications in transportation and structures with vibrating surfaces and non-bering loading

Please do not confuse acoustic black hole with astrophysical black hole

ABH Possible Application in Naval





Sea level

Utilisation of ABH in no load bearing walls