



## Optimization and 3D design of a dual density stiff hybrid injected foam-foam insulator

A. Duval, L. Dejaeger, V. Marcel, J. Monet-Descombet, M-T. Hoang  
SAPEM 2014

faurecia

## Objective of the Hybrid foam project

### ■ Hybrid foam-foam dash insulator technology industrial goals:

- Weight reduction effectivity versus Light-Weight Concept Foam/HL/Foam with heavy layer weighting less than  $1,4 \text{ kg/m}^2$  with sufficient overall stiffness for car assembly.
  - Total weight target  $< 2,5 \text{ kg/m}^2$
- Acoustic performance equivalent to LWC for petrol ABC segment and therefore much better than bi-permeable felt solution for insulation particularly
- Cost competitive versus bi-permeable compressed felt /felt absorbing solutions
- Full 3D design of both stiff absorbing and soft insulating foam layers

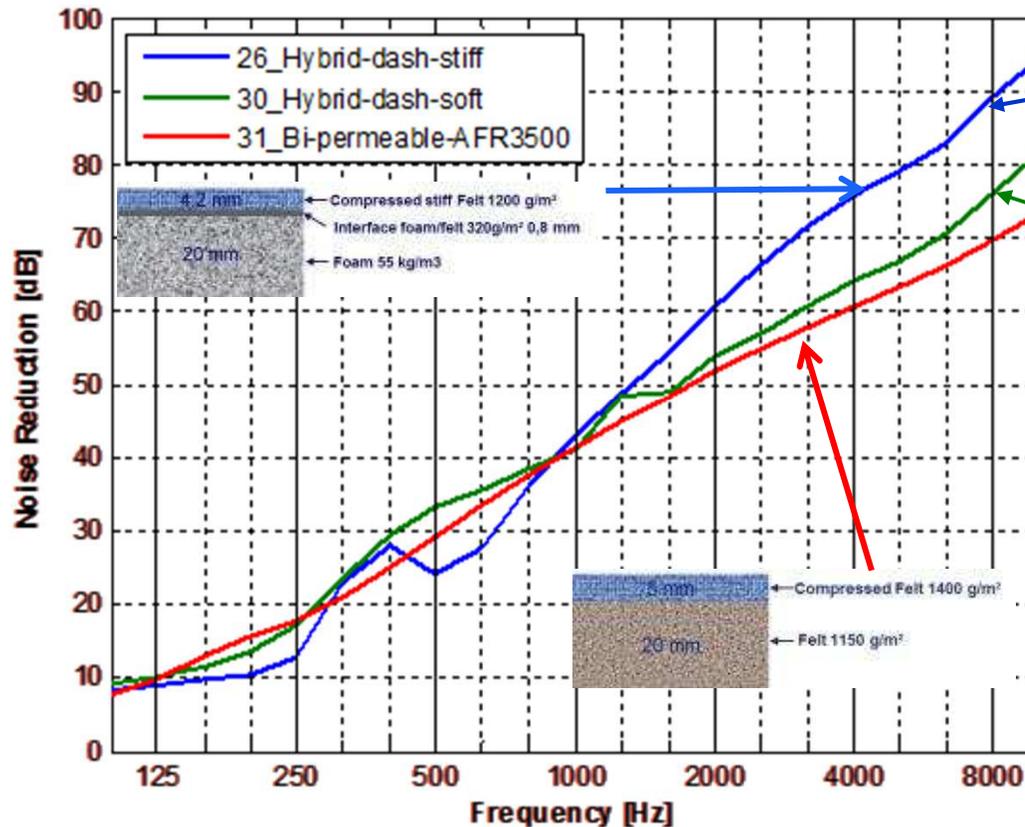


# Influence of the stiffness of the upper compressed felt



- Hybrid foam-foam 3D technology technical goals vs. Hybrid foam-felt 2D:
  - Noise Reduction (dB): Stiff Hybrid Foam-Felt 2D Concept (*high  $\sigma$  and high  $E$* )

$$NR_{(dB)} = TL - 10 \log \left( \frac{S}{A} \right)$$



$$B = E \cdot h^3 / 12 = 0,52$$

$$B = E \cdot h^3 / 12 = 0,0000625$$

The airtight intermediate layer foam/felt of the Hybrid Stiff Concept captures the mass insulation performance of the stiff compressed felt (not the case for the classical bi-permeable concept even with high AFR)

Upper felt technology requests high compressions in order to get high stiffnesses, which leads to 2D low thicknesses and thus to low absorption

# Hybrid foam concept description

## ■ Hybrid foam-foam dash insulator 3D technology description:

- 1st layer : injected absorbing 3D PU foam at  $90 \text{ kg/m}^3$  to  $120 \text{ kg/m}^3$  (high airflow resistance  $RPA = \sigma \cdot h$  and bending stiffness  $B = E \cdot h^3 / 12$ )
- 2nd layer : injected insulating 3D PU foam at  $50 \text{ kg/m}^3$  (standard soft injected foam)



**1st layer of foam : absorption**

***Inter-penetration layer : 350-500 g/m<sup>2</sup>***

**2<sup>nd</sup> layer of foam : insulation**



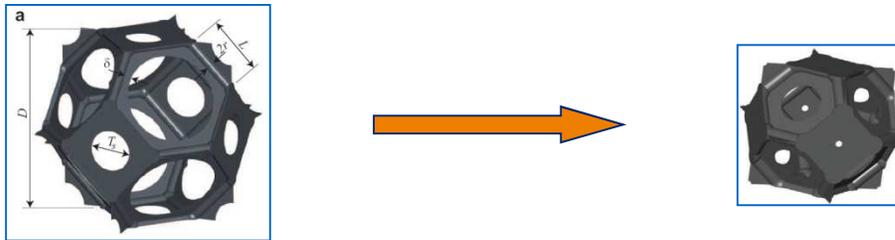
- Air blowing during 2nd step (cf. LWC process) to control foam penetration and avoid collapsing of the foam

**Same chemical foam formulation -> change of PU injection parameters only.  
The high Young's modulus is thus independent of the 3D thickness.**

# Morphology control of foams

## ■ Morphology control: high airflow resistivity and young's modulus target

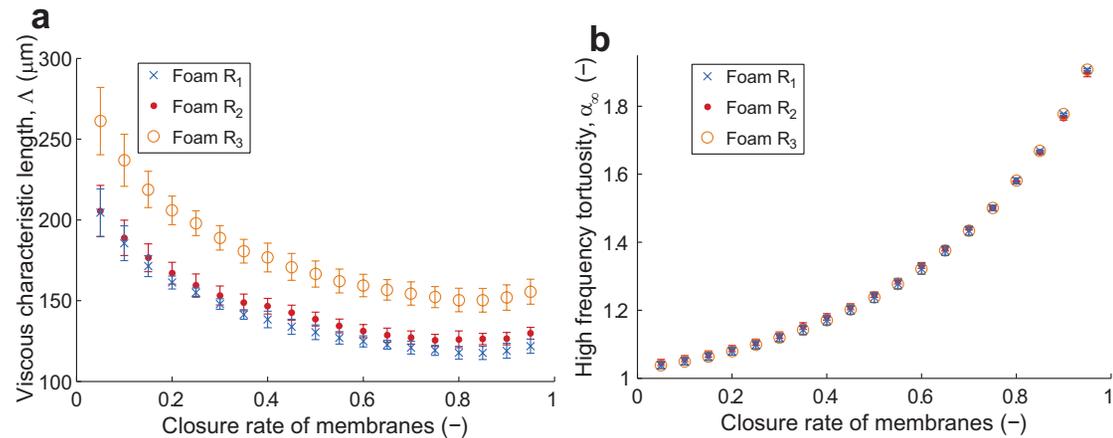
- Closure rate of the membranes (effects on the Biot parameters) and higher urethane bonds counts, through foam formulation and injection process



		Foam membrane closure
Geometrical	Thickness (mm)	20
	Porosity $\Phi$	→
	Thermal Characteristic Length $\Lambda'$ ( $\mu\text{m}$ )	↘
Transport	Airflow Resistivity $\sigma$ (N.m <sup>-4</sup> .s)	↗↗
	Tortuosity $\alpha_\infty$	↗↗
	Viscous Characteristic Length $\Lambda$ ( $\mu\text{m}$ )	↘↘

Membranes closure & homothetic reduction of the cell size

Porosity and static permeability are constant

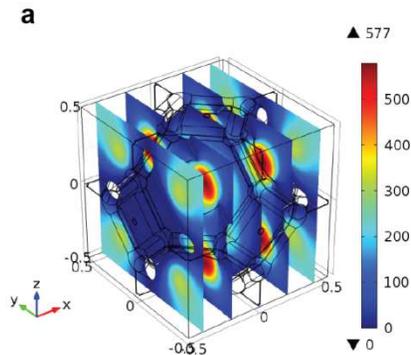


Source: M. T. Hoang and C. Perrot, "Solid films and transports in cellular foams", J. Appl. Phys. , **112**, 054911-6 (2012)

# Macroscopic parameters are computed from three asymptotic calculations



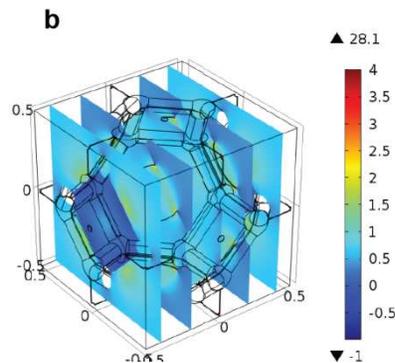
1



- Viscous Navier-Stokes flow at low frequencies yields:

- Static viscous permeability  $k_0 = \eta/\sigma$
- Static viscous tortuosity  $\alpha_0$

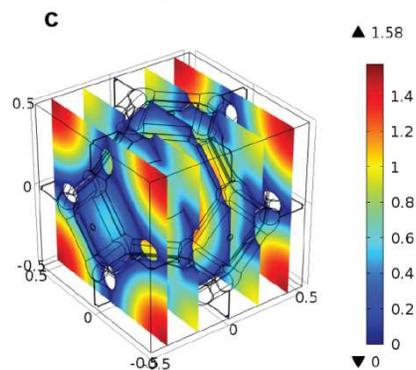
2



- Inertial Laplace potential flow (*identical to electric conduction*) at high frequencies yields:

- Tortuosity (high frequency limit)  $\alpha_\infty$
- Viscous characteristic length  $\Lambda$

3



- Thermal conduction (*similar to diffusion-controlled reaction*) at low frequencies yields:

- Static thermal permeability  $k'_0$
- Static thermal tortuosity  $\alpha'_0$

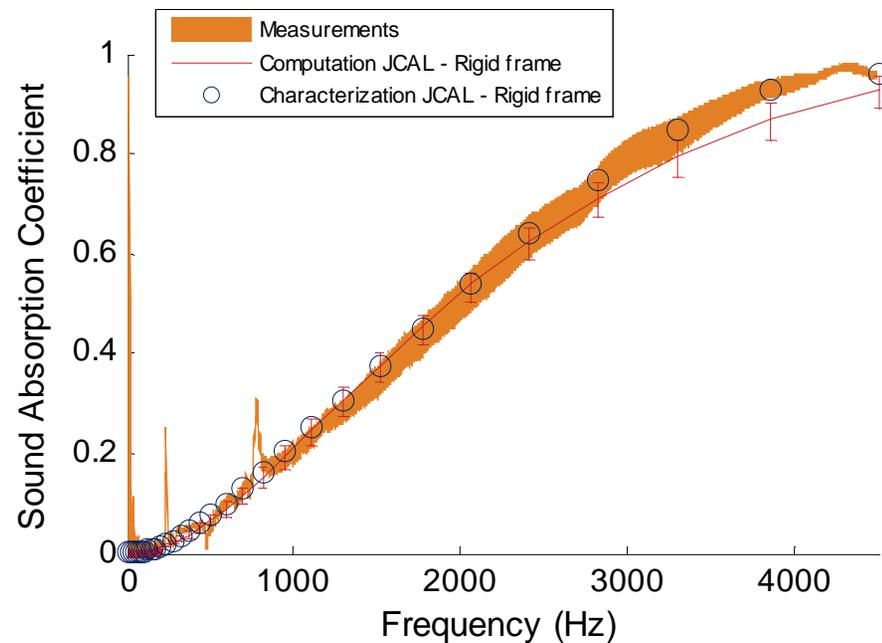
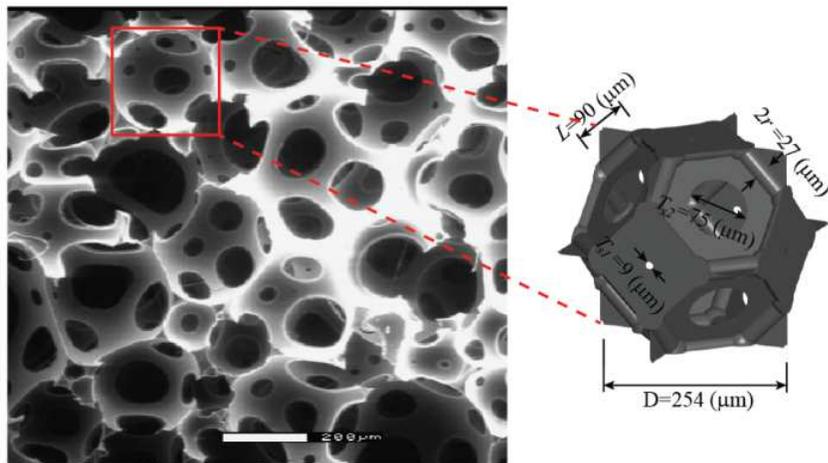
# 3D unit-cell based simulation

## Link between microstructure and macro properties



### ■ Bottom-up approach for microstructure optimization

- Correlation between measurements and 3D unit-cell based simulation method: upper injected absorbing « barrier » foam



**The cell size has been divided by almost 2 and the closure rate of membranes is 1,6 times closer resulting in a  $\sigma$  multiplied by 6 and a high tortuosity above 2 here.**

# Acoustic Galvanometer 3D

## 3D Trims development strategy



		Insulation		Mixed Insulation/Absorption			Absorption			
		Foam Heavy Layer	LWC Foam HL Felt 2D	LWC Foam HL Foam	LWC Foam HL Felt 3D	Quadri-permeable Hybrid	Hybrid foam-felt 2D	Hybrid foam-foam 3D	Bi-permeable	Tunable Absorber
Simulations	2D Flat Samples									
	FTMM 2.5D									

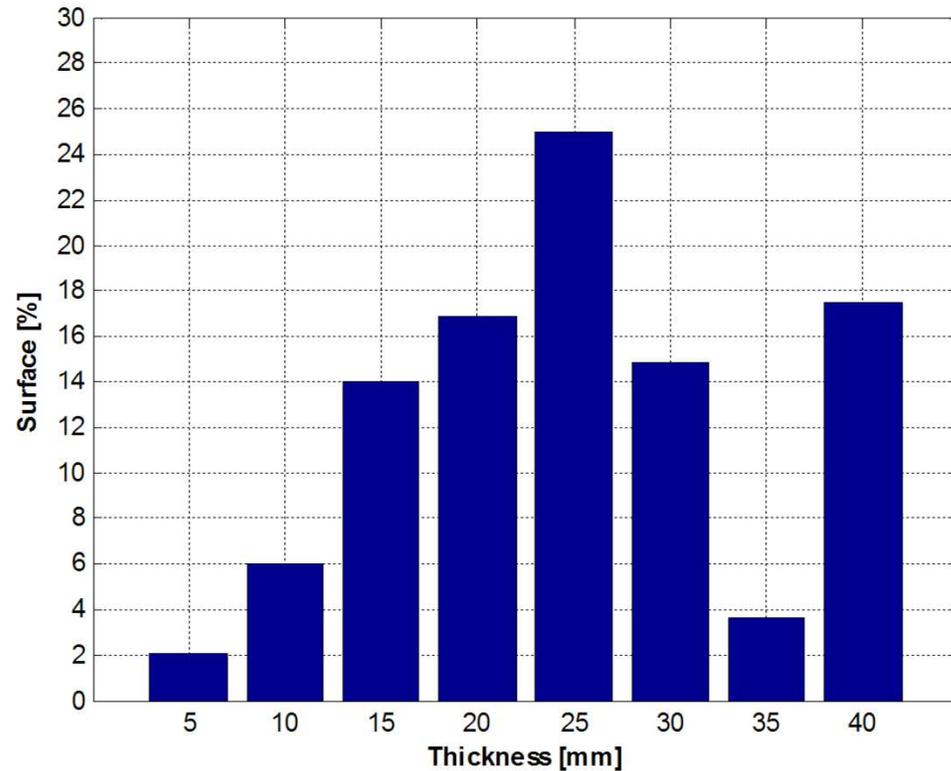
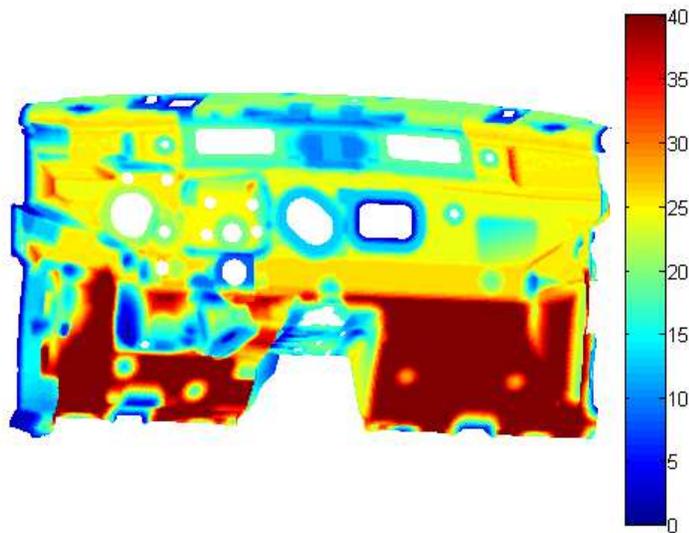
Diesel > 1,4 kg/m<sup>2</sup>

Petrol < 1,4 kg/m<sup>2</sup>

Equivalent barrier variation



# Thickness cartography – Dash Inner

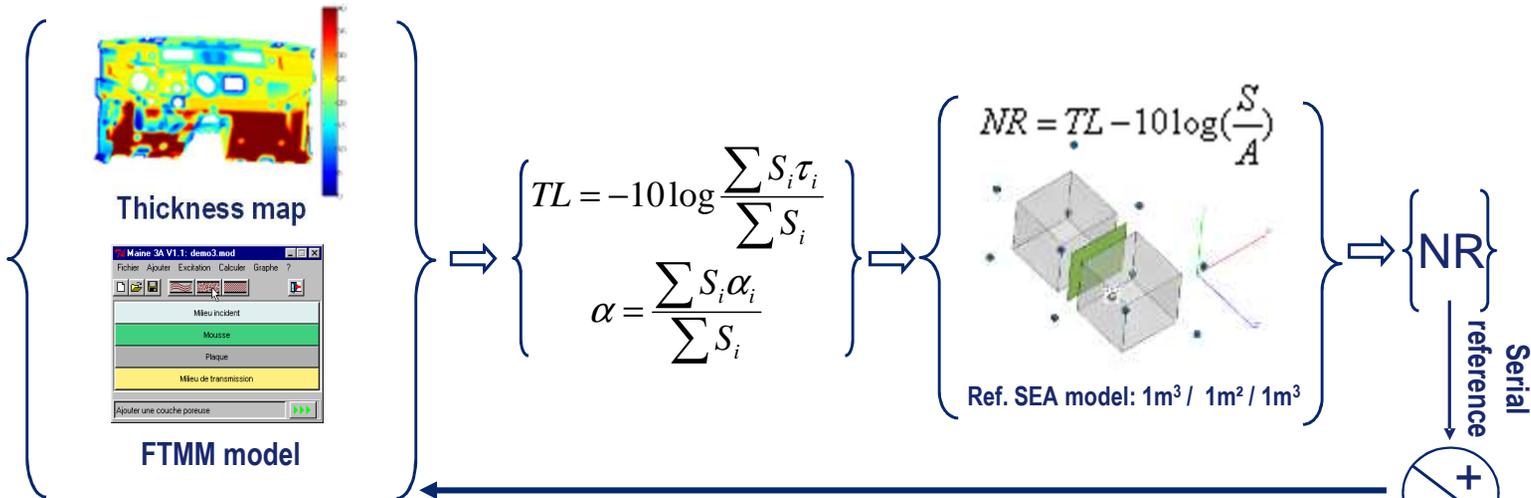


**Used thickness distribution for Dash Inner:**

Thickness Range [mm]	Surface [%]
0mm -> 5mm	2.1%
5mm -> 10mm	6.0%
10mm -> 15mm	14.0%
15mm -> 20mm	16.9%
20mm -> 25mm	25.0%
25mm -> 30mm	14.8%
30mm -> 35mm	3.7%
35mm -> 40mm	17.5%

**[with taking into account the low thicknesses]**

# Acoustic package optimization method: FTMM 2,5D

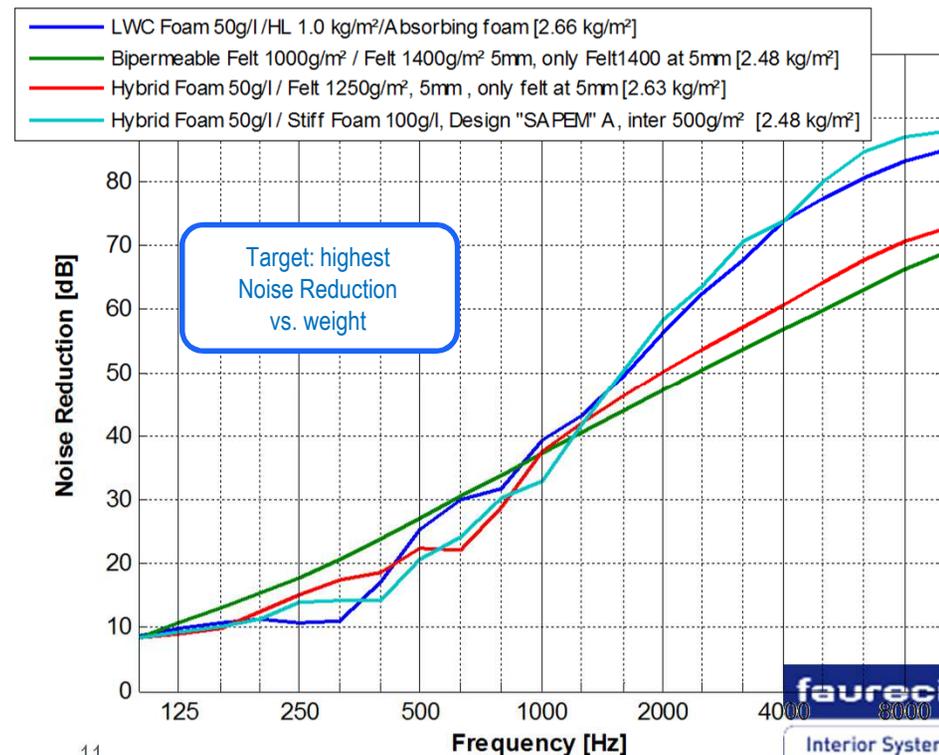
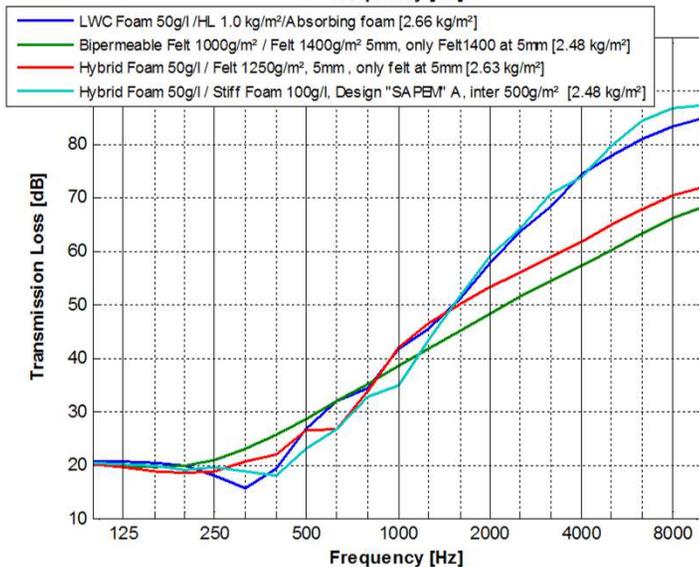
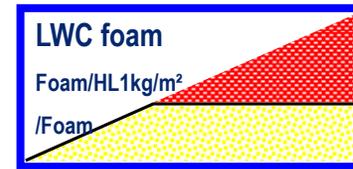
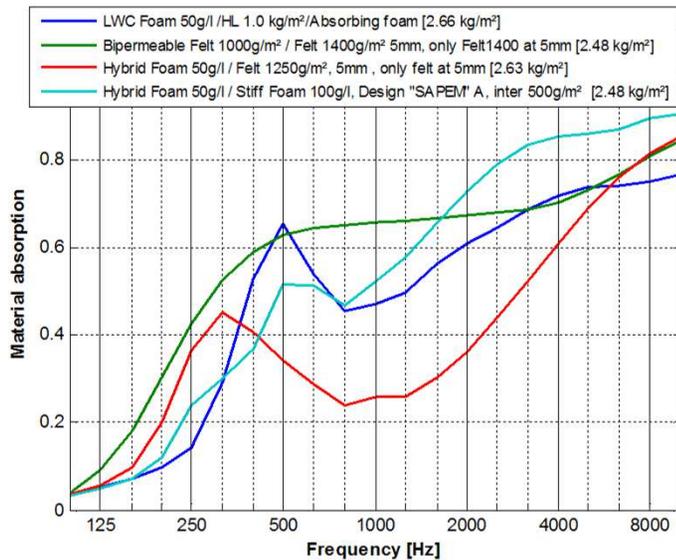


- TL*: Transmission Loss of the global part
- S<sub>i</sub>*: Surface of single model
- τ<sub>i</sub>*: Transmission coefficient of single model
- α*: Absorption coefficient of the global part
- α<sub>i</sub>*: Absorption coefficient of single part
- NR*: Noise Reduction of the global part
- S*: Surface of the global part
- A*: Equivalent absorption area of reception room

Tot.Thick. 6mm	Tot.Thick. 10mm	Tot.Thick. 15mm	Tot.Thick. 20mm	Tot.Thick. 25mm	Tot.Thick. 30mm	Tot.Thick. 35mm	Tot.Thick. 40mm
Stiff foam, ep 2mm	Stiff foam, ep 4mm	Stiff foam, ep 6mm	Stiff foam, ep 9mm	Stiff foam, ep 14mm	Stiff foam, ep 15mm	Stiff foam, ep 15mm	Stiff foam, ep 15mm
Interface foam foam, ep 1mm							
Foam, ep 3mm	Foam, ep 5mm	Foam, ep 8mm	Foam, ep 10mm	Foam, ep 10mm	Foam, ep 14mm	Foam, ep 19mm	Foam, ep 24mm

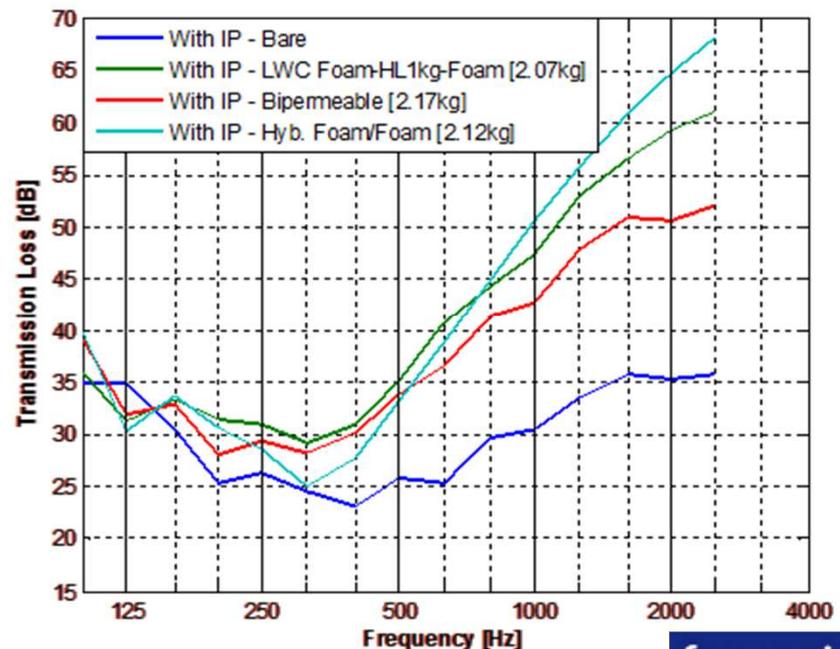
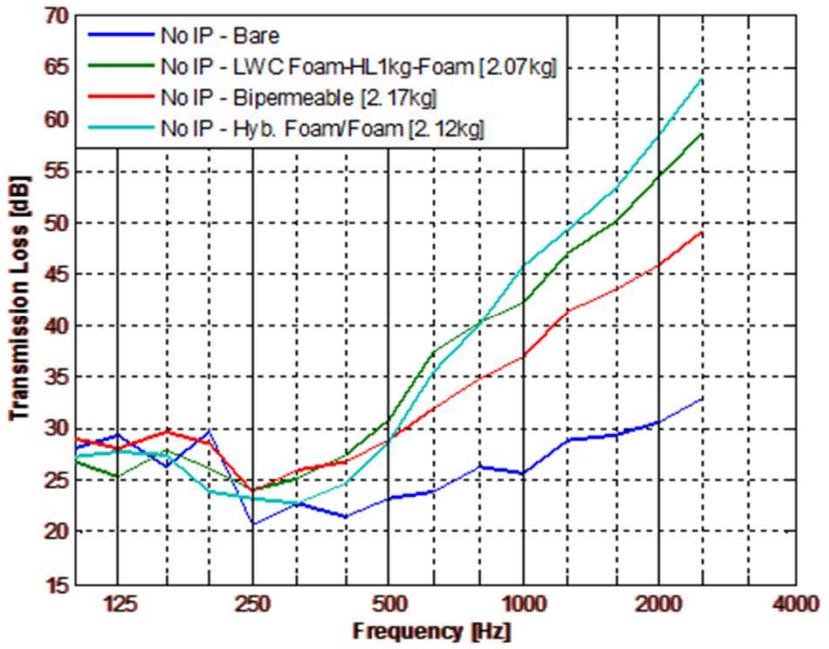
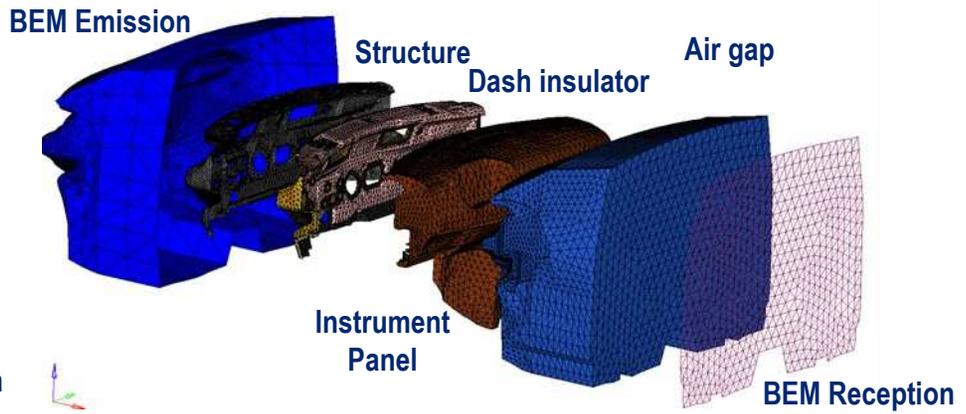
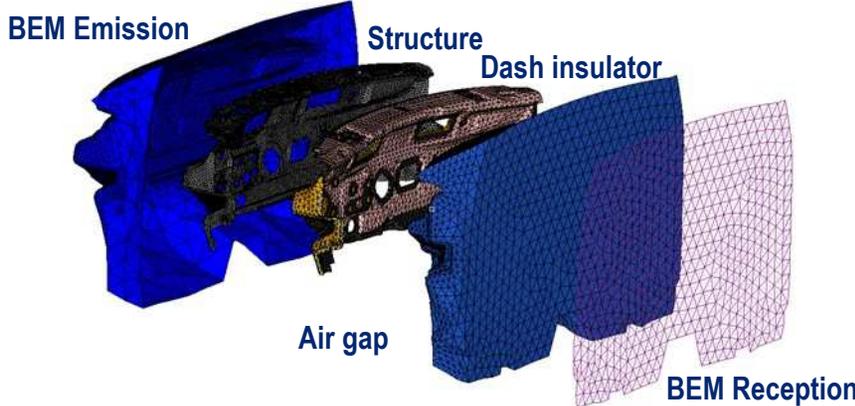
# Hybrid foam

## Acoustic package optimization method: FTMM 2,5 D



# BEM/FEM/PEM trim Transmission Loss simulations

Poroelastic finite elements: 3D automatic meshing



# Hybrid foam

Process validations on a dash insulator



## ■ Process validation using a LWC foam/HL/foam tooling



**Part weight achieved : 4.8 kg**

**Hybrid foam offers a further weight reduction potential of – 18 % at iso-acoustic performance (1,1 kg here) vs. LWC**

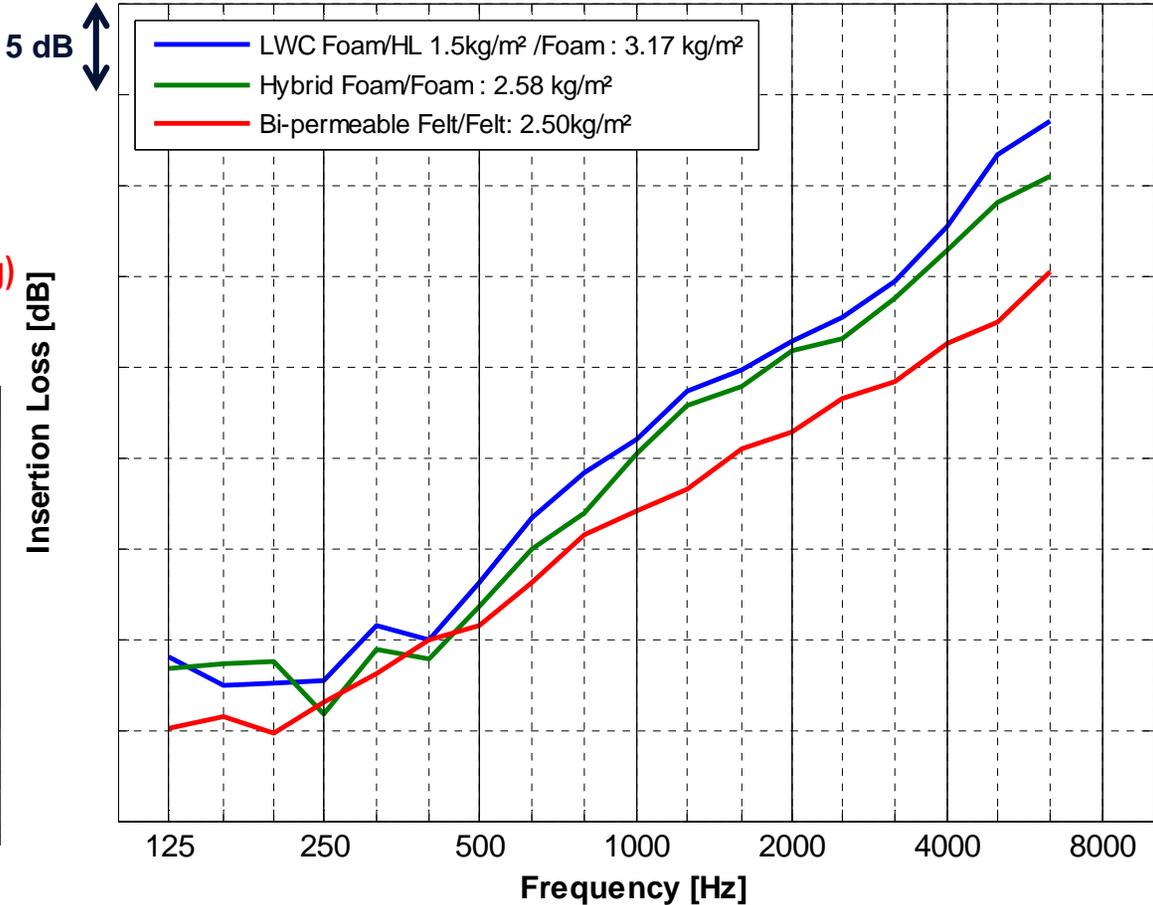


# Acoustical validations on a dash insulator

Reverberant room measurements

## Comparison: LWC Foam/HL/Foam , Hybrid Foam/Foam and Bi-permeable Felt/Felt Configuration : part alone

- LWC Foam/HL/Foam : 3.17 kg/m<sup>2</sup> (5,9 kg)
- Hybrid Foam/Foam : 2.58 kg/m<sup>2</sup> (4,8 kg)
- Bi-permeable Felt/Felt: 2.50 kg/m<sup>2</sup> (4,7 kg)



This light Hybrid foam dash insulator is much better for insulation than Bi-permeable Felt/Felt solution and slightly below a heavier LWC (w/o IP & w/o Pass-throughs)

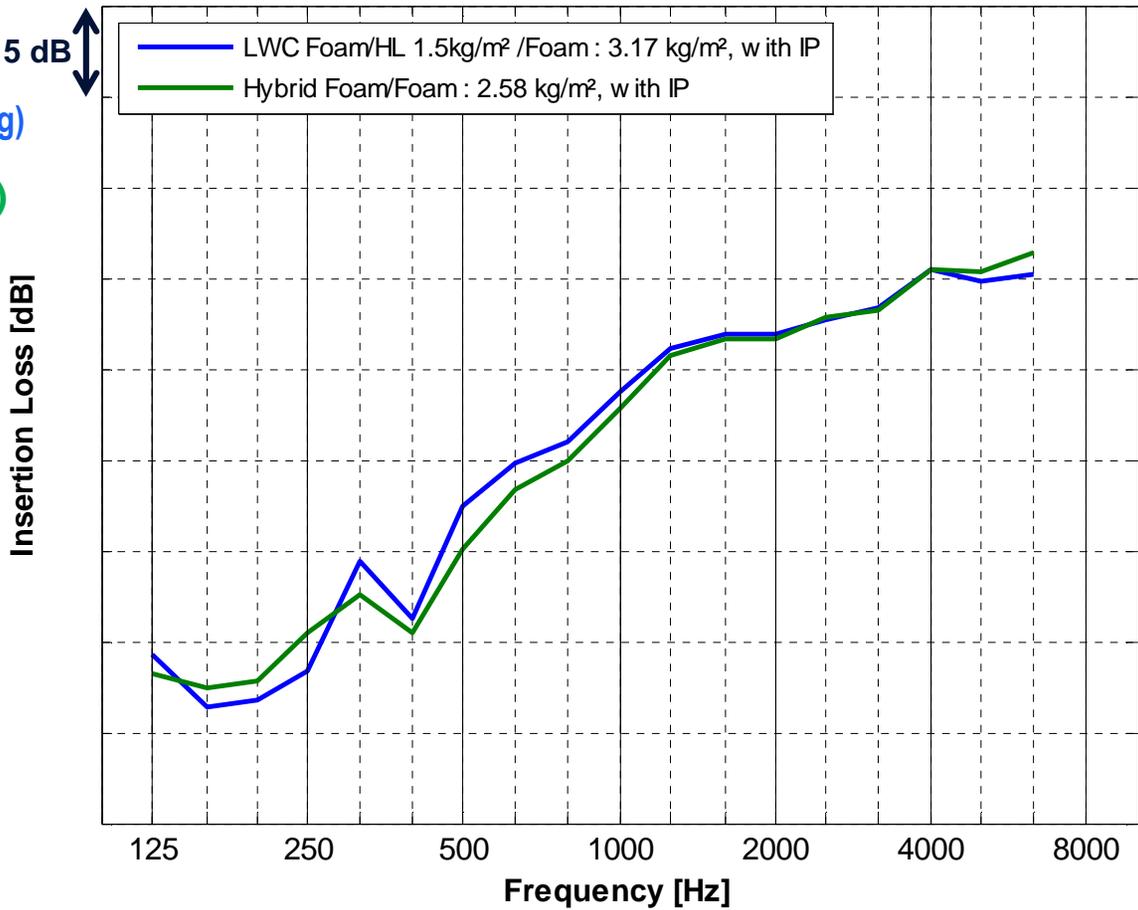
# Acoustical validations on a dash insulator

Reverberant room measurements

## Comparison: LWC Foam/HL/Foam and Hybrid Foam/Foam

Configuration : part with I.P. without P.T.

- LWC Foam/HL/Foam : 3.17 kg/m<sup>2</sup> (5,9 kg)
- Hybrid Foam/Foam : 2.58 kg/m<sup>2</sup> (4,8 kg)



The Hybrid foam dash is on the line for global insulation vs. a heavier LWC in HF thank to better absorption and slightly below in MF (with IP & w/o Pass-throughs)

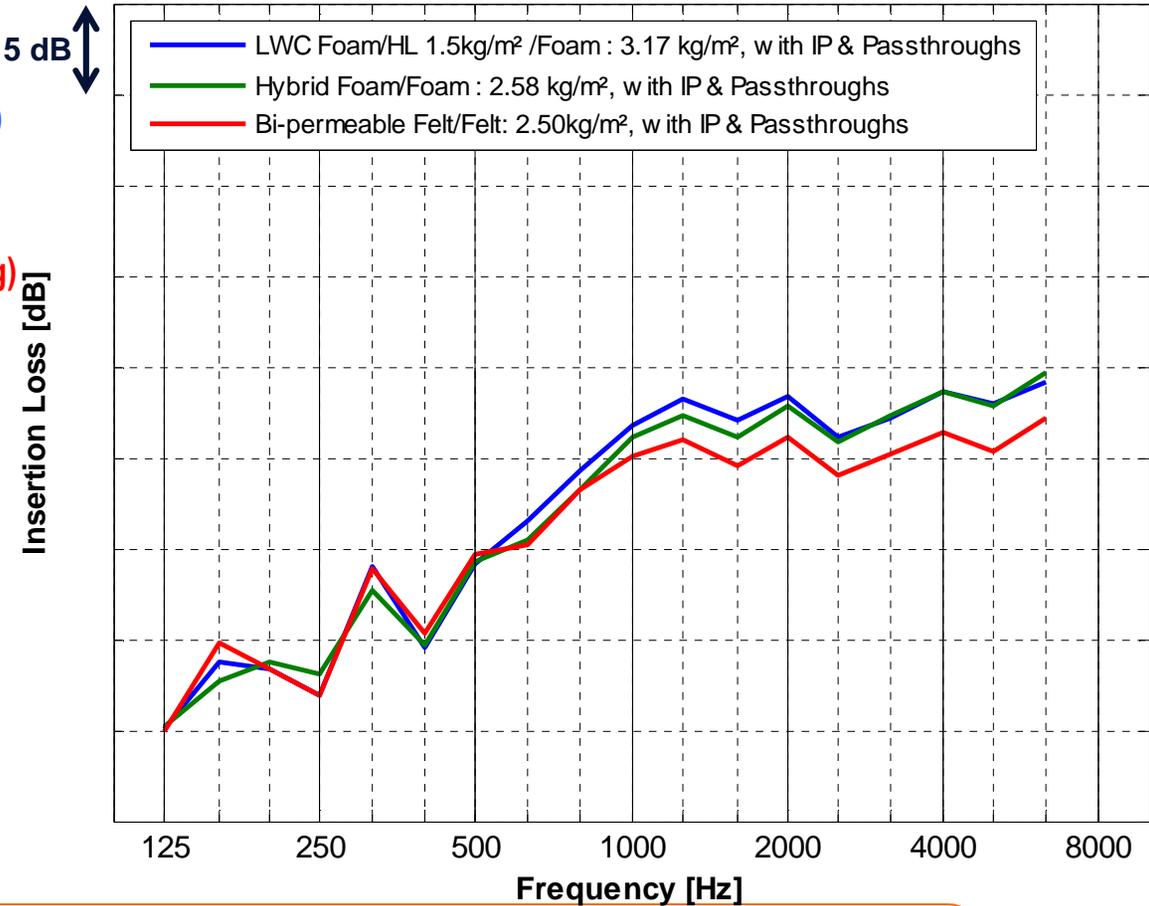
# Acoustical validations on a dash insulator

Reverberant room measurements

## Comparison: LWC Foam/HL/Foam, Hybrid Foam/Foam and Bi-permeable Felt/Felt

Configuration : part with I.P. with P.T.

- LWC Foam/HL/Foam : 3.17 kg/m<sup>2</sup> (5,9 kg)
- Hybrid Foam/Foam : 2.58 kg/m<sup>2</sup> (4,8 kg)
- Bi-permeable Felt/Felt: 2.50 kg/m<sup>2</sup> (4,7 kg)



The Hybrid foam dash is on the line for global insulation vs. a heavier LWC broadband (with IP & with Pass-throughs) and much better than Bi-permeable Felt/Felt in HF

## ■ Hybrid foam technology advantages:

- Very good absorption in the middle and especially high frequency range, while having good “mass-spring” like insulation slopes (18 dB/oct).
- Very light insulator concept with an equivalent barrier weighting less than 1,4 kg/m<sup>2</sup>, allowing to go in a flexible way from 1600 g/m<sup>2</sup> overall weight up to 2800 g/m<sup>2</sup>.
- Real 3D design thank to the two injection steps, which is very favorable to the overall absorption performance.
- Only one PUR foam formulation
- No draft angle required.
- No cutting step.
- Flexible Capex (only standard mold-holders necessary).

**faurecia**

*Technical perfection, automotive passion*

