POLITECNICO
MILANO 1863

Optimal design of damping composite lamination

Barcelona, 18-21 October 2022

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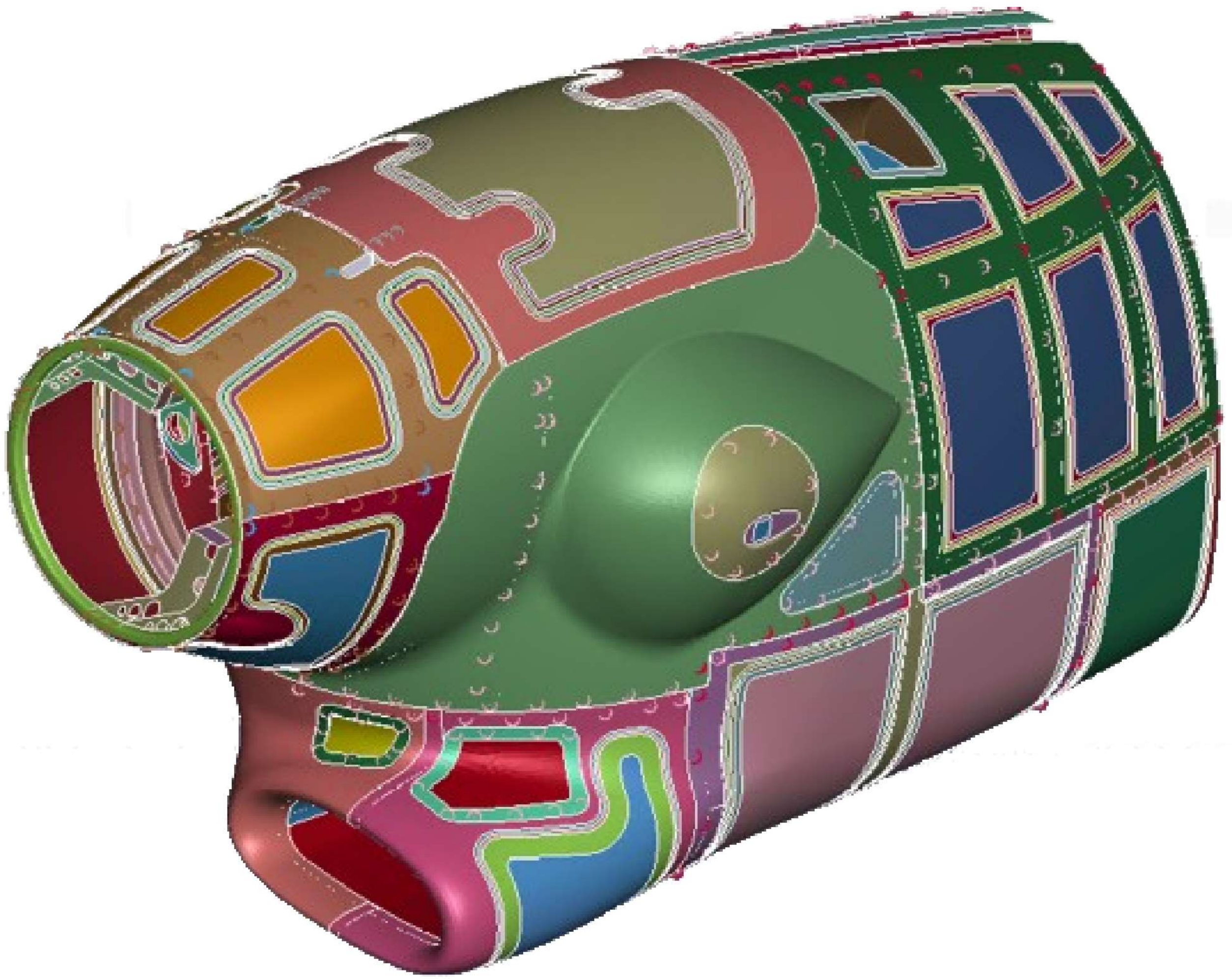
Optimal design of damping composite lamination (for noise and vibration reduction)

Minimize transmitted and generate noise

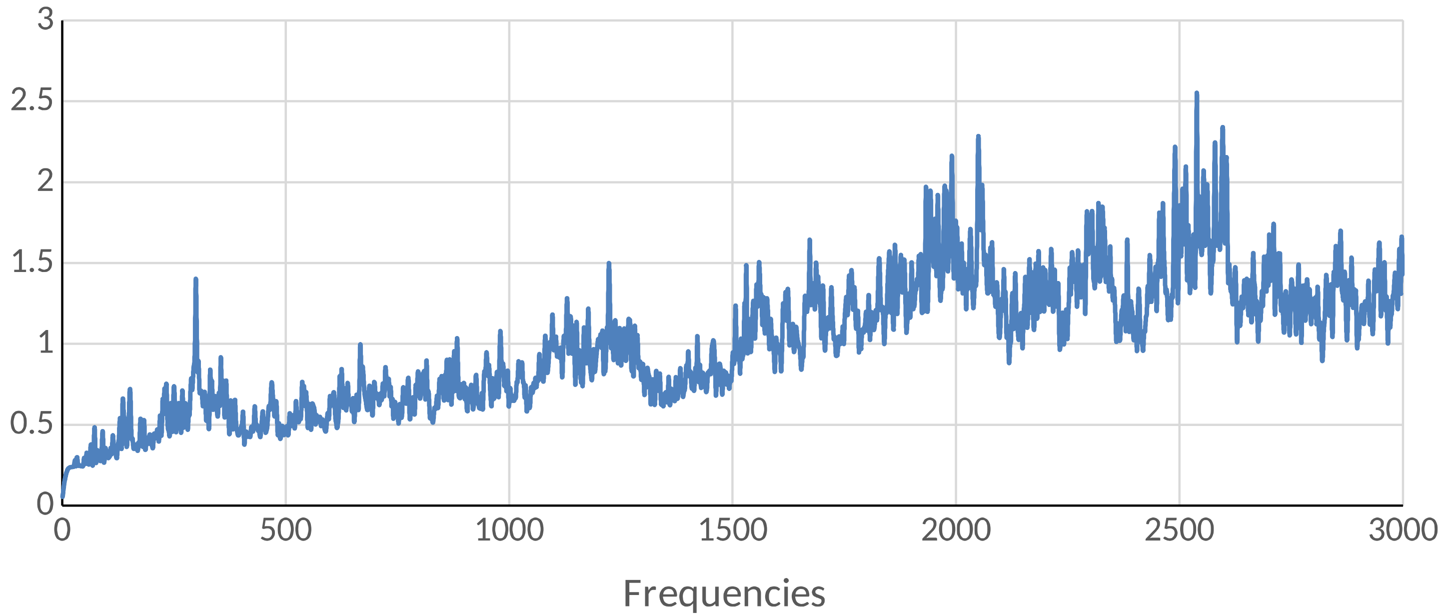


Input data

- Known:
  - transmission gears ratios and angular velocities

- Unknown:
- everything else
  - gearbox
  - nacelle structure (to be designed)
  - engine and gearbox connection (to be designed)
  - engine noise and vibrations spectra
  - hydraulic system vibration and noise

Modal analysis – estimation of generated air pressure



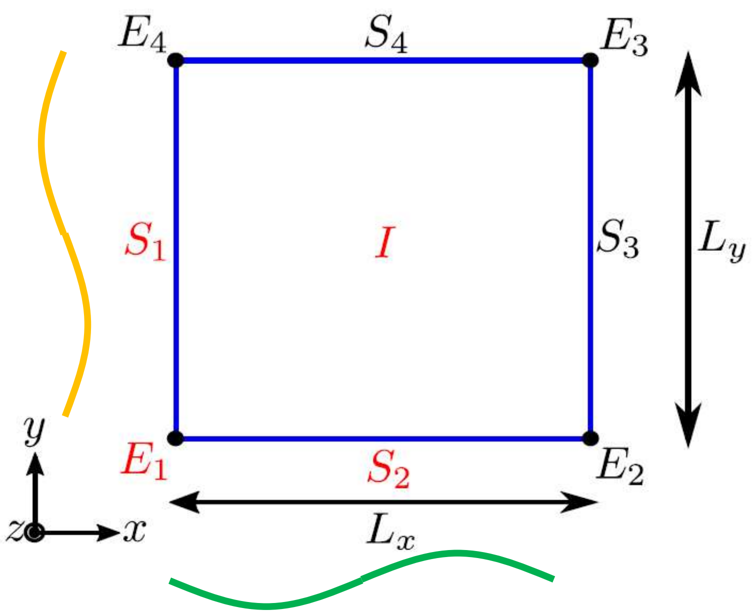
No reliable, missing data

Maximize nacelle shell DLF and TL

- Transfer Matrix Method

- FE $\mathbf{D}(\omega)\{\boldsymbol{q}\}=\{\boldsymbol{e}\}$

- Unit cell



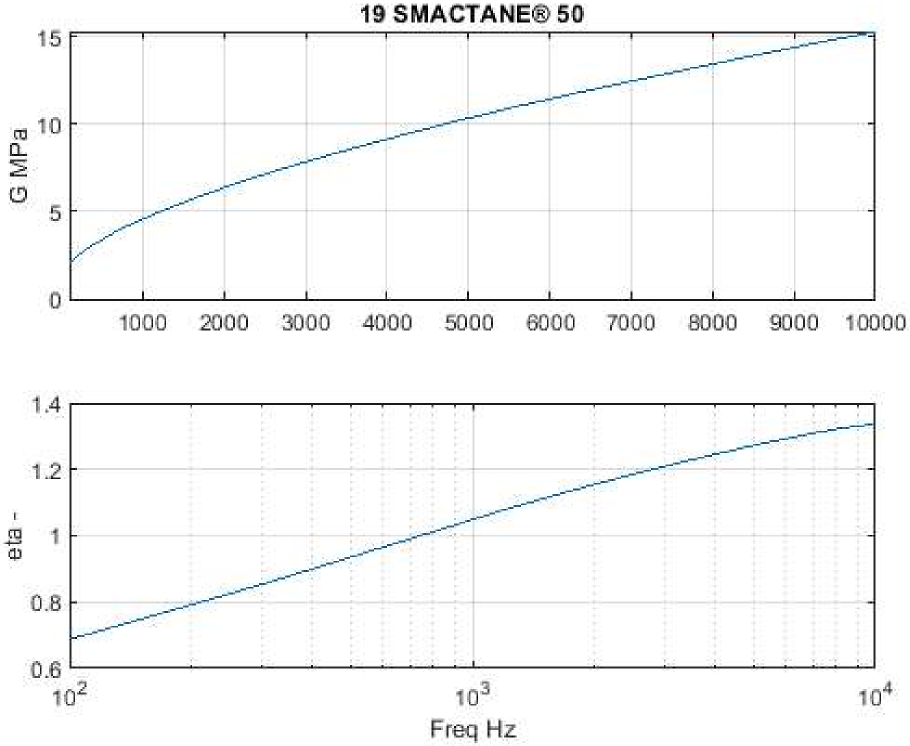
Periodic Boundary Conditions:

Transfer Matrix form [1]: $\mathbf{T}(\omega, k_x, n)\{\boldsymbol{q}'_{\boldsymbol{T}}\,\boldsymbol{e}'_{\boldsymbol{T}}\}^{\boldsymbol{T}}=\{\boldsymbol{q}'_{\boldsymbol{B}}\,\boldsymbol{e}'_{\boldsymbol{B}}\}^{\boldsymbol{T}}$

[1] Parrinello & Ghiringhelli JSV 2016

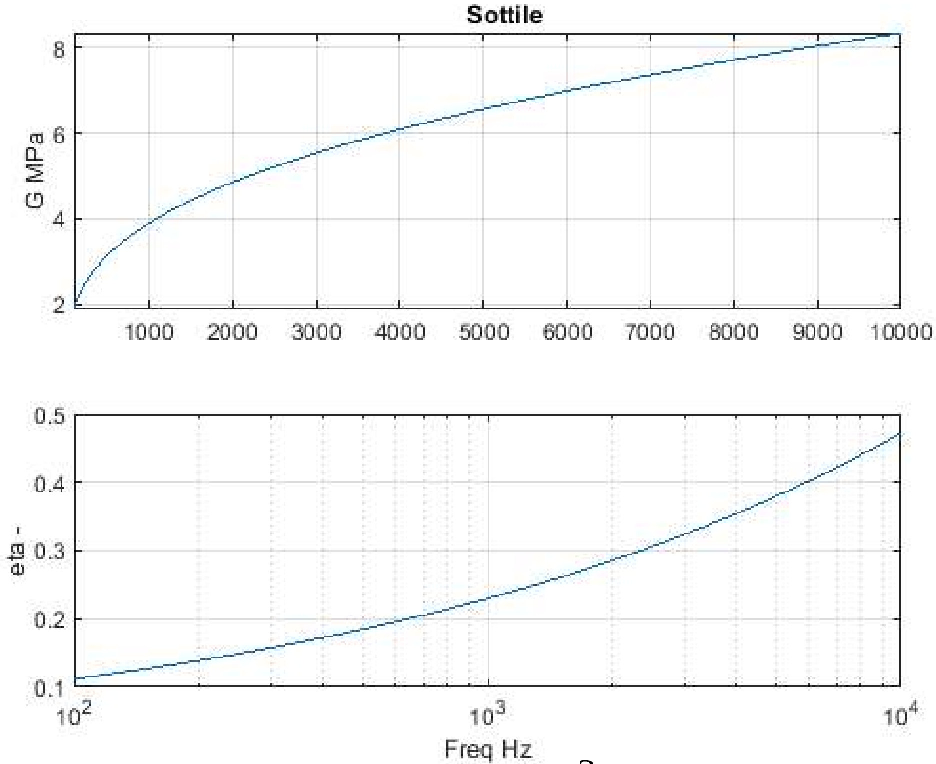
Damping material properties

SMACTAINE 50



$$\rho = 1190 \ \mathrm{kg/m^3}$$
$$\nu = 0.49$$

Experimental: chloroprene 3015



$$\rho = 1500 \ \mathrm{kg/m^3}$$
$$\nu = 0.48$$

CFRP, Honeycomb

$$E_{zz} = ??$$

Damping material properties

CFRP, Honeycomb

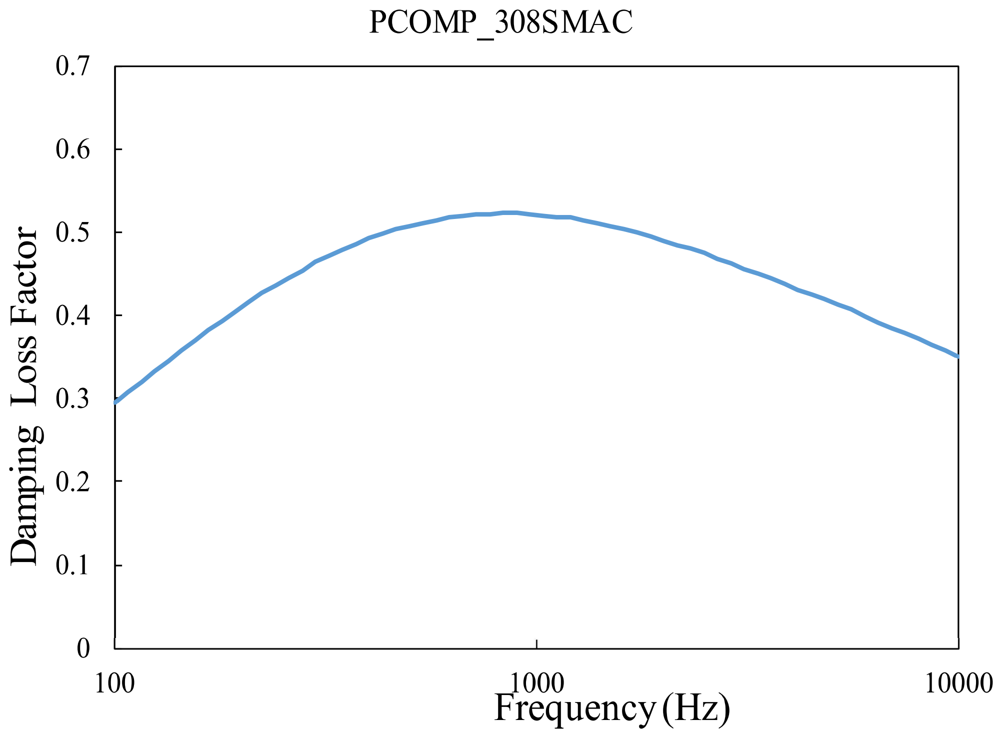
$$E_{zz} = ??$$

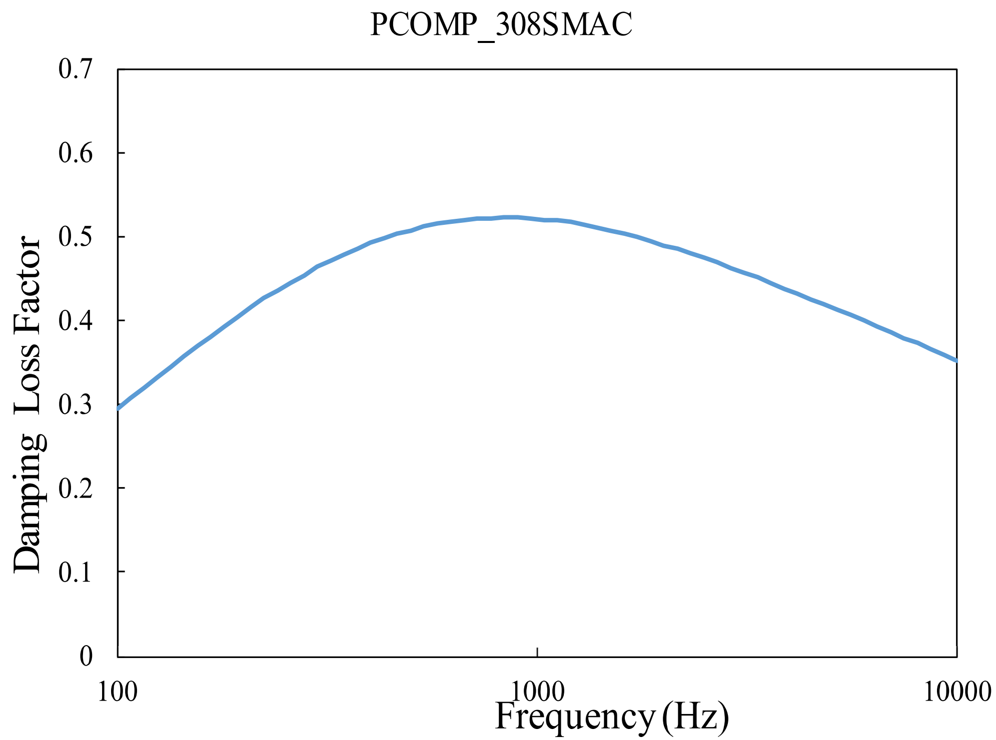
1

$E_{xx} = 10^6 (Pa)$
$E_{yy} = 10^6 (Pa)$
$E_{zz} = 131 \times 10^6 (Pa)$
$G_{yz} = 24.1 \times 10^6 (Pa)$
$G_{zx} = 44.8 \times 10^6 (Pa)$
$G_{xy} = 10 \times 10^6 (Pa)$
$\nu_{xy} = 0.9$
$\nu_{zx} = 0.01$
$\nu_{yz} = 0.01$
$\eta = 0.025$

2

$E_{xx} = 10^6 (Pa)$
$E_{yy} = 10^6 (Pa)$
$E_{zz} = 138 \times 10^6 (Pa)$
$G_{yz} = 24 \times 10^6 (Pa)$
$G_{zx} = 38 \times 10^6 (Pa)$
$G_{xy} = 1 \times 10^6 (Pa)$
$\nu_{xy} = 0.9$
$\nu_{zx} = 0.01$
$\nu_{yz} = 0.01$
$\eta = 0.025$

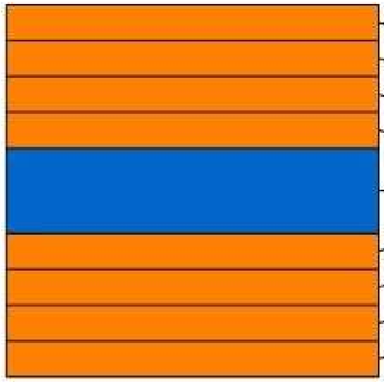




Typical lamination sequence

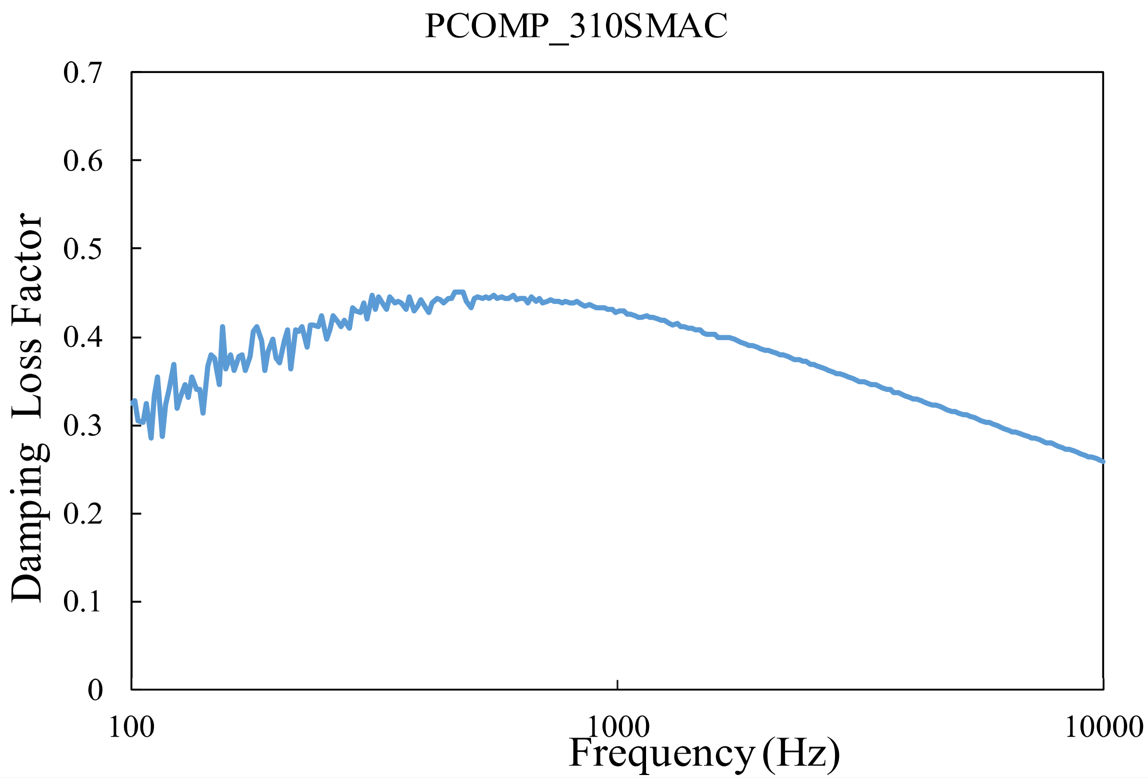
Case:

PCOMP_310SMAC

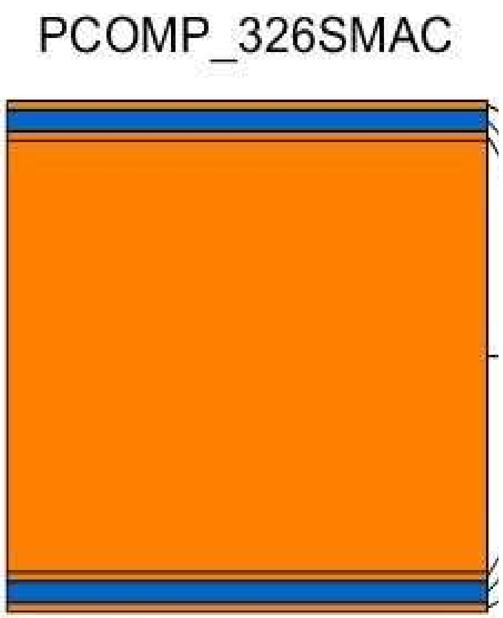


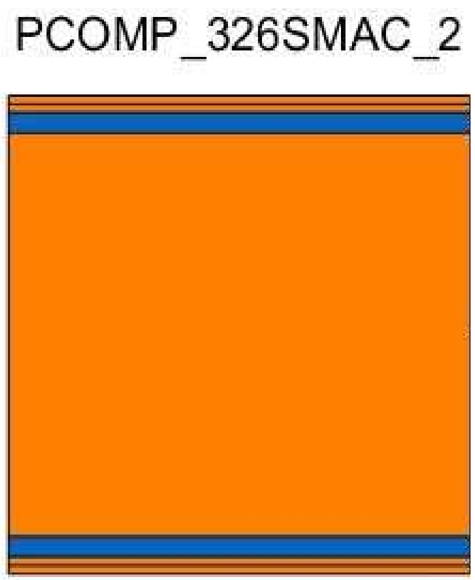
Stacking Sequence

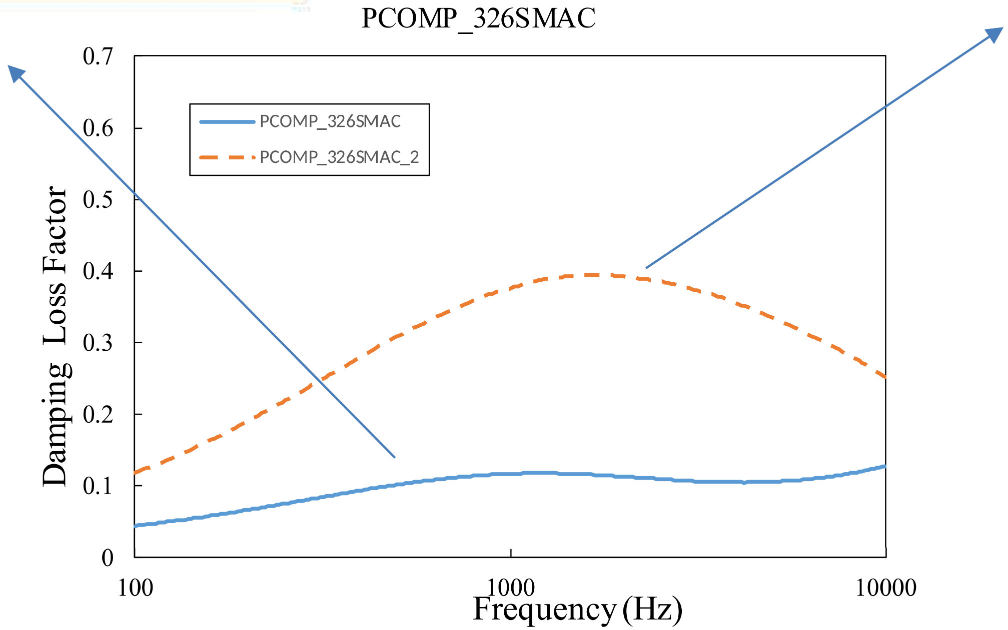
Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.5mm	0.595kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.18mm	3.152kg/sm



Typical lamination sequence







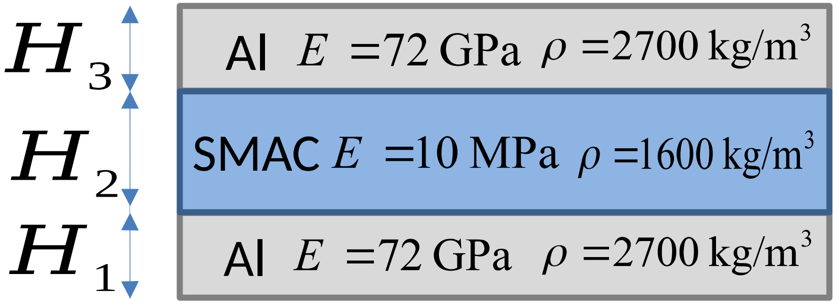
Simple optimization tests

$$f(H) = \frac{\int_{f=f_{Min}}^{f=f_{Max}} DLF \, df}{Mass}$$

Constraining layer: Aluminum

Damping layer: SMAC

Base structure: Aluminum



Case 1:

Objective function: $\text{Max}(f(H))$

Constrains: $\begin{cases} H_1 = 0.5 \text{ mm} \\ H_1, H_2, H_3 \leq 3 \text{ mm} \end{cases}$

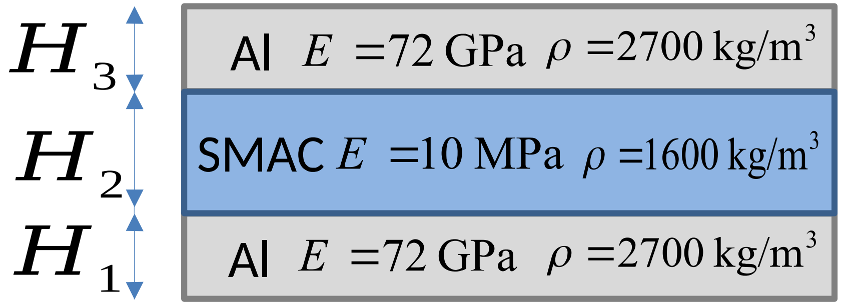
Result: $\begin{cases} H_1 = 0.5 \text{ mm} \\ H_2 = 0.668 \text{ mm} \\ H_3 = 0.216 \text{ mm} \end{cases}$

Simple optimization tests

Constraining layer: Aluminum

Damping layer: SMAC

Base structure: Aluminum



Case 2:

Objective function: $\mathrm{Max}(f(H))$

Constrains:
$$H_1 + H_3 \geq 2\ \mathrm{mm}$$
$$H_1, H_2, H_3 \leq 3\ \mathrm{mm}$$

Result:
$$H_1 = 1.0\ \mathrm{mm}$$
$$H_2 = 1.4\ \mathrm{mm}$$
$$H_3 = 1.0\ \mathrm{mm}$$

Case 3:

Constrains:
$$H_1^3 + H_3^3 \geq 8\ \mathrm{mm}^3$$
$$H_1, H_2, H_3 \leq 3\ \mathrm{mm}$$

Result:
$$H_1 = 1.6\ \mathrm{mm}$$
$$H_2 = 2.1\ \mathrm{mm}$$
$$H_3 = 1.6\ \mathrm{mm}$$

Composite

Case:

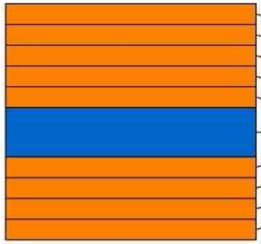
PCOMP1SMAC

Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.18mm	0.2142kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.07mm	3.0908kg/sm

Case:

PCOMP1SMAC

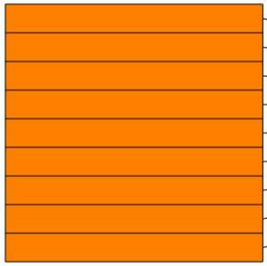


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.5mm	0.595kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.39mm	3.4716kg/sm

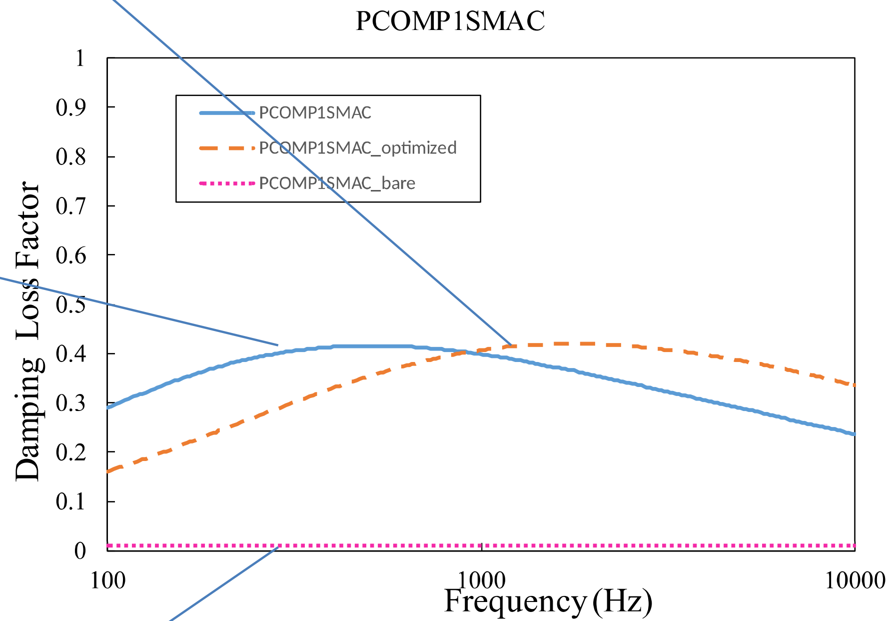
Case:

PCOMP1



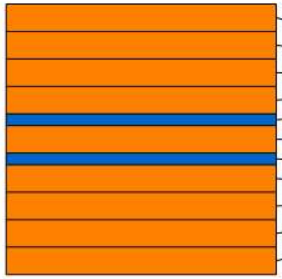
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	1.89mm	2.8766kg/sm



Composite – keep symmetric lamination

Case:
PCOMP1SMAC3



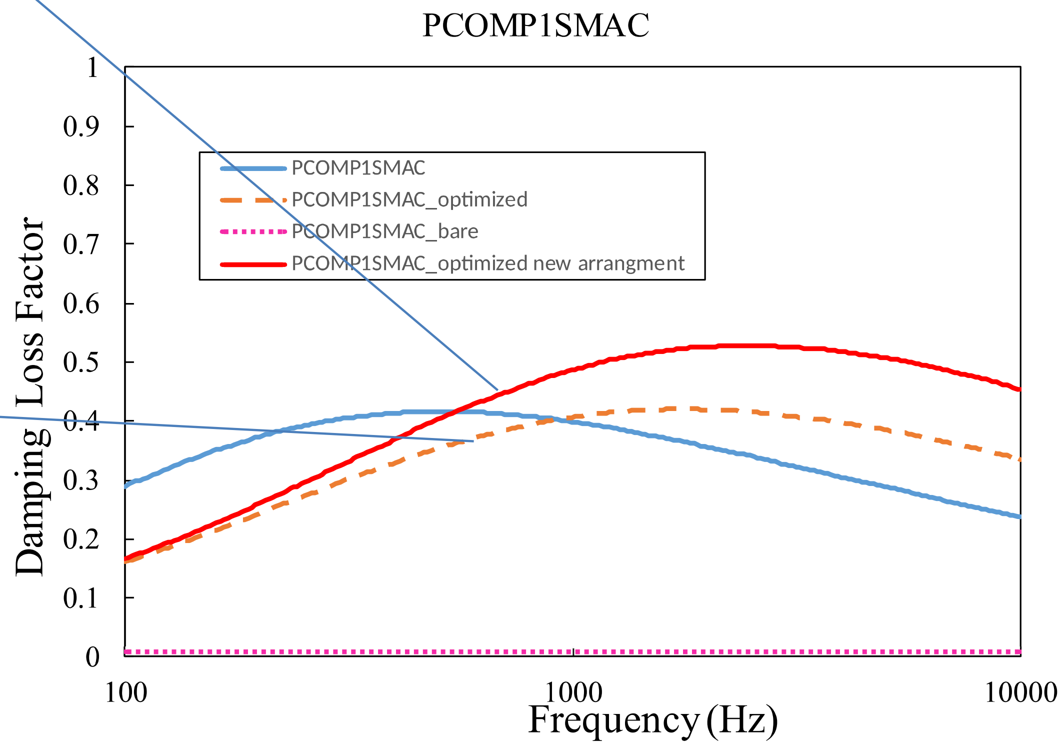
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.09mm	0.1071kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.09mm	0.1071kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.07mm	3.0908kg/sm

Case:
PCOMP1SMAC

Stacking Sequence

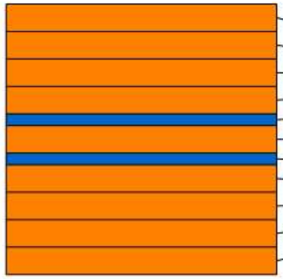
Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.18mm	0.2142kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.07mm	3.0908kg/sm



Composite – keep symmetric lamination

Case:

PCOMP1SMAC3

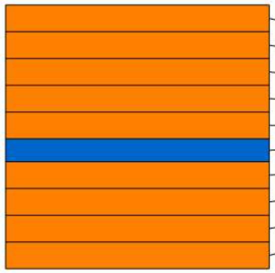


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.09mm	0.1071kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.09mm	0.1071kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.07mm	3.0908kg/sm

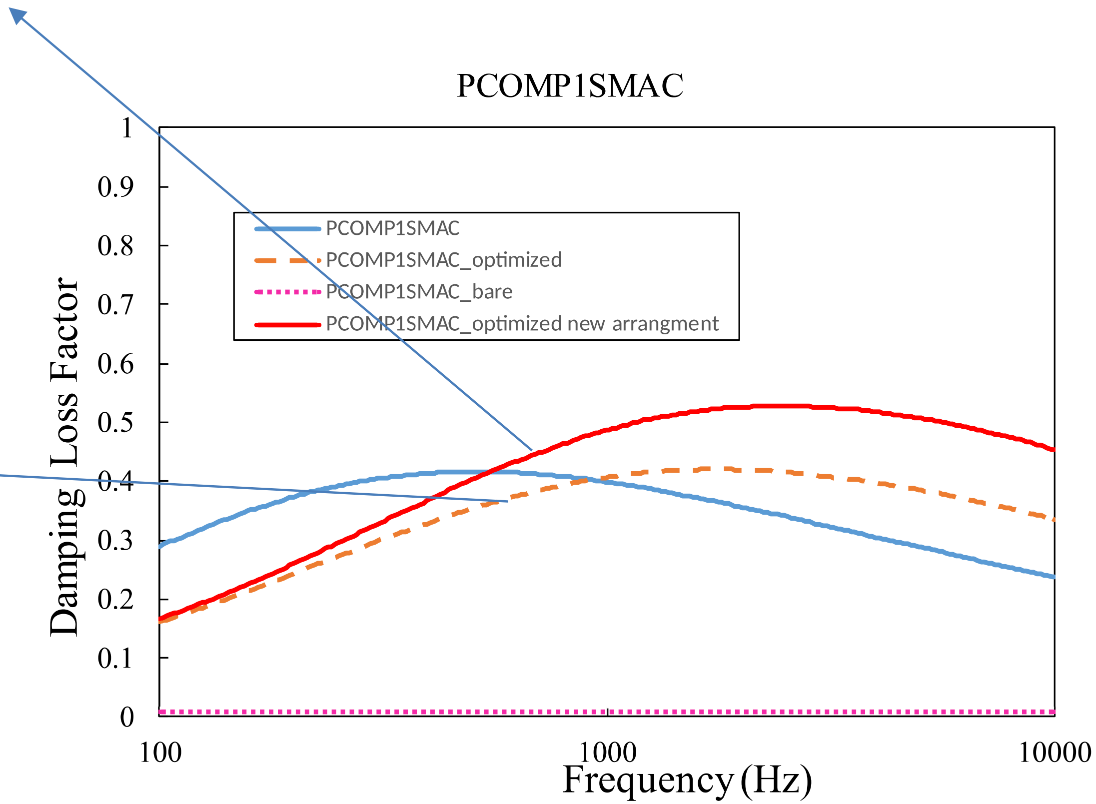
Case:

PCOMP1SMAC



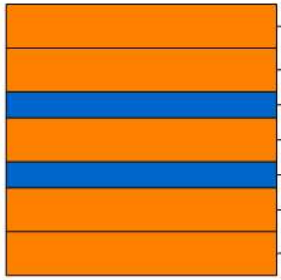
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.18mm	0.2142kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
	2.07mm	3.0908kg/sm



Composite – keep symmetric lamination

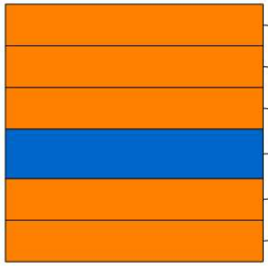
Case:
PCOMP_308SMAC3



Stacking Sequence

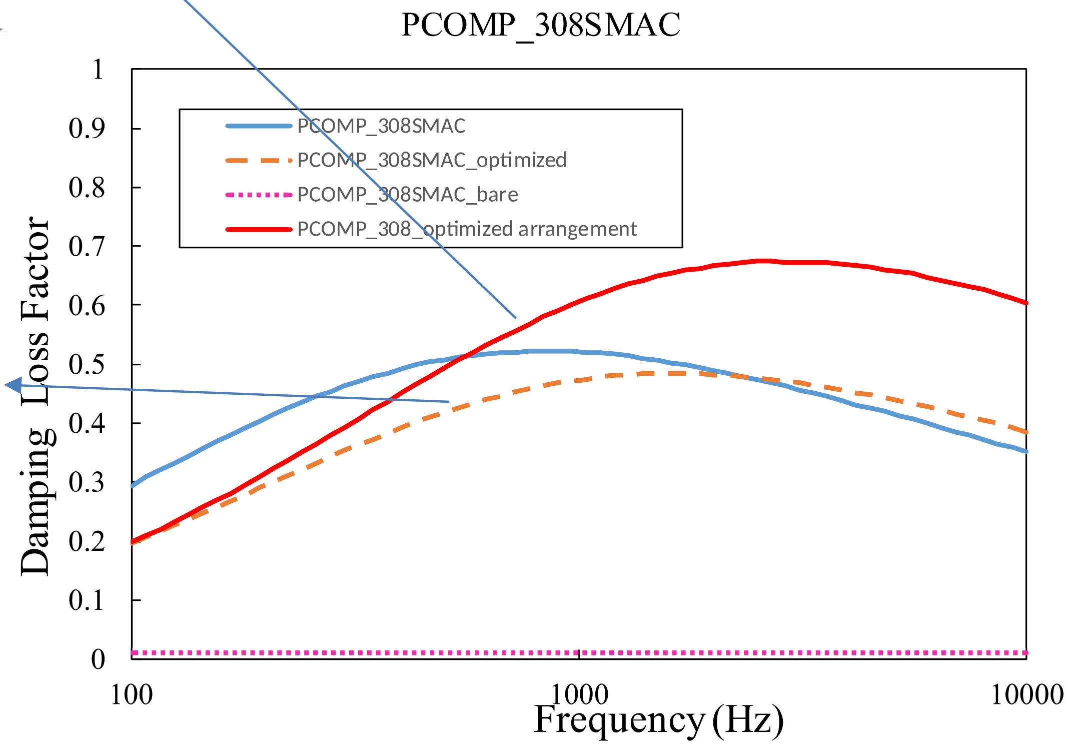
Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.125mm	0.14875kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.125mm	0.14875kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	1.3mm	1.8956kg/sm

Case:
PCOMP_308SMAC



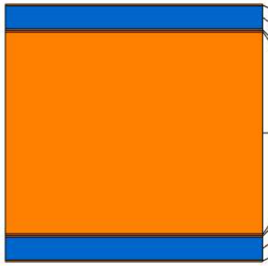
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.25mm	0.2975kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	1.3mm	1.8956kg/sm



Honeycomb

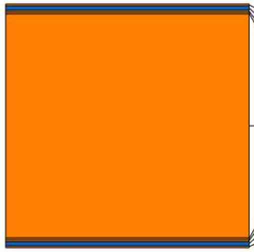
Case:
PCOMP_429SMAC



Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	2.9mm	3.451kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
55 NOMEX A1-3-48 I.MA.TEC. da Rep:Comfort 2	25.4mm	1.2192kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	2.9mm	3.451kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	32.46mm	10.0389kg/sm

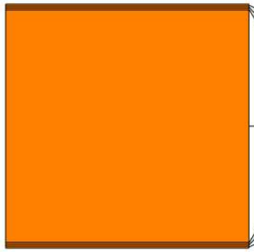
Case:
PCOMP_429SMAC



Stacking Sequence

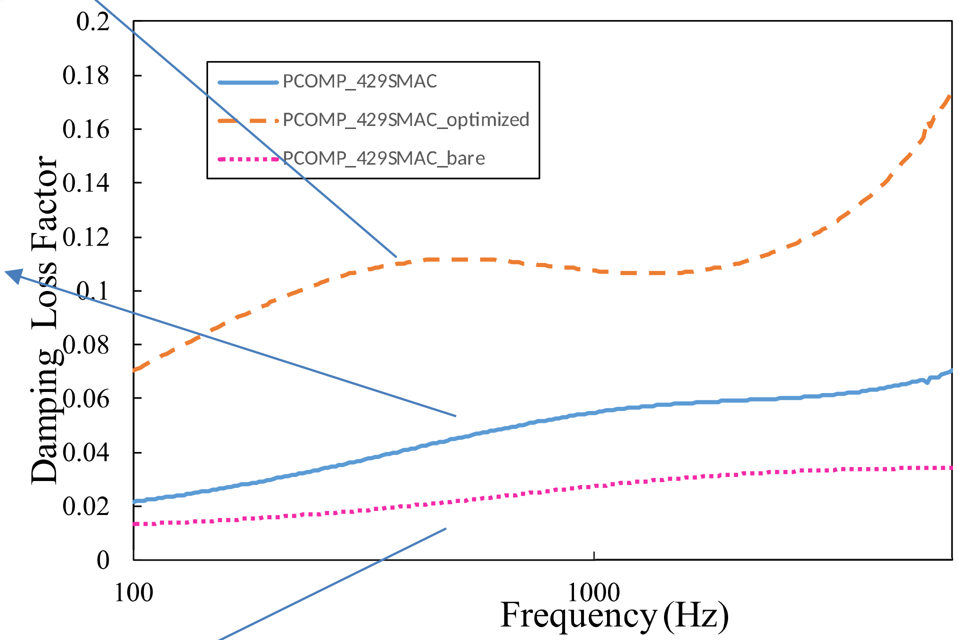
Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.5mm	0.595kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
55 NOMEX A1-3-48 I.MA.TEC. da Rep:Comfort 2	25.4mm	1.2192kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.5mm	0.595kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	27.66mm	4.3269kg/sm

Case:
PCOMP_429



Stacking Sequence

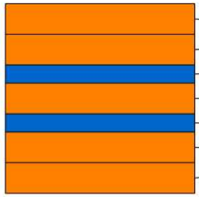
Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
55 NOMEX A1-3-48 I.MA.TEC. da Rep:Comfort 2	25.4mm	1.2192kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	26.66mm	3.1369kg/sm



Transmission loss – added barrier

Case:

PCOMP_308SMAC3

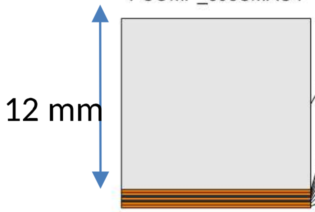


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.125mm	0.14875kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.125mm	0.14875kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	1.3mm	1.8956kg/sm

(a)

PCOMP_308SMAC4



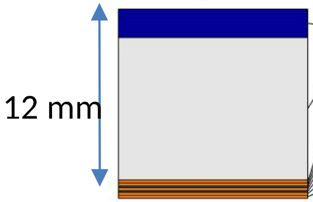
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
25 SMAC FOAM eq.RepComfort 0	12mm	0.108kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	1.9917kg/sm

(b)

Case:

PCOMP_308SMAC4



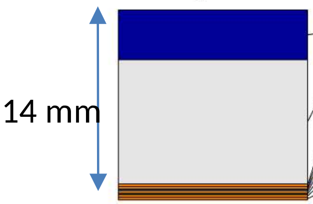
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	2mm	3.02kg/sm
25 SMAC FOAM eq.RepComfort 0	10mm	0.09kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	4.9937kg/sm

(c)

Case:

PCOMP_308SMAC4



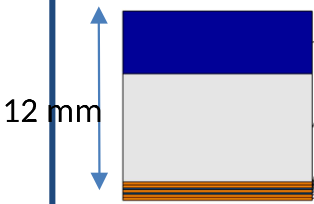
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	4mm	6.04kg/sm
25 SMAC FOAM eq.RepComfort 0	10mm	0.09kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	15.29mm	8.0137kg/sm

(d)

Case:

PCOMP_308SMAC4



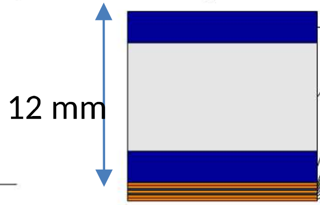
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	4.4mm	6.644kg/sm
25 SMAC FOAM eq.RepComfort 0	7.6mm	0.0684kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	8.5961kg/sm

(e)

Case:

PCOMP_308SMAC4

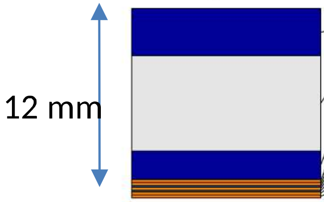


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	2.2mm	3.322kg/sm
25 SMAC FOAM eq.RepComfort 0	7.6mm	0.0684kg/sm
24 SMAC BARRIER 0	2.2mm	3.322kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	8.5961kg/sm

(f)

PCOMP_308SMAC4



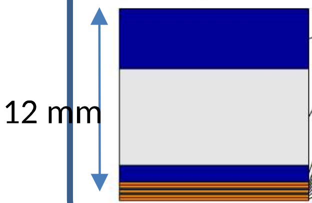
Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	3.31mm	4.9981kg/sm
25 SMAC FOAM eq.RepComfort 0	6.69mm	0.06021kg/sm
24 SMAC BARRIER 0	2mm	3.02kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	9.962kg/sm

(g)

Case:

PCOMP_308SMAC4

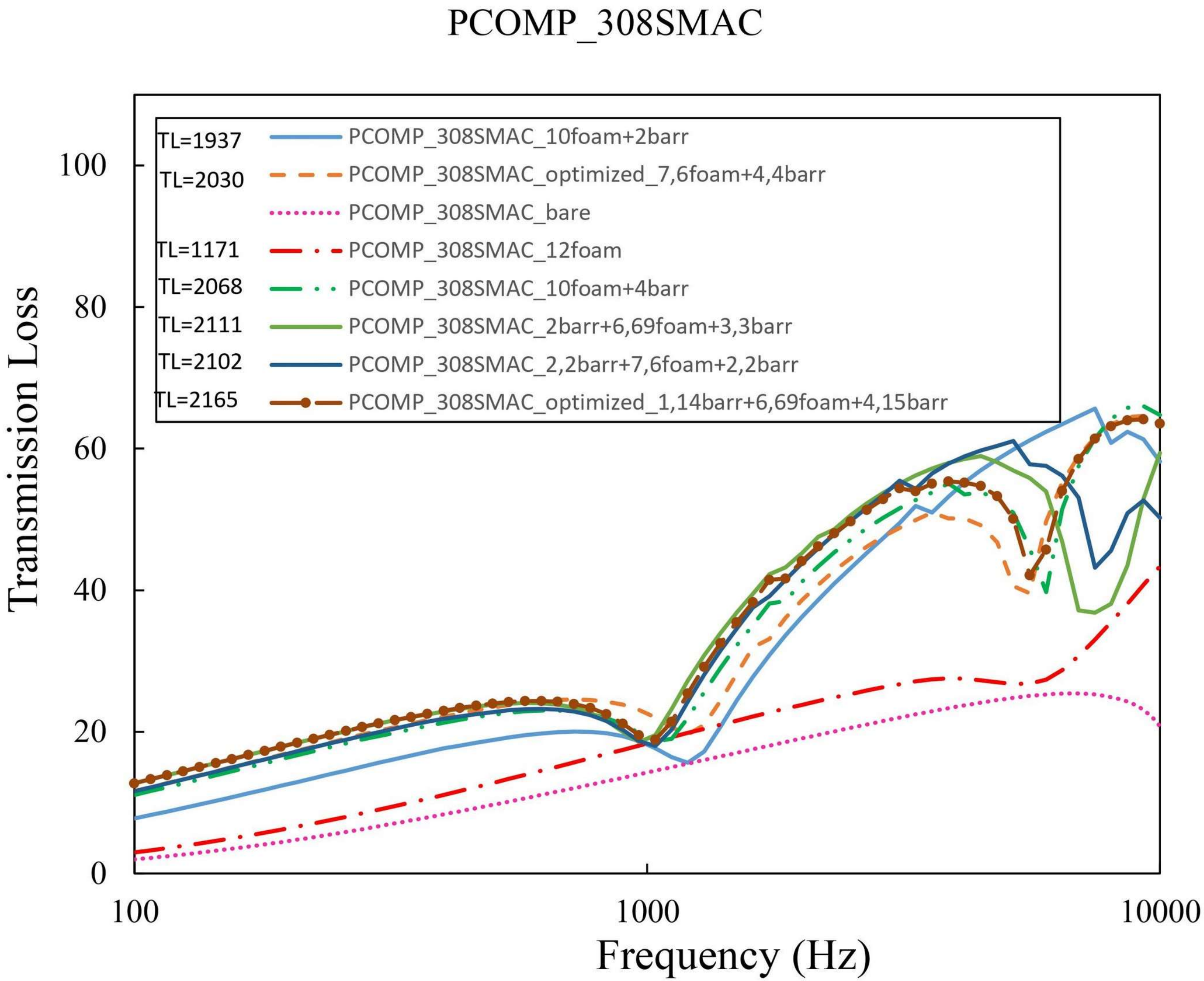


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	4.153mm	6.27103kg/sm
25 SMAC FOAM eq.RepComfort 0	6.6967mm	0.0602703kg/sm
24 SMAC BARRIER 0	1.149mm	1.73499kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	13.29mm	9.95kg/sm

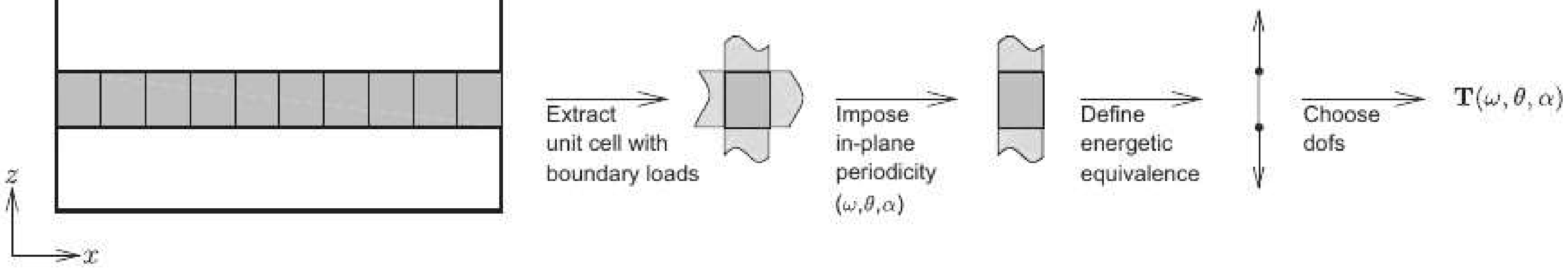
(h)

Transmission loss – added barrier



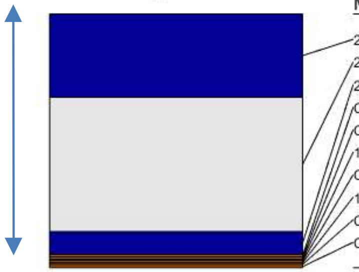
The project leading to this application has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 864726. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

Transfer Matrix Method



Proportion law

Case:
PCOMP_308SMAC4

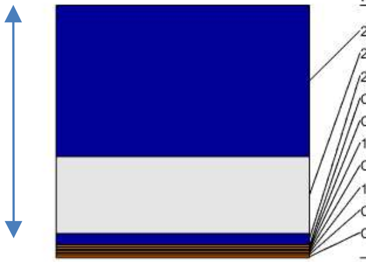


Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	8.306mm	12.5421kg/sm
25 SMAC FOAM eq.RepComfort 0	13.3934mm	0.120541kg/sm
24 SMAC BARRIER 0	2.298mm	3.46998kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	25.29mm	18.0163kg/sm

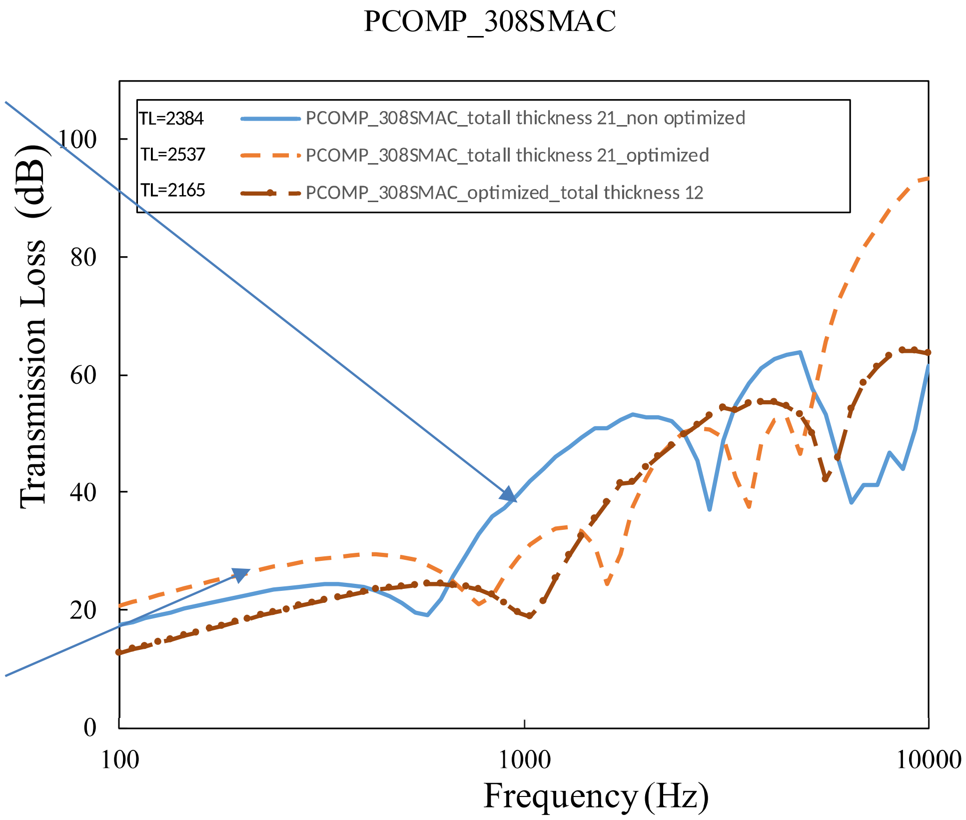
Optimized

Case:
PCOMP_308SMAC4



Stacking Sequence

Material / Mesh	Thickness	Specific Mass
24 SMAC BARRIER 0	15.142mm	22.8644kg/sm
25 SMAC FOAM eq.RepComfort 0	7.7275mm	0.0695475kg/sm
24 SMAC BARRIER 0	1.1305mm	1.70705kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
19 SMACTANE® 50 0	0.12mm	0.1428kg/sm
CFRP TRAIL 0	0.21mm	0.31962kg/sm
CFRP TRAIL 45	0.21mm	0.31962kg/sm
	25.29mm	26.5247kg/sm



- We can conclude that the optimization for different total thicknesses does not obey the proportion law