Sub-wavelength acoustic liner
via “metamaterials”

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AERIALIST

AdvancEd aircRaft-noIse-AlLeviation devIceS using meTamaterials

• To disclose the potential of metamaterials to envisage innovative devices for the mitigation of the civil aviation noise

• Achieve the noise reduction targets foreseen by the Advisory Council for Aeronautics Research in Europe (ACARE) Flightpath 2050
  – Reduce perceived noise emission of flying aircraft by 65%.

• Focus on the reduction of the noise propagating outside turbofan nacelles
In modern aircraft, most of the engine noise attenuation is provided by liners, in the internal walls of the nacelle, designed to reduce both broadband and tonal noise.

- **Design Limitations**
  - Frequency response is dependant on resonator depth.
  - High depths result in narrow peaks for low and high frequencies.
  - Shallow depths result in broader peaks at higher frequencies.
Acoustic Metamaterials

• Synthetic material that exhibits global mechanical properties beyond natural behaviour
  – Often represented by a structure with a periodic pattern

• Proposed Acoustic metamaterial classification depending on the type of acoustic response
  – energy absorption (subtraction of the energy associated to the acoustic pressure perturbations in the field by “trapping” and/or dissipation effects)
  – energy redistribution (directivity pattern distortion of the total acoustic field by scattering)
Explored designs
DENORMS design

• Benchmark design proposed by the DENORMS COST Action consists of a periodic structure of cubes with a spherical internal cavity connected through cylindrical openings on each face of the cube.

• Design variations
Influence of printing technology on acoustic performance
Influence of printing technology on acoustic performance
Reduced-order Models
10 layer deep DENORMS cell
Reduced-order Models
combined 4, 6, 8 and 10 layer depths of the DENORMS cell

- Exp. DLP (Polymer)
- Exp. FDM (Polymer)
- Num. Full viscothermal model
- Num. Low Reduced Frequency $D_h=0.5\text{mm}$
- Num. Low Reduced Frequency $D_h=1.3\text{mm}$
- Num. Low Reduced Frequency $D_h=2.6\text{mm}$
Reduced-order Models
combined 4, 6, 8 and 10 layer depths of the DENORMS cell
A sub-wavelength test configuration

- Staggered perforations alternated between patterns A and B
- Air gap of 2 mm
- Direct patterns of A or B
## Configurations

<table>
<thead>
<tr>
<th>Configuration 1</th>
<th>AB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Configuration 2</td>
<td>ABAB</td>
</tr>
<tr>
<td>Configuration 3</td>
<td>ABABAB</td>
</tr>
<tr>
<td>Configuration 4</td>
<td>AAA</td>
</tr>
</tbody>
</table>
Configuration 2

![Diagram showing absorption coefficient vs. frequency for Configuration 2 with numerical and experimental data.](image-url)
Configuration 3
Configuration 3
Configuration 3
Configuration 4
Staggered vs Direct

Absorptivity

- COMSOL direct
- COMSOL staggered

Hertz

0 500 1000 1500 2000 2500 3000 3500 4000

alpha

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

mm

0 5 10 15

Colors represent:

- 0
- 0.02
- 0.04
- 0.06
- 0.08
- 0.1
- 0.12
- 0.14
- 0.16
- 0.2
Conclusions

➢ Experimental and numerical absorption in agreement
  ➢ Plate resonances in experiments between 1250Hz and 2000 Hz
  ➢ Mass added in an attempt to counter act this effect
➢ Configuration 3 possesses the best response over the range starting at the lowest frequency
  ➢ Greatest cavity depth
➢ Dramatic subwavelength results
  ➢ Thicknesses of cells of order 4mm, 3mm
➢ Optimise sub-wavelength modelling
  ➢ Losses occur in gaps
Thank You