Experimental Investigation of Porous Materials for Trailing-Edge Noise Reduction

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Motivation

- Long-term collaborative research initiative *CRC 880: Fundamentals of High Lift for Future Civil Aircraft*

**Focus**: quiet short take-off and landing (STOL) for civil aircraft operations in close proximity to the population

**Technology Challenge**: Extreme lift augmentation vs. low noise immersion

**Concept**: active high lift system, non-slotted flap with flow control (Coanda effect), droop nose
Research goals

Airframe noise from active high-lift systems

(1) Physical understanding of source mechanisms

(2) High-lift noise reduction by advanced porous materials

(3) Development of aeroacoustically tailored materials

M. Pollenske, AIAA 2010-3881
Generic setup - DLR F16 2D-airfoil

- parametric investigations effect of porous materials on trailing-edge noise

Block porous TE add-ons:

Acoustic Wind Tunnel Braunschweig (AWB)
Material characterization

Computertomography (CT) for porosity, pore morphology (and damage behavior)

1. Measurement: Image stacks of radiographic images 0-360°
2. Reconstruction of sample, 2-D planes (grey scale)
3. 3-D volume with detected surface

- Measurement of structures and porosity with defect detection for Regions of Interest (ROI)
- 2-D cross sections of volume for line segmentation technique (leading to segment length)

CT Reconstruction of PA 200-250 (left: material ; right: porosity color coded)

CT Reconstruction of TE of PA 200-250 (left: material ; right: ROI-6 for porosity analysis)

(Source: J. Tychsen, N. Lippitz, J. Rösler, Metals, 8, 598 (2018))
Material characterization

Flow resistivity (and acoustic absorption) measurements:

• Problems:
  - samples with $\phi = 100$ mm ideally needed
  - trailing edges cannot be characterized
  - thin areas of TEs do not have representative amount of volume (pores may directly connect upper and lower side)

➢ comparative samples needed (made of constant rolled material)

Setup for measuring flow resistance with the air-flow process (Process B) according to DIN EN 29 053
(Source: adapted from N. Lippitz, NFL Forschungsbericht 2017-18, TU BS–NFL)

2 mm – sample separated by electrical discharge machining
left: surface (pores directly connecting upper and lower side)
right: original sample (thickness=16 mm) with eroded disc (2 mm)
Results – parameter variations (pore size, flow resistivity)

(1) Pressure release across TE necessary

(2) Largest low-f. (< 10 kHz) noise reduction, $R_{TE}^0 < 100 \text{Ns/m}^3$

(3) No High-f. excess noise (f < 20 kHz) when $w_p \leq 160 \mu m$
Tailored porous inserts for optimized noise mitigation performance

→1 chord length above from the TE

Lennart Rossian, DLR, 2017
$U = 50 \text{ m/s}$ \quad $\alpha = -0.6^\circ$

~ 2 dB noise reduction at 1.25 kHz

**SPL**$_{1/3}$ in dB

- **Solid TE**
- **PA 80-110**
- **PA 200-250 50%**
- **PA 80-110 + 120-150**
- **PA 80-110 + 200-250**
- **PA 120-150 + 200-250**
- **PA 80-110 gradient**
- **PA 200-250 gradient**

Oliver Maas, 2017

$f_{1/3}$ in kHz

Pore size

PA 120-150 + 200-250
PA 200-250 gradient
PA 80-110 + 200-250
PA 200-250 50%
PA 80-110 + 120-150
PA 80-110 gradient
PA 200-250 gradient
PA 80-110 reference
Low frequency noise (1.25-3.15 kHz)

\[ f_m = 3.15 \text{ kHz} \]

- Solid TE
- PA 80-110
- PA 80-110 + 120-150
- PA 80-110 gradient

Effect of flow resistivity or stepwise resistivity adjustment?

Materials props not constant (different batch!)

Oliver Maas, 2017
Excess noise at high frequencies (12.5 kHz)

\[ f_m = 12.5 \text{ kHz} \]

\[ \text{SPL}_{1/3} \text{ in dB} \]

\[ x \text{ in mm} \]

Oliver Maas, 2017
Variability of samples properties related to the manufacturing process

<table>
<thead>
<tr>
<th></th>
<th>Porosity</th>
<th>Pore size</th>
<th>Flow resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>μm</td>
<td>$10^3$ Ns/m^4</td>
</tr>
<tr>
<td>Reference, solid</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>PA 80-110</td>
<td>0.46</td>
<td>305</td>
<td>145.5</td>
</tr>
<tr>
<td>PA 200-250 50%</td>
<td>0.29</td>
<td>480</td>
<td>122.8</td>
</tr>
<tr>
<td>PA 80-110 gradient</td>
<td>0.27 - 0.57</td>
<td>222 - 416</td>
<td>839.6 - 44.2</td>
</tr>
<tr>
<td>PA 200-250 gradient</td>
<td>0.29 - 0.57</td>
<td>480 - 1052</td>
<td>122.8 - 4.0</td>
</tr>
<tr>
<td>PA 80-110 + 120-150</td>
<td>0.57 / 0.55</td>
<td>416 - 630</td>
<td>44.2 - 15.6</td>
</tr>
<tr>
<td>PA 80-110 + 200-250</td>
<td>0.57 / 0.57</td>
<td>416 - 1125</td>
<td>44.2 - 4.0</td>
</tr>
<tr>
<td>PA 120-150 + 200-250</td>
<td>0.55 / 0.57</td>
<td>630 - 1125</td>
<td>15.6 - 4.0</td>
</tr>
</tbody>
</table>
Material samples properties variability

Variations in flow resistivity

Variations in pore size
Material samples properties variability – effect of permeability gradient

\( u_\infty = 50 \text{ m/s} \)
\( \alpha = -0.6^\circ \)

**PA120-150 (2018)**
- reference w. blunt TE
- reference w. sharp TE
- PA120-150 (2-2018)
- PA120-150 interim. grad.
- PA120-150 strong grad.

**PA120-150 (2019)**
- reference w. blunt TE
- reference w. sharp TE
- PA120-150 (3-2019)
- PA120-150 weak grad.
Mitigation of high-frequency excess noise

Hole diam.: 45 μm – 90 μm

Hollow supporting structure
High-lift system with active flow control

Porous TE inserts

400 mm
High-lift system with active flow control

Porous insert

96 mics. Phased array

8 free-field microphones (above/below wing)
High-lift system with active flow control
High-lift system with active flow control
High-lift system with active flow control

\[ u_c = 50 \text{ m/s} \]
\[ \alpha = -0.6^\circ \]

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\( u_c = 35 \text{ m/s} \)
\[ \alpha = 11^\circ \]

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Array measurements from above

Assumed trailing-edge noise directivity
Conclusions

**Material characterization:**
- samples with $\varnothing = 100\text{mm}$ ideally needed
- trailing edges (as in the experiment) cannot be characterized
- thin areas of TEs do not have representative amount of volume (pores may directly connect upper and lower side)

**Acoustics**
- Pressure release across TE necessary
- Largest low-f. (<10kHz) noise reduction, $R_{TE}^0 < 100 \text{Ns/m}^3$
- No High-f. excess noise ($f < 20 \text{kHz}$) when $w_p \leq 160 \mu m$
- Conflicting criterias!
- Combination of hydraulically smooth porous plates and porous metals
- **Consistency of manufacturing process is critical to ensure consistency materials properties**
Conclusions

**Acoustic continued …**
- Quantification of the effect of graded porous properties difficult in the experiment
- Results of the generic test at a 2D airfoil successfully transposed to active flow control high-lift system (TE noise reduction on the order of ~10 dB)
- Porous insert integration details might be important in defining largest noise reduction
- Noise reduction at low frequencies (< 2kHz): **25%** of porous length sufficient for equivalent results