DETERMINATION OF ACOUSTIC CHARACTERISTICS OF SAMPLES OF MULTILAYER HONEYCOMB ACOUSTIC LINERS BASED ON NUMERICAL SIMULATION

O. Yu. Kustov,
I.V. Khramtsov,
V.V. Palchikovskiy
Using acoustic liner to reduce aircraft engine fan noise
Facility "Acoustic Interferometer"

Interferometer-30 in LNGMMA of the PNRPU

Acoustic Interferometer in the JSC «UEC-Aviadvigatel»

Scheme of the LNGMMA Interferometer-30:
1 – sound driver, 2 – supporting ring, 3 – liner sample, 4 – piston, 5 – guide sleeve
Impedance determination by transfer function method

\[
P_{1k}^{(j)} = \frac{1}{N} \sum_{n=0}^{N-1} p_{1n}^{(j)} e^{-i \frac{2 \pi k n}{N}}
\]

\[
P_{2k}^{(j)} = \frac{1}{N} \sum_{n=0}^{N-1} p_{2n}^{(j)} e^{-i \frac{2 \pi k n}{N}}
\]

\[
S_{P_2P_1}^{(j)}(f_k) = (P_{2k}^{(j)})^* \cdot P_{1k}^{(j)}
\]

\[
S_{P_2P_2}^{(j)}(f_k) = \frac{1}{j} \sum_{j=1}^{j} S_{P_2P_2}^{(j)}(f_k)
\]

\[
S_{P_2P_1}^{(j)}(f_k) = \frac{1}{j} \sum_{j=1}^{j} S_{P_2P_1}^{(j)}(f_k)
\]

\[
H_{21}(f_k) = \frac{S_{P_2P_2}(f_k)}{S_{P_2P_1}(f_k)}
\]

\[
R(f_k) = \frac{H_{21}(f_k) - e^{-i \frac{2 \pi k f}{c}(l_2-l_1)}}{e^{i \frac{2 \pi k f}{c}(l_2-l_1)} - H_{21}(f_k)} \cdot e^{2i \frac{2 \pi k f}{c} l_2}
\]

\[
Z(f_k) = \frac{1 + R(f_k)}{1 - R(f_k)}
\]

\[
\alpha(f_k) = 1 - |R(f_k)|^2
\]
Determination of acoustic characteristics of samples of acoustic liners based on numerical simulation

Based on the Helmholtz equation:

• Федотов Е.С., Пальчиковский В.В. Исследование работы резонатора гельмгольца в волноводе прямоугольного сечения // Математическое моделирование в естественных науках. 2014. Т. 1. С. 268-271.
• Комкин А.И., Быков А.И. Инерционная присоединенная длина горла резонаторов Гельмгольца // Акустический журнал. 2016. Т. 62. №3. С. 277-287.

Taking viscosity effects into account using linearized Navier - Stokes equations:

Determination of acoustic characteristics of samples of acoustic liners based on numerical simulation

Complete system of non-linear Navier-Stokes equations:
using only simplified samples of acoustic liner - one resonator (mainly of cylindrical shape) with one hole of perforated sheet in the center of the cell:

Complete system of non-linear Navier-Stokes equations:


Frequency 3.0 kHz

Determination of acoustic characteristics of samples of acoustic liners based on numerical simulation

Frequencies (1.0; 1.2; 1.4; 1.5; 1.6; 1.8; 2.0; 2.5; 3.0; 5.0 kHz).
The 3D computations are performed for two frequencies (1.5; 5.0 kHz).

Density contours when 160 dB normal incident planewave is imposed.

Frequency 3.0 kHz
Geometric parameters of acoustic liner sample

Acoustic liner sample is a single Helmholtz resonator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of perforated sheet, t</td>
<td>2 мм</td>
</tr>
<tr>
<td>Perforation, F</td>
<td>3 %</td>
</tr>
<tr>
<td>Diametr of hole, d</td>
<td>5 мм</td>
</tr>
<tr>
<td>Height of sample, H</td>
<td>20 мм</td>
</tr>
<tr>
<td>Outer diameter of sample, D</td>
<td>30 мм</td>
</tr>
<tr>
<td>Inner diameter of sample, $D_{vn}$</td>
<td>29 мм</td>
</tr>
</tbody>
</table>
Numerical simulation by COMSOL

- The system of linearized Navier-Stokes equations;
- Axisymmetric formulation of the problem;
- Frequency domain solution;
- Frequency step by 10 Hz;
- Pressure of the given amplitude at the inlet;
- Number of Elements 30486

Scheme of computational domain
Numerical simulation by ANSYS Fluent. Axisymmetric formulation

- System of Navier-Stokes equations taking into account compressibility;
- Method of solution – unresolved DNS;
- Axisymmetric formulation of the problem;
- Time increment of 1/65536 sec is simulated;
- Input signal is a random signal (white noise) with a uniform spectrum in the frequency range from 500 to 3600 Hz;
- Sound pressure levels – 130, 140, 150 dB.

Mesh:
61386 nodes
30347 elements
Numerical simulation by ANSYS Fluent. 3D formulation

- System of Navier-Stokes equations taking into account compressibility;
- Method of solution – unresolved DNS;
- 3D formulation of the problem;
- Time increment of $1/65536$ sec is simulated;
- Input signal it a random signal (white noise) with a uniform spectrum in the frequency range from 500 to 3600 Hz;
- Sound pressure levels – 130, 140, 150 dB.

Mesh:
300 000 elements
Numerical simulation a sample of double-layer acoustic liner by ANSYS Fluent

The problem statement is similar to a single-layer acoustic liner

Scheme of computational domain

Sound absorption coefficient

Field of pressure, speed and vorticity
Numerical simulation a sample of triple-layer acoustic liner by ANSYS Fluent

Scheme of computational domain

Sound absorption coefficient

Field of pressure, speed and vorticity
Comparison of numerical simulation results and experiments

Acoustic liners samples series

Sound absorption coefficient for sample №3 (hole diameter is 3 mm.)
The semi-empirical impedance model of acoustic liners is sensitive to geometry errors!

\[ Z = Z_{orifice} + Z_{cavity} \]

There is a noticeable discrepancy in the prediction of impedance between the semi-empirical model and experiment.
Numerical simulation of physical processes in a test sample of single-layer acoustic liner (d30)

Test sample

Computational model test liner sample: a) – geometry, b) – mesh

Acoustic characteristics of the test sample: solid curve – experiment, dashed curve – numerical simulation
Samples of single-layer acoustic liner with increased number of resonators (d50)

<table>
<thead>
<tr>
<th>Layer designation</th>
<th>Perforation (%)</th>
<th>Number of holes (piece)</th>
<th>Resonator height (mm)</th>
<th>Resonant frequency obtained in numerical simulation (Hz)</th>
<th>Resonant frequency obtained in experiment (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H24D50</td>
<td>7.5</td>
<td>35</td>
<td>24</td>
<td>1504</td>
<td>1544</td>
</tr>
<tr>
<td>H14D50</td>
<td>4.2</td>
<td>35</td>
<td>14</td>
<td>1640</td>
<td>1664</td>
</tr>
<tr>
<td>H10D50</td>
<td>2.5</td>
<td>21</td>
<td>10</td>
<td>1496</td>
<td>1556</td>
</tr>
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Numerical simulation of physical processes in a sample of single-layer acoustic liner with increased number of resonators. H24D50

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Used a detailed grid consisting of rectangular elements with an average linear element size of 0.5 mm and thickening on a wall of 20 layers with a growth factor of 1.2. The size of the parietal cell is 0.005 mm.
Numerical simulation of physical processes in a sample of single-layer acoustic liner with increased number of resonators. H24D50

Acoustic characteristics of H24D50 sample:
solid curve – experiment, dashed curve – numerical simulation

The meshes contain from 1.9 to 2.5 million elements.
Numerical simulation of physical processes in a sample of single-layer acoustic liner with increased number of resonators. H14D50

The meshes contain from 1.9 to 2.5 million elements.

Acoustic characteristics of H14D50 sample:
solid curve – experiment, dashed curve – numerical simulation
Numerical simulation of physical processes in a sample of single-layer acoustic liner with increased number of resonators. H10D50

The meshes contain from 1.9 to 2.5 million elements.

Acoustic characteristics of H10D50 sample:
- solid curve – experiment
- dashed curve – numerical simulation
Numerical simulation of physical processes in a sample of double-layer acoustic liner

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<th>Number of holes (piece)</th>
<th>Resonator height (mm)</th>
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Acoustic characteristics of the double-layer sample:
- solid curve – experiment, dashed curve – numerical simulation

Mesh: 4.7 mln. elements

Numerical simulation of physical processes in a sample of double-layer acoustic liner

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The computation of the sample took about 12 days when parallelized to 64 cores.

Computational model of the double-layer sample: a) geometry, b) mesh
Numerical simulation of physical processes in a sample of triple-layer acoustic liner

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</tr>
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Acoustic characteristics of the triple-layer sample: solid curve – experiment, dashed curve – numerical simulation

Mesh: 6.7 mln. elements

Numerical simulation of physical processes in a sample of triple-layer acoustic liner

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Computational model of the double-layer sample: a) geometry, b) mesh
Conclusions

Numerical simulation confirms the need for a qualitative approach to the experiment.
To verify the results of numerical simulations, the experiments with a test sample were conducted previously in a normal incidence interferometer with diameter of tube 30 mm. The manufacture of the sample was carried out using 3D printing technology. Then, acoustic liner samples with increased number of resonators were created and tested in a normal incidence interferometer with diameter of tube 50 mm. The geometric characteristics of the samples also corresponded to the parameters of acoustic liners used in aircraft engines.
As a result of the studies, it was found that the acoustic characteristics obtained in numerical simulation are in good agreement with the experimental data. Thus, we can conclude that the proposed approach can be applied in the future to predict the acoustic characteristics of various single-layer and multilayer acoustic liners operating under conditions of high sound pressure levels.
Thank you for the attention

Kustov Oleg Yurievich
- PNRPU
- Tel.: 8922-312-22-42
- E-mail: KustovOU@yandex.ru

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