# Fan Noise Reduction by Acoustic Liners Combined with Fine-Perforated-Film: Noise Tests by a Small Turbofan Engine DGEN 380

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**ABSTRACT**

**Resonant-type liner panels are one the primary countermeasures for the fan noise of aircraft engines, though the noise reduction performances of the liners are known to be tolerated by the flow streaming on the liner surface. Therefore, suppressing the effect of the flow on the liners is greatly important for larger noise reduction. In this study, a liner panel with a special surface structure was manufactured and applied to an outdoor test using a small turbofan engine, DGEN 380. The surface structure consisted of a special thin film, Fine-Perforated-Film (FPF), and a gap. The gap was fixed between the FPF and liner surface. In addition, a typical resonant-type liner and a hard wall were used for comparison, to investigate the effect of the structure. During the test, the samples were installed to the exhaust bypass duct of the DGEN 380 engine. The acoustic pressure was measured with a far field microphone array. Analysis and comparison of the results showed that the new structure suppressed the effect of the grazing flow and caused a larger amount of noise reduction, compared to the typical liner sample.**

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## 1. INTRODUCTION

Acoustic liner panels are passive devices that are one of the primary countermeasures for the fan noise of aircraft engines. Technical developments on the geometry of modern aircraft engines have realized higher efficiency, and increased the importance of fan noise reduction as well. The increment of the bypass ratio has lowered fuel consumption and jet noise emission, but was unbeneficial for fan noise components. In addition, larger diameter of fans decreased the line area per cross-section and lowered the noise frequency. A shorter nacelle concept [1] reduced the engine weight and further contributed to lower fuel emission during cruse, but decreased the area to install acoustic liner panels. Therefore, liner panels with less area for installation, or in other words, panels with better noise reduction efficiencies are highly required.

The most common type of liner panels is classified as resonant-type liners. These resonant-type liners consist of a perforated surface plate, a cavity, and a rigid back-plate, and the noise reduction properties have strong narrowband frequency peaks under static condition. Therefore, they are considered to be suitable for reducing tonal fan noise.

However, it is known that the noise reduction performances of resonant-type liners are depressed in most cases where there is flow, i.e., grazing flow, on the surface of the liners [2-4]. This makes it difficult to realize liner panels with high performance. The following tendencies are generally seen under grazing flow conditions:

- The amount of energy dissipation is depressed;
- The peak of energy dissipation broadens;
- The peak frequency of energy dissipation slides toward the higher direction.

These are generally explained to be caused by the flow streaming inside the liner opening [5,6].

To reduce the effect of the flow and realize high reduction performances under grazing flow conditions, a new liner concept with a special surface structure was proposed by the authors in a previous study [7]. The surface structure consisted of an acoustically transparent thin film called a Fine-Perforated-Film (FPF), and a gap (Figure 1) [8]. The structure had the purpose of preventing air flow from streaming inside the opening of the liner, and consequently reducing the general effects of grazing flow. Tests using a flow duct rig indicated that the new structure successfully reduced the deterioration of the noise reduction performance of the liner under grazing flow conditions. The structure showed promising results in a fundamental test, i.e., the flow duct test, but for further research, there was a need to apply it to more practical tests.

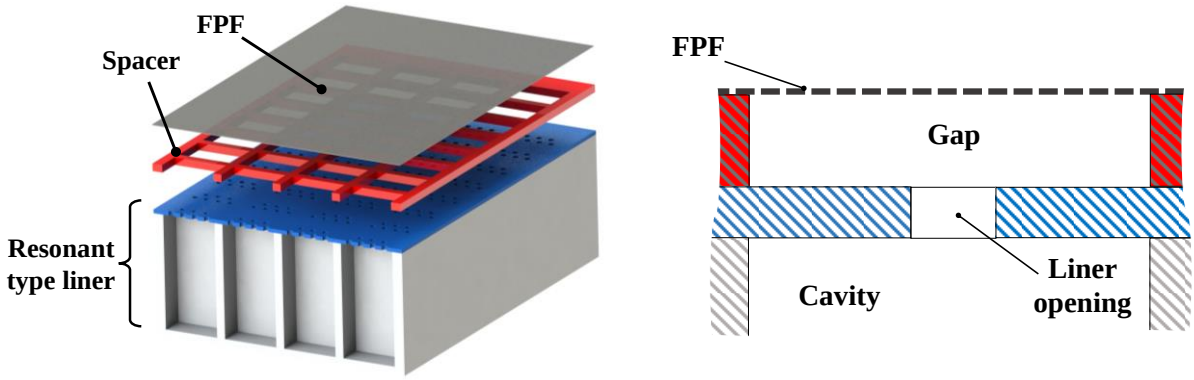



Figure 1: The configuration diagrams (left) and schematic cross section of the new concept liner.

In this study, a liner panel sample with the special surface structure was applied to an outdoor test using a small turbofan engine, DGEN 380. A typical resonant-type liner sample and a hard wall was also tested for comparison. During the tests, the samples were sequentially installed to the extended exhaust bypass duct of the engine. Results indicated that the two liner samples both largely reduced the noise around 1 BPF and 2 BPF, although the reduction of the typical liner sample was limiting. The sample with the special surface structure showed superiority over the "baseline" sample.

## 2. EXPERIMENTAL METHOD

### 2.1. The DGEN 380 Turbofan Engine

DGEN 380 is a high-pressure ratio, two-spool geared turbofan developed by Akira Technologies in France. Its fan diameter and axial length is 0.35 m and 1.13 m, respectively. The maximum thrust at sea level is 2,580 N, and the bypass ratio is 7.6. The cutaway view of DGEN 380 is shown in Figure 2. DGEN 380 is known for its easy operability; it can be started with the help of an electric motor and can be operated with a simple console. While running, engine parameters are monitored on a laptop PC and the engine is controlled by an automatic program referring to its corrected speed.

Figure 2: Cutaway view of the DGEN 380 turbofan engine

### 2.2. Outdoor Test Setup

The outdoor test took place at Shikabe Airport in Hokkaido, a northern island of Japan. Figure 3 shows the DGEN engine placed on the outdoor test stand. The engine was fixed 2 m above the ground to avoid debris-sucking and ground vortices. In addition, an Inflow Control Device (ICD) was placed upstream of the engine intake to reduce the effect of atmospheric turbulence. The ICD was mechanically separated from the engine to prevent vibration. During the test, acoustic liner samples were installed to the exhaust bypass duct.

Sound radiated from the DGEN 380 was measured by a 20-meter arc microphone array. Quarter-inch microphones, Brüel & Kjær Type 4938 or GRAS Type 40BP, were set in 24 radiation angles from 10 to 160 degrees from the inlet axis (Figure 4). The microphones were combined with half inch pre-amps, Brüel & Kjær Type 2669 or GRAS Type 26AK, using adaptors, Brüel & Kjær Type

UA0035, and then attached to microphone stands. The microphones were fixed vertically downwards to face rigid marble plates, with quarter-inch spaces between the microphones and plates (Figure 5). Figure 6 shows a photograph of the DGEN 380 and microphones at the test site. The microphone sets were connected to a signal conditioning amplifier, Brüel & Kjær Type NEXUS. A 100 Hz high-pass analog filter was connected before the amplifier to remove wind noise. Signals were simultaneously recorded with a high-speed DAQ system, National Instruments PXIe unit, with the sampling rate of 100 kHz, and then post-analyzed to narrowband and 1/3 octave band spectra. The post-analysis included several kinds of correction: distance, air absorption, and reflection at the marble plate.

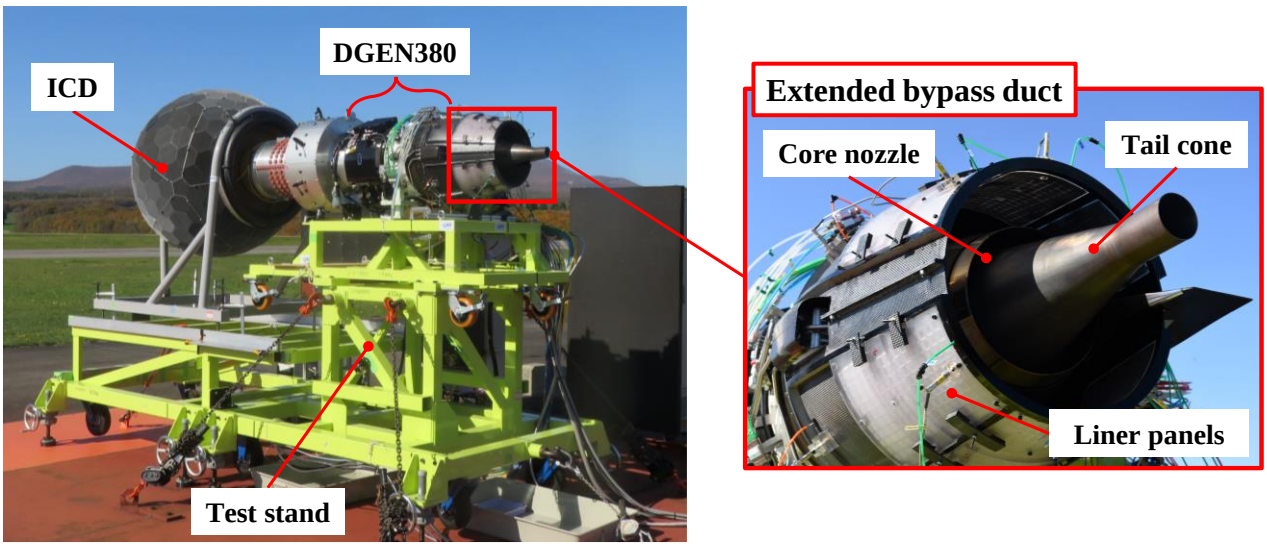



Figure 3: Photograph of the DGEN 380 on the outdoor test stand.

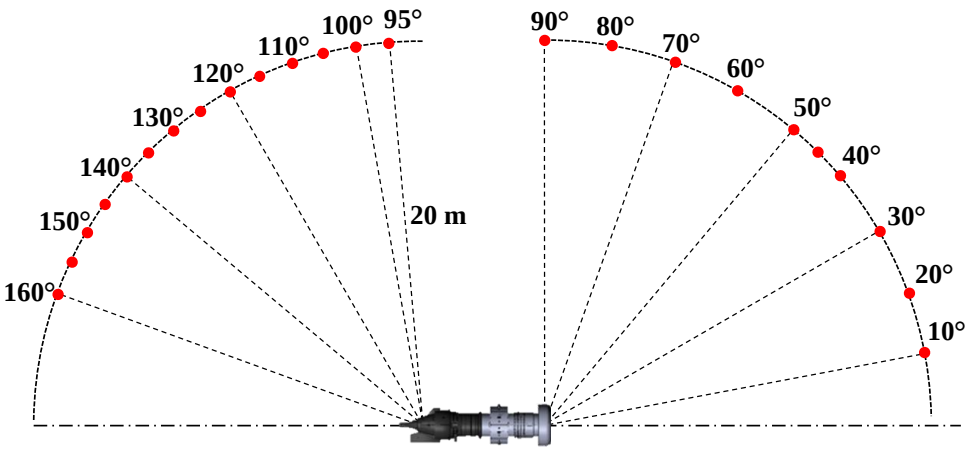



Figure 4: Positions of the far field microphones.

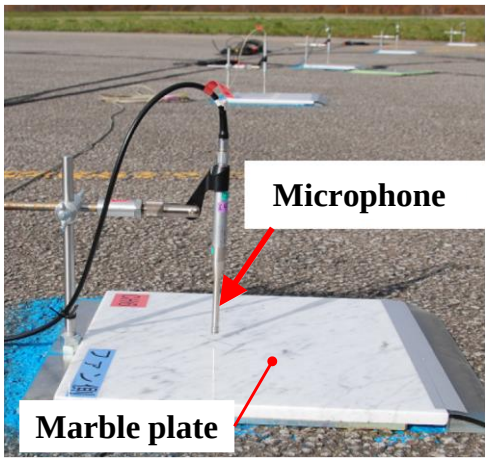



Figure 5: Photograph of the microphone stands.

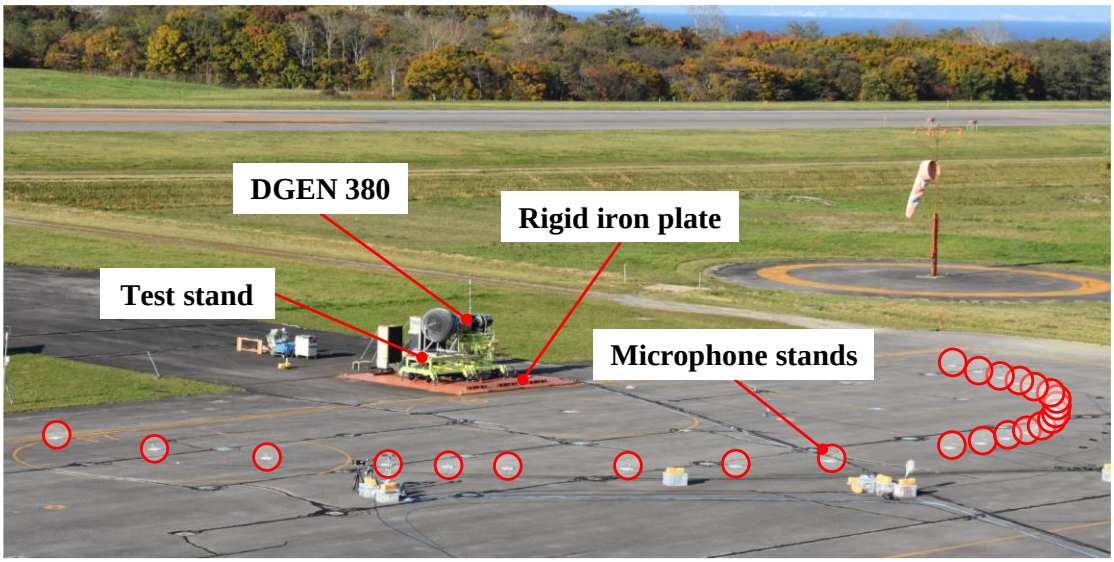
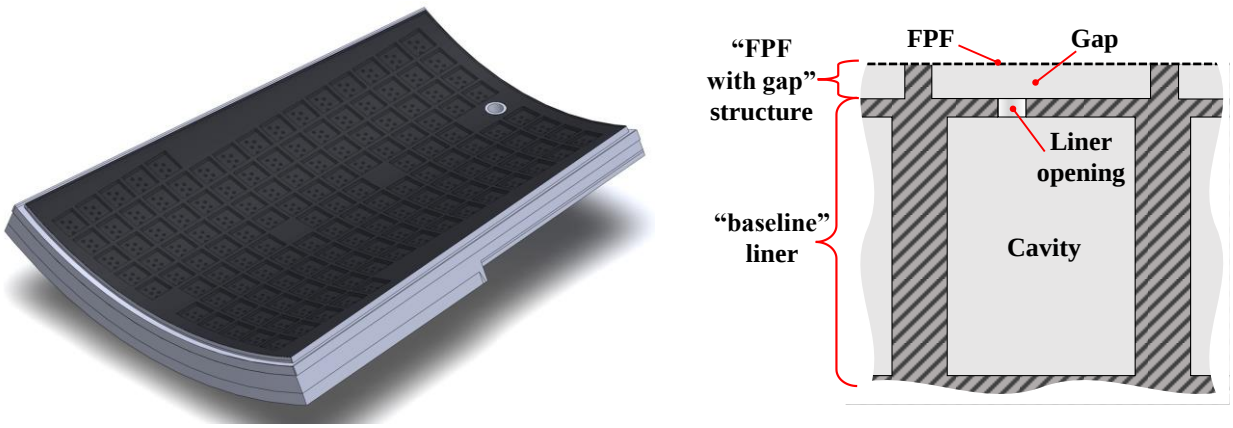



Figure 6: Photograph of the DGEN 380 and microphones.

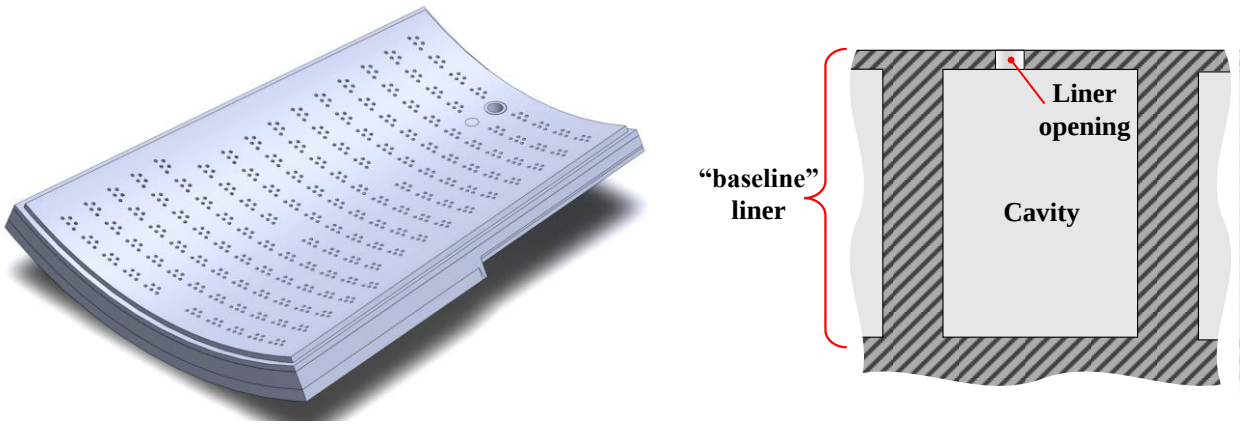
### 2.3. Acoustic Liner Panel Samples

Acoustic liner panel samples were installed to the extended bypass duct. Six pockets were arranged on the circumference of the duct, and the same type of samples were installed to them.

In this study, two types of samples were used in addition of a rigid hard wall. The first sample was a liner with a special surface structure ("FPF with gap"), and the other was a typical resonant-type liner ("baseline"). It should be noted that with the "FPF with gap" liner the special structure, consisting of a FPF and a gap, was applied to the surface of the "baseline" liner. Figure 7 shows the structures of the two samples.




(a) "FPF with gap"




(b) "baseline"

Figure 7: The 3D model (left) and the schematic cross section (right) of the "FPF with gap" and "baseline" samples.

The structure and design of the “FPF with gap” liner sample were based on the concept proposed in a previous study [7,8]. With the special surface structure, the peak frequency of the liner, i.e., the “baseline” liner, was thought to be maintained even under grazing flow condition, or in other words, even inside the exhaust bypass duct. Figure 8 and Table 1 show the arrangement and dimensions of the surface structure, respectively. Figure 9 shows a photograph of the surface of the FPF.

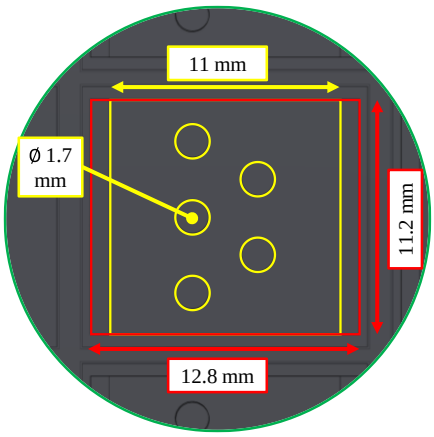



Figure 8: Arrangement of the “FPF with gap” surface structure.
Yellow: geometry of the “baseline” liner, red: geometry of the gap.

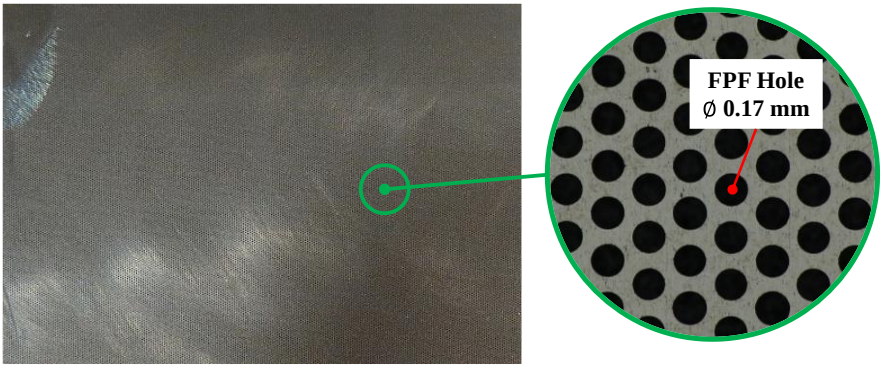



Figure 9: Photograph of the FPF surface.

Table 1: Dimensions of the “FPF with gap” surface structure.

| | | |
|---|---|---|
| **FPF** | Material | Stainless |
| | Perforation Ratio [%] | 30 |
| | Hole Diameter [mm] | 0.17 |
| | Thickness [mm] | 0.15 |
| **Gap** | Cross Section [mm × mm] | 11.2 × 12.8 |
| | Depth [mm] | 2 |

Four kinds of liners with different resonant frequencies were combined for each “baseline” liner panel. The four liners had the same dimensions except the cavity depth. The cavity depths were fixed so the peak of the energy dissipation of each liner would cover the 1 BPF (Band Pass Frequency) and 2 BPF tones of the fan noise in several running conditions of the DGEN 380. In particular, the panels aimed to reduce the fan tones in the case where the low-pressure spool was rotating in 80 (herein called the “80% NL” case) to 90 (herein called the “90% NL” case) % of its maximum speed. Figure 10 shows the 1 and 2 BPF tones in the “80% NL” and “90% NL” cases.

The depths were determined by a simple analysis, based on a combination of acoustic impedance educed in a flow duct rig and duct acoustic theory [9]. The acoustic impedance of a representing liner sample (a sample with the same dimensions except the cavity depth) was educed from flow duct test, and then applied to an analysis calculating the acoustic field inside a simple annular duct model, representing the exhaust bypass duct. The analysis provided an estimation of the peak frequencies of the energy dissipation when the cavity depth was changed.

Figure 11 and Table 2 show respectively the arrangement and dimensions of the four liners constituting the “baseline” panel. As shown, two pairs of liners each aimed to reduce the 1 and 2 BPF tones, respectively. Among each pair, one liner had a lower peak frequency (“1BPF-L” and “2BPF-L”) than the other (“1BPF-H” and “2BPF-H”). The peak frequencies differed from each other so the peak of the combined energy dissipation would broaden and cover the BPF tones even when they shifted due to increasing NL of the DGEN engine.

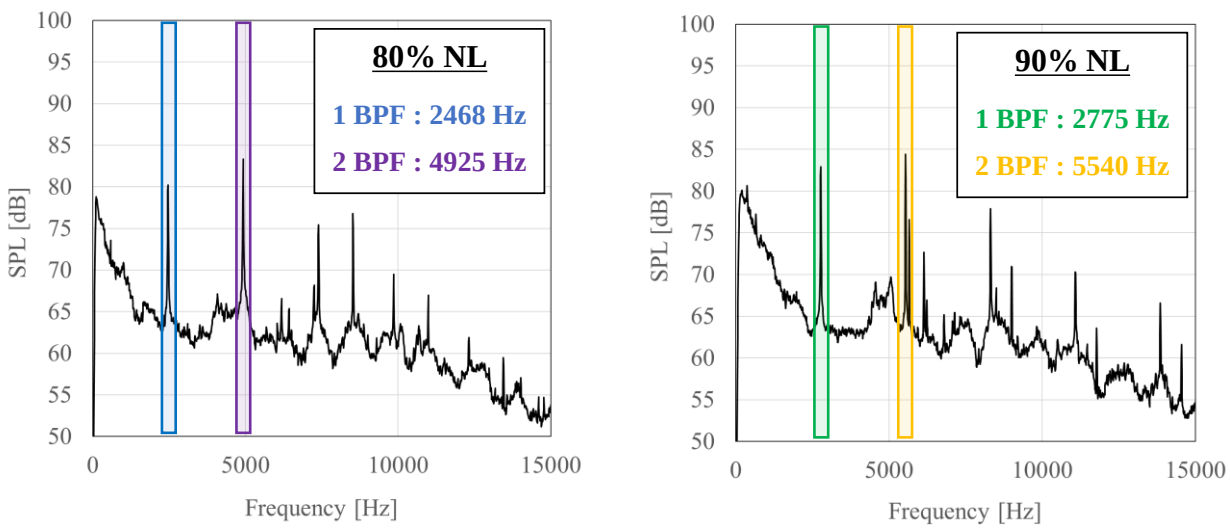



Figure 10: Narrowband spectra of the acoustic field at 130 deg from the inlet axis, in the 80% NL case (left) and 90% NL case (right).

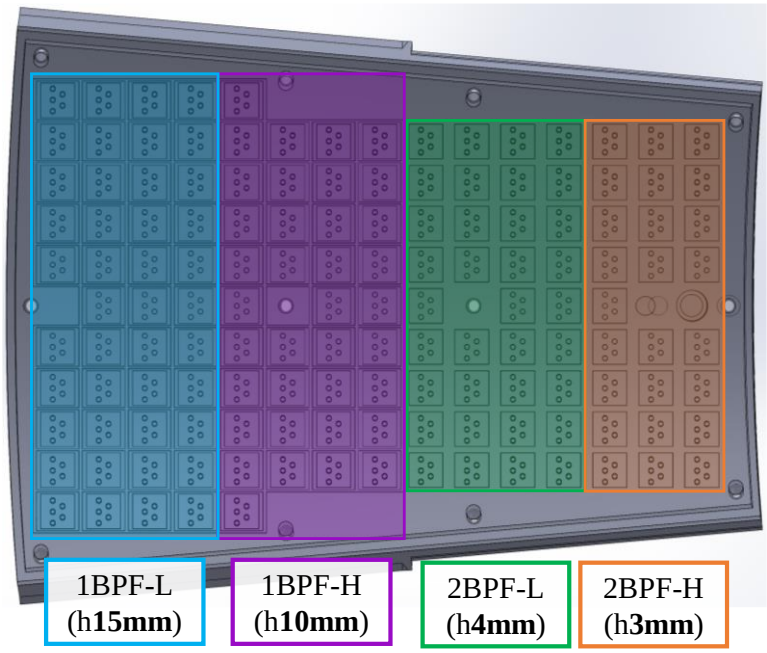



Figure 11: Arrangement of the four liners constituting the “baseline” panel.

Table 2: Dimensions of the four liners constituting the “baseline” panel.

| | **“1BPF-L”** | **“1BPF-H”** | **“2BPF-L”** | **“2BPF-H”** |
|---|---|---|---|---|
| Perforation Ratio [%] | 2.9 | | | |
| Hole Diameter [mm] | 1.7 | | | |
| Surface Plate Thickness [mm] | 1 | | | |
| Cavity Cross Section [mm × mm] | 11.2 × 11 | | | |
| Cavity Depth [mm] | 15 | 10 | 4 | 3 |
| Axial Length [mm] | 63.8 | 63.4 | 64.8 | 50.6 |
| Estimated Peak Frequency of Energy Dissipation [Hz] | **2360** | **3010** | **4930** | **5520** |

## 3. RESULTS AND DISCUSSION

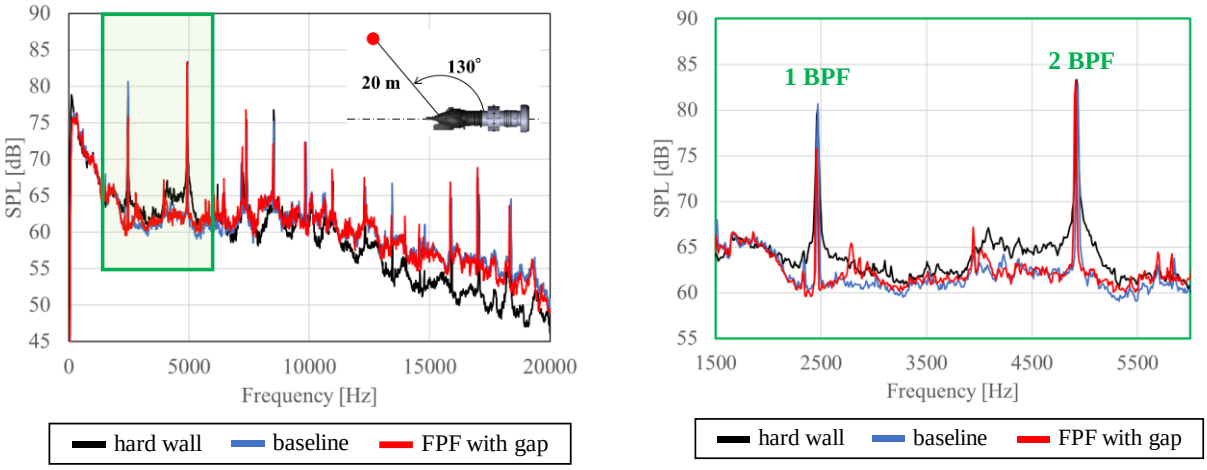
### 3.1. Narrowband and 1/3 Octave Band Analysis Results

The narrowband spectra of the acoustic field at 130 degrees from the inlet axis in the 80% and 90% NL cases are shown in Figure 12. The SPL was largely reduced near the 1 and 2 BPF tones when the liner samples were installed. In the 80% NL case, the “FPF with gap” and “baseline” samples both showed broadband reduction at the range between 2,000 to 6,000 Hz. The 1 BPF tone was largely reduced, with a reduction near 5 dB, with the “FPF with gap “sample, while the reduction of the “baseline” sample was limiting. Considering the results of previous tests [7], these results seem to indicate that the noise reduction peak of the liner was maintained by the “FPF with gap” structure, while the peak was broadened and depressed without it. On the other hand, the reduction of the 2 BPF tone was limiting even with the “FPF with gap” sample. This is thought to be a problem of the peak frequency of the “2BPF-L” liner, since it turned out to be slightly higher than 2 BPF. Basic tendencies were the same in the 90% NL case results, although the noise reduction of the “baseline” sample was further depressed. Both 1 and 2 BPF tones were largely reduced by the “FPF with gap” sample, with reductions near 5 dB, as the tones seemed to be within the noise reduction peaks of the liner. The SPL of the two liner samples in the range between 6,000 to 20,000 Hz were larger than that of the hard wall. This is thought to be caused by environmental factors, since the tests of the “FPF with gap” and “baseline” samples were conducted on the same day, while the hard wall tests were conducted on another.

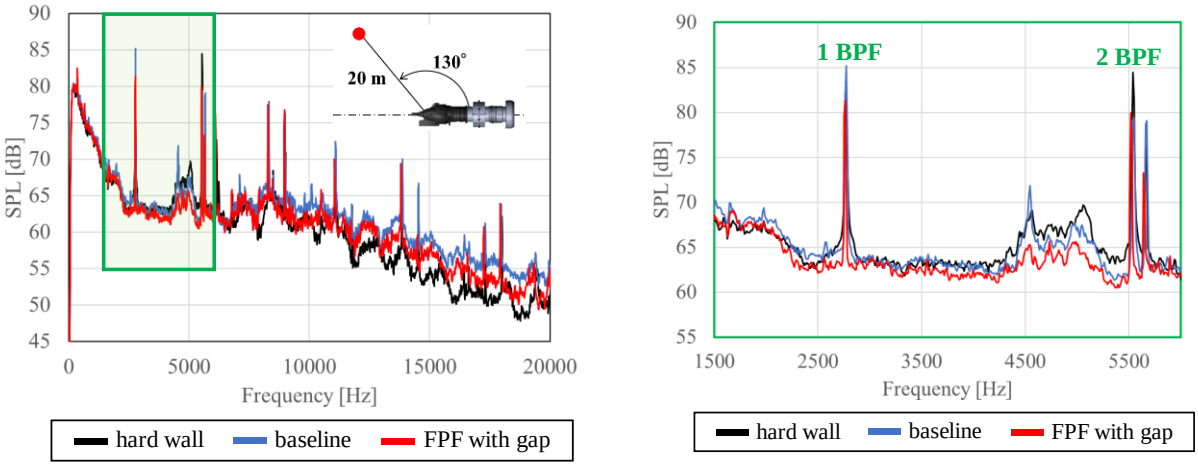
The 1/3 octave band spectra of the acoustic field at 130 degrees from the inlet axis in the 80% and 90% NL cases are shown in Figure 13. The results of the 2,500 Hz and 5,000 Hz bands are shown in an enlarged view since they each include the 1 and 2 BPF tones, respectively. The 1 and 2 BPF tones are largely decreased by the “FPF with gap” sample in both NL cases, with nearly or more than 3 dB compared to the hard wall results. Advantage over the “baseline” sample can also been seen in both BPF tones and NL cases, except for the 2 BPF tone in the 80 % NL case, where the noise reduction peak of the “FPF with gap” sample seems to be untuned with the 2 BPF tone.

### 3.2. Far Field Directivity

The directivity pattern of the 1/3 octave band SPL for the 2,500 Hz band, 5,000 Hz band, and overall frequency range, in the 80% and 90% cases are shown in Figure 14. The results indicate that the BPF tones seem to have strong directivities; the sound waves propagating in the downstream direction is strongest around 120 degrees, while the sound waves traveling in the upstream direction is strongest around 50 degrees. The liner samples have reduced the SPL largely in these directions, and especially in the downstream direction (around 120 degrees), where reduction of nearly or more than 3 dB can be observed. The advantage of the “FPF with gap” sample over the “baseline” sample can also been seen in this figure. There is no apparent difference in the OASPL between the two samples and the hard wall.

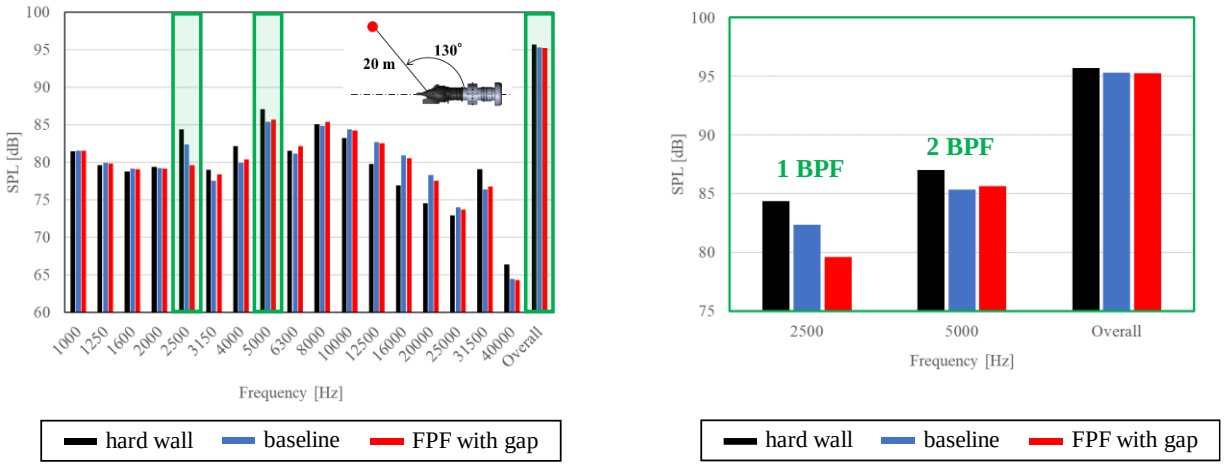



(a) 80% NL case

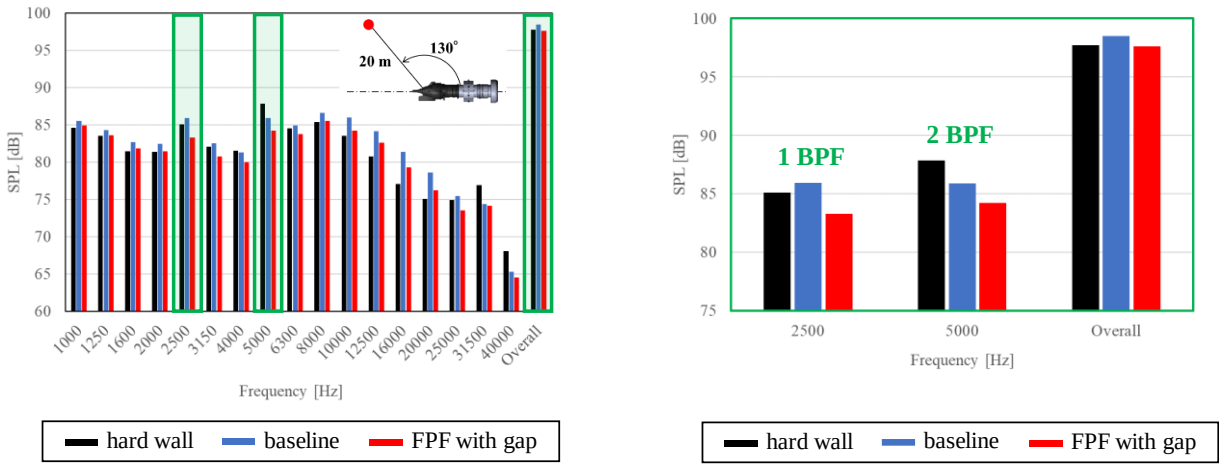



(b) 90% NL case

Figure 12: Narrowband spectra of the acoustic field at 130 deg. from the inlet axis (left), and the enlarged view near the 1 and 2 BPF tones (right), in the 80% and 90% NL cases. Black: hard wall, blue: “baseline”, red: “FPF with gap”.

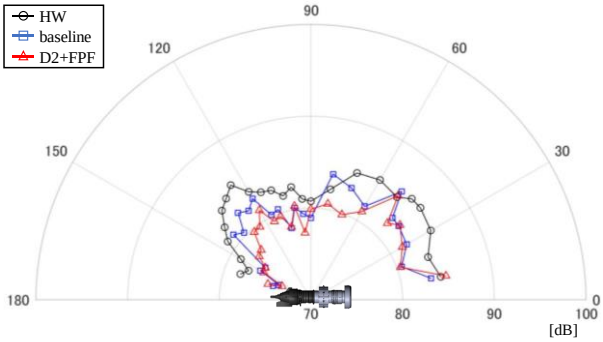



(a) 80% NL case

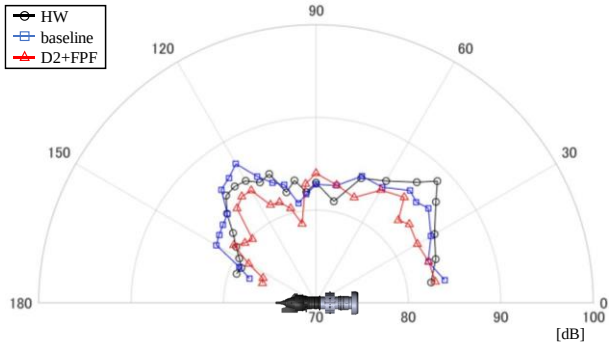



(b) 90% NL case

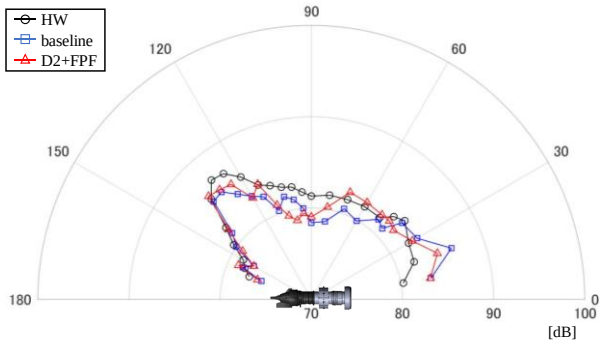
Figure 13: 1/3 octave band spectra of the acoustic field at 130 deg. from the inlet axis (left), and the enlarged view of the 2,500Hz band, 5,000 Hz band, and the overall SPL (right), in the 80% and 90% NL cases.
Black: hard wall, blue: “baseline”, red: “FPF with gap”.



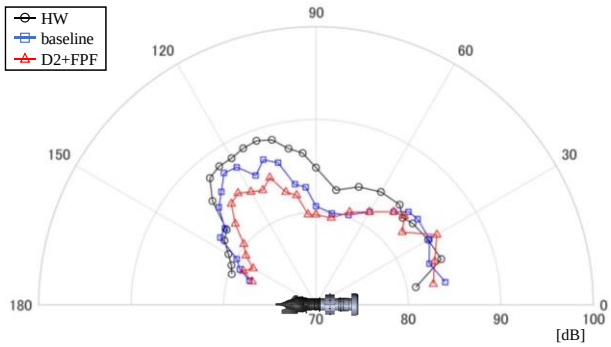

(a-1) 80% NL case, 2,500 Hz



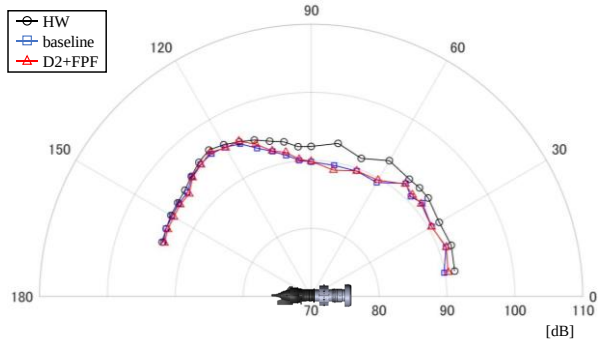

(a-2) 90% NL case, 2,500 Hz



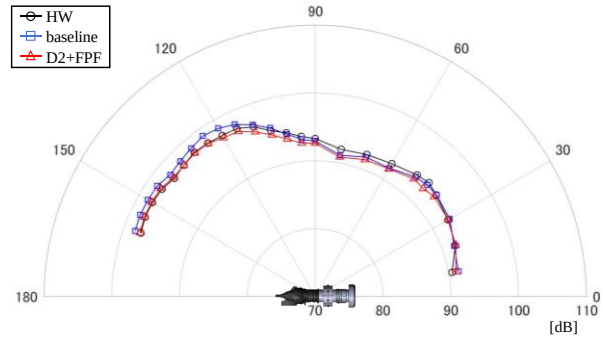

(b-1) 80% NL case, 5,000 Hz




(b-2) 90% NL case, 5,000 Hz




(c-1) 80% NL case, Overall




(c-2) 90% NL case, Overall

Figure 14: Directivity patterns of the 1/3 octave band SPL for the 2,500 Hz band, 5,000 Hz band, and overall frequency range, in the 80% and 90% cases. Black: hard wall, blue: “baseline”, red: “FPF with gap”.

## 4. CONCLUSIONS

In this study, a liner panel sample with a special surface structure ("FPF with gap"), consisting of a fine-perforated-film and a gap, was applied to an outdoor test using a small turbofan engine, DGEN 380. A typical resonant-type liner sample ("baseline") and a hard wall was also tested for comparison. Results indicated that the two liner samples ("FPF with gap" and "baseline") both reduced the noise near 1 BPF and 2 BPF, although the reduction of the "baseline" sample was limiting. The "FPF with gap" sample showed superiority over the "baseline" sample, as was indicated in a previous study. Further studies will be performed to gain more information on the surface structure and optimize the design of the liner samples.

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