Al-Khwarizmi Engineering Journal, Vol. 16, No. 4, December, (2020)
P. P. 19- 26

Al-Khwarizmi Engineering Journal

Impact of using Double Layers Perforated Liners on the Acoustic Treatments of the Combustor Systems

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(Received 13 August 2020; accepted 25 October 2020)
https://doi.org/10.22153/kej.2020.10.002

Abstract

The response of the combustor's liner to the air-flow that passes through it is the key reason for the combustion chamber's noise, hence, the instabilities of the chambers that decrease the mechanical efficiency of such sections by increasing its mechanical vibrations, which increases the failure rate that is created during the origination of the cracks that spread by the shakes that are produced by a series of high-level frequencies. Accordingly, any work debating the impact of the context of the liners in the combustion chamber can provide grasping for the combustion noise generated by the undesirable vibrations, and benefits the industrial firms to design an ideal production procedure which increases the lifespan of the combustor. The goal of this work is to examine the influence of the acoustic treatment using a double layers cylindrical perforated liner on the acoustic transmission loss of gas turbines. The liners layout influences on this acoustic parameter were examined using experimental data gained by the insertion of full scale single and double patterns of perforated liners into the unique large scale acoustic wind tunnel at the acoustic research center at Hull University. The experimental tests, using the designed acoustic signals, were established firstly without existing air cross-flow velocity (i.e., 0m/s), then by employing air with velocities interval 5m/s ranging between 10m/s to 25m/s. MATLAB script was used to simulate, analyze, and figure out the data collected by the insertion of single and double layer patterns of the perforated liner. The experiments demonstrated that, if the perforation acoustic treatments are applied, the acoustic transmission loss will decrease particularly obviously at higher level frequencies. Furthermore, the results exposed that the air tunnel with the insertion of the liner with double layers reveals an improved perforation acoustic treatment with a percentage of about 19 % in most cases.

Keywords: Acoustic treatment, Acoustic wind tunnel, Perforated liner, Sound transmission loss (STL).

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1. Background

The mechanical instabilities inside combustion systems such as gas turbines are extensively common. This phenomenon usually damages such systems, reducing their mechanical efficiency, and the lifespan of their components [1]. The more efficient turbines are the engines that have premixed combustion technology, which has combustion stability and low carbon emission. Consequently, a stable operating engine has smooth and stable combustion during the operation periods for the combustors.

Different techniques are used to control the combustion instability for combustors, such as the fuel supplying optimization method by scheduling the fuel injection [2]. Further, using an adjustment strategy for a combustor's length. Furthermore, the installation of a passive damping device such as a Helmholtz resonator, quarter- or half-wave tube, or the perforated acoustic liner(s) as applied in this work. However, using the first two approaches be contingent on the weight and space limitations of the combustors [3].

The perforated liner is used as an acoustic damper by absorbing the pressure fluctuations inside the combustion chambers, where using the liner as a damper involves vortex generation over the border of its perforations [4].

Nowadays, there are respective studies that have revealed outstanding summaries on the progress, status, and challenges of the application of the perforated liner as an acoustic damper for different combustor systems [5]. However, most of those studies have been primarily focused on the simulation and experimental characterization of the single-layer liners.

To reduce an operating temperature of metal-wall below the true- or engineering-strength borders, the thermal loads on the combustor's wall of the aero-engines, to ensure in other gas-turbines, is reduced by applying multi-perforated liners [6]. Furthermore, a double-layers liner is thought to supply better patterns for an acoustic transmission loss TL than the single-layer liner [5]. Therefore, the existing literature of this field of knowledge needs more researches to enrich it; the focus should be oriented to cylindrical double-layers perforated liners with the context of wind-tunnel experimental tests instead of simulation and numerical analysis.

The sound transmission loss (STL) is the parameter used to count the amount of sound energy that is traveling via the acoustic treatment devices, furthermore, it is an accumulation for the amount of the sound acoustic pressure wave intensity that propagates outwards from the sound source, where the intensity of the sound wave can be reduced by increasing the range of wave attenuation and/or wave spreading [7]. Consequently, to decrease the power of sound crossing inside any wind-tunnel, it is prevalent to stratify single and/or double layers of perforated liners. Stratifying such liners with different perforation styles, percentage of holes, and sizes in the acoustic treatment will impact the amount of transmission loss of sound [8].

There are prime dilemmas that emerge with the use of an acoustic treatment in the installation of the wind-tunnel, the tuning is one of which, where the unwanted level of frequency of sound pressure fluctuation is most effectively macerated or attenuated to the required frequency, by making the sound frequency of the resonant is as close to the required frequency as much as manageable, through changing specifications concerning the geometry of the liner such as the percentage of its porosity (i.e., numbers and size of holes), and its plate thickness [8].

A provided controlled air-stream that is produced by the wind-tunnel can be used to help examine the effects of the movement resistance or drag force, which arises from the air on any object impacted by the air-stream, where it does not matter whether the stationary selected model can withstand the high force of the wind pressure [9], or whether or not the model that is being tested is styled by a technique permits it to easily move through a stream of air or not as it conducted in this experimental work.

Calculating STL for different frequencies assists in showing some parameters such as the sound transmission loss distribution [10]. The perforated liners are typically tubular cylinders in a single layer, double layer, or multiple layers, which have slots or holes with small diameters created before operating and assembling the cylinder itself [11]. The size of layers and their numbers help figure out the durability of the liner and its efficiency to withstand strong vibrations. However, a liner with a single-layer can be applied for long operating time conditions, while a multiple-layers liner has a priority when operating in high heat-load conditions. Meanwhile, they are all used in combustor techniques to absorb the power of the incident acoustic waves.

The sound transmission loss indicates the total intensity reduction of a sound wave-front power through sound noise propagation away from the source. Furthermore, as common in most acoustic applications, the intensity reduction as a sound wave-front propagates through a certain design [3].

This experimental work attempts to enrich the existing available works by performing experimental investigations through a wind-tunnel with the context of single- and double-layers cylindrical perforated liners. A brief search shows that most of the available researches focus on the characterization of cylindrical liners that consist of a single-layer, using computational and numerical simulations and analyses. This work addresses a different approach to enrich the existing available literature of this field of knowledge. The significance of this work is to illustrate how increasing the liner layers can eventually reduce harmful vibration and ultimately raise the efficiency of combustors, through analyzing some key physical parameters like layout combinations of the single- and double-layers perforated liners and also the velocity of the air-flow, by investigating and optimizing the double-layers perforated liners through acoustic experimental investigations. Therefore, these concepts will provide the performance-enhancing of the issues of the combustion chamber design.

2. Methods

2.1 Experimental Methodology

Two strategies that have been experimentally attempted during this work are the acoustic experiments using the wind tunnel, which has been arranged alongside the single-and double-layers cylindrical perforated liner.

In the same procedures and setups for the large scale acoustic wind-tunnel, the experimental tests with the presence of both full-scale double- and single-layer perforated liner patterns, which are (inner4+outer2) and (inner1), respectively, as shown in Table 1, which was performed using a noise generator, loudspeaker, amplifier, four microphones, a computer connected to data acquisition apparatus and the sound card, and a single processing unit.

The specifications of the acoustic treatment that have been employed in the experimental tests are shown in Table (1). It can be seen that the outer and inner layers of the double liner were manufactured in different porosity distributions, sizes, and thicknesses. The arrangements and configurations of the perforated liners are used in this work are illustrated in Figures (1) and (2).

After starting-up of the tunnel, the sucked air by the fan of the tunnel is brought up to the required velocity and will be guided using an external vent to pass it through the intake partition to the perforated liners that provide a terminus for the echoic across its walls while it moves out from this partition (i.e., removing the sound noise from the fan itself and from the flow of air which travels past the fan into the main partitions of the tunnel). Then the sound will be generated and added as a white noise signal to the air-stream as it passes through the position of the loudspeakers, which connects to a noise generator via an amplifier, before it propagates as a sound wave downstream towards the rest of the tunnel's straight section. The loudspeakers were installed in different sizes to provide different ranges of frequency at this partition. Then, the stream of air that accompanied the sound waves passes through the main full-scale perforated liner, which is clamped securely either side in place far enough downstream of the tunnel to permit the plane sound waves to travel through a fully developed flow. Consequently, the sound was terminated and removed again before exiting the tunnel through the tunnel's rear vent.

The experimental tests were firstly started by collecting and taking readings for the condition of no airflow (i.e., 0m/s), using Agilent data capture software installed in the computer available for this purpose. Then the velocity was set by measurements for the cross-flow velocity, starting at 10m/s up at intervals of 5m/s to a maximum of ٢٥m/s. Likewise, the program of Agilent data capture was used to take 30 readings for each stream of airflow.

Fig. 1. Illustrates the layout of a single-layer perforated liner pattern utilized at this work.

Fig. 2. Illustrates the layout of a double-layers perforated liner pattern utilized at this work.

2.2 Theoretical Methodology

The performance of the transmission loss for certain acoustic materials differs greatly with the level of the frequency applied, thus, STL can be marked as the ratio of the level of a sound power transmitted through the material during an acoustic treatment to the level of an incident sound power [12].

$$\mathrm{STL} = 20\log\left(\frac{1}{\mathrm{TF}}\right) \quad \ldots (1)$$

$$\mathrm{TF} = \frac{\mathrm{P_i}}{\mathrm{P_t}} \quad \ldots (2)$$

where the transmission factor is represented by TF, while the transmitted and incident sound powers are represented by (P_t) and (P_i), respectively. In general, the decibels (dB) scale mathematically terms the measurement of the sound transmission loss. The sound powers are demonstrated in Figure (3).

3. Results

Using the four microphones installed on the single-and double-layers perforated liner, the procedure of the experimental tests illustrated in detail above was performed and carried out to acquire the sound transmission loss against the level of the frequency applied. Then, the test's data was processed to gain the pertinent diagrams. The data of sound transmission loss against the level of the frequency were plotted in Figures (4) to (8). The presented results are the average of thirty scenarios of the experimental tests with and without the context of the cross-velocity of airflow through the single- and double-layers perforated liners, which are figured out as illustrated in Table (1).

4. Discussion

As shown in Figure (4), it is clear that the magnitude of the sound transmission loss is highly dependent on the level of the frequency applied. Additionally, it can be recognized that at 225Hz the liner decreases the level of incident sound power by 10dB. Furthermore, at roughly 660Hz and above, the tunnel's liner did not decrease the level of the incident sound power at all. Furthermore, it can be accepted that the results have outlandish dicrotic notches, particularly recognized at frequency levels less than 260Hz. Basically, there is a lack of satisfaction with this behavior, especially in case of no presence of the air crossflow. This behavior can be attributed to the rate at which sound power decays in a liner during the sound attenuation process for the intensity of the acoustic wave either by sound power absorption or by the sound power reflection.

The hole (acoustic treatment) decreases the effective sound transmission loss, particularly distinguished at a higher level of the frequencies [12], as shown in Figures (4) to (8). As the hole (acoustic treatment) gets larger, the liner's effect was not introduce dramatically as at the initial perforation holes, but was especially introduced at the higher level of the frequencies.

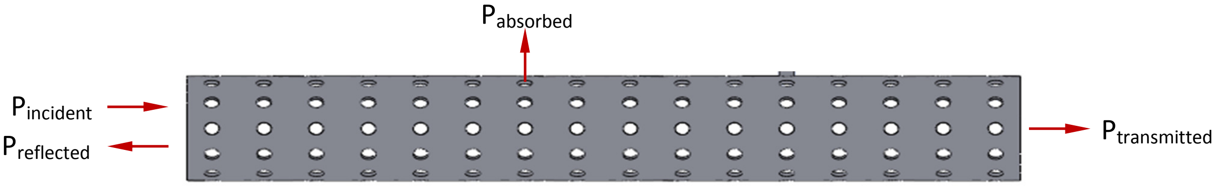

Fig. 3. demonstrates the sound powers through the perforated liners. The ($P_{transmitted}$), ($P_{absorbed}$), ($P_{reflected}$), and (Pi) represents the transmitted, absorbed, reflected, and incident sound powers, respectively.

Table 1,
Illustrates the characteristics of the double-layers and single-layer perforated liner.

	Liner				**Perforations**	
Cylinder	**Internal Diameter (mm)**	**Thickness (mm)**	**External Diameter (mm)**	**Length (mm)**	**NO.***	**Diameter (mm)**
INNER 1	160.65	1.6	163.85	524	3402	0.725-0.875
INNER 4	162.14	2	166.14	524	2256	0.775-0.975
OUTER 2	176.6	1.6	179.8	524	384	3.525-3.675

* Refers to a number of rows and a (holes/row) for each liner. For inner1 they are 54 and 63, respectively. For inner4 they are 47 and 48, respectively. For outer2 they are 16 and 24, respectively.

The style of staggering used in acoustic treatments is the most widespread style. Additionally, its structural strength more than other patterns of the perforation as concluded by [18]. Furthermore, the increase of the perforation orifices chamfering decreases the effective thickness of the hole (i.e., the edge profile of the hole), as concluded by [19].

The data presented in Figures (4) to (8) clearly show an obvious slow-down pattern in the decay of the sound transmission loss of the acoustic power with an increase in the magnitude of the air cross-flow velocity. The decay level of this parameter gradually rises above the level of slow-down of the 10m/s tests. Consequently, the larger the velocity of air cross-flow, the stronger rise in decay style, thus, for this work, it can be concluded that the sound transmission loss for the 10m/s is preferable.

Finally, at least it is clear that the air-tunnel with the presence of the double-layers liner shows better sound transmission loss results. This may depend on the number of the perforation holes and the style of the distribution of those holes at the same liner or may be due to the layers thickness and/or the gap thickness between the two layers used. It concludes that using a liner with the context of double-layers may produce a better result than those gained by applying a liner with the context of a single-layer.

5. Conclusions

The sound transmission loss helps on how to determine and improve the acoustic properties of acoustic materials, and it can be a perfect scale with which to inspect the efficacy of a tunnel in decrease of sound energy transmission, using the small perforation holes that extremely decrease the transmission loss parameter.

Depending on the findings of this work, it can be stated that it is needful to use a typical perforated liner to efficiently remove or control the sound noise that is originated from the dynamical vibrations to reach the noise to a specific level of the dB scale. Additionally, increasing the velocity of the air cross-flow leads to at least the slowing-down in the decay which occurs in the sound transmission loss magnitude. Moreover, in terms of the sound transmission loss, the air-tunnel revealed better results with the presence of the liner composed by double-layers.

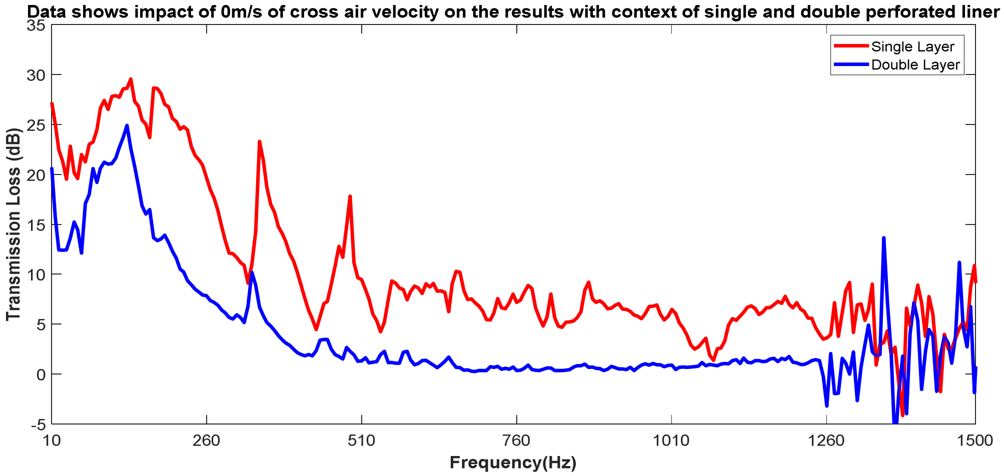

Fig. 4. The acoustic transmission loss versus frequency. The data were collected with air cross-velocity equal to (0m/s) using the perforated liners.

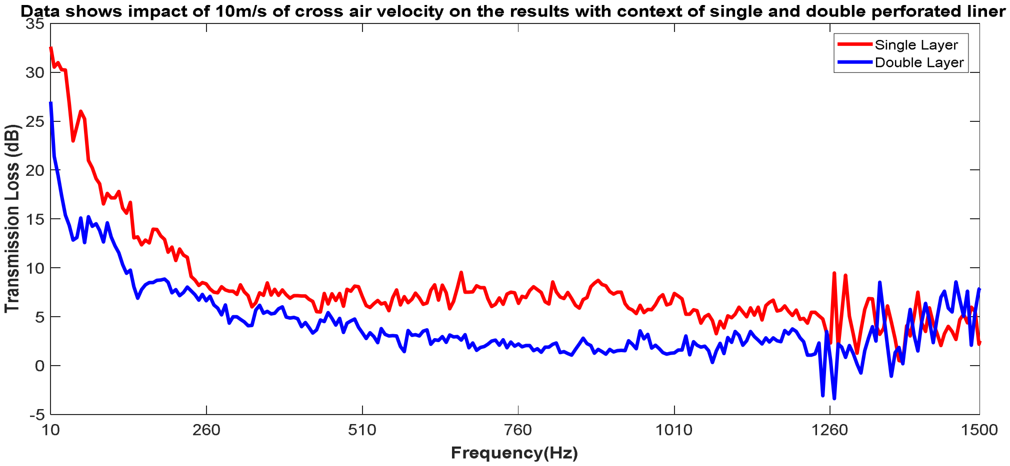

Fig. 5. The acoustic transmission loss versus frequency. The data were collected with air cross-velocity equal to (10m/s) using the perforated liners.

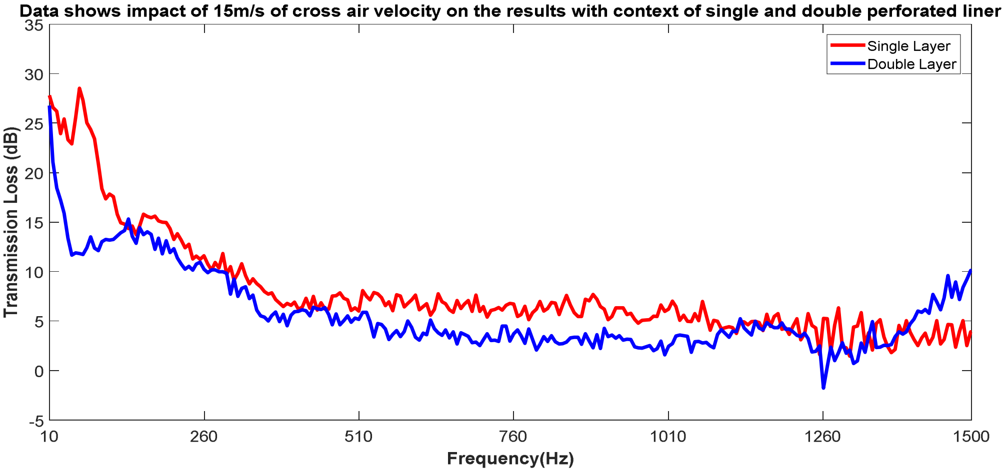

Fig. 6. The acoustic transmission loss versus frequency. The data were collected with air cross-velocity equal to (15m/s) using the perforated liners.

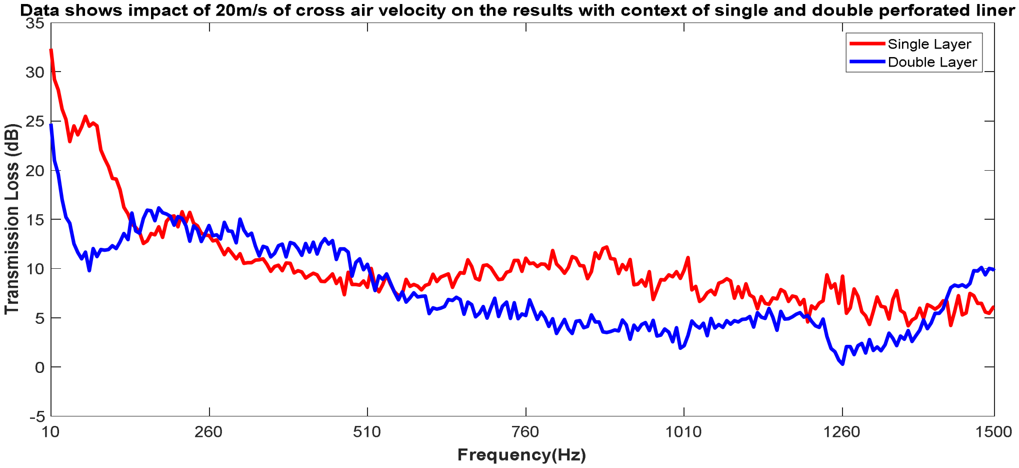

Fig. 7. The acoustic transmission loss versus frequency. The data were collected with air cross-velocity equal to (20m/s) using the perforated liners.

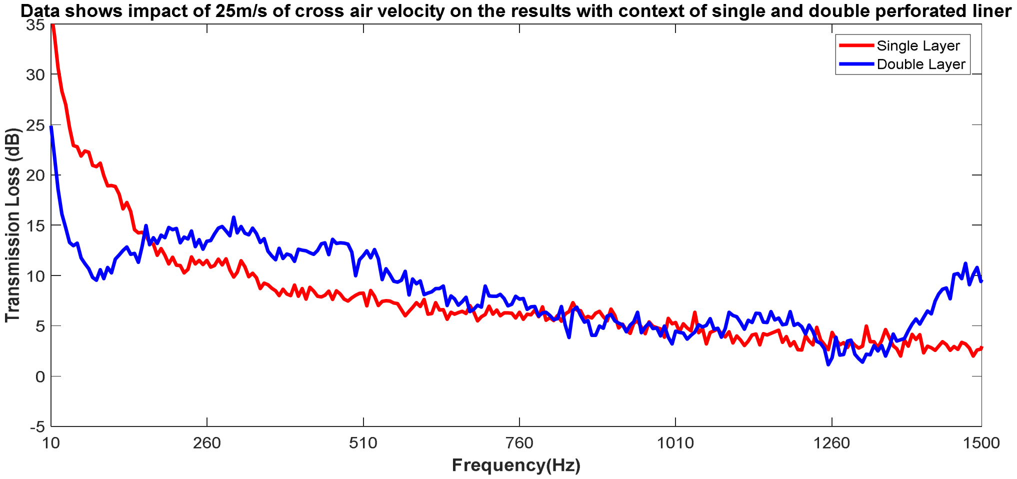

Fig. 8. The acoustic transmission loss versus frequency. The data were collected with air cross-velocity equal to (25m/s) using the perforated liners.

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تأثير استخدام بطانات مزدوجة مثقبة على الخصائص الصوتية للتوربينات الغازية

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الخلاصة

يعتبر التداخل بين الهواء المتدفق داخل غرفة الاختراق في المحركات التوربينية وبين البطانات التي تغلف تلك الغرفة المصدر الرئيسي لضوضاء الاحتراق وبالتالي السبب في عدم استقرار الاحتراق. وهذا يمكن أن يؤدي إلى انخفاض في أداء المحرك، وزيادة اهتزاز المكونات، وزيادة معدل الانهيار الميكانيكي للمحرك بسبب انتشار التشقق الناتج من الاهتزاز الذي يحدث بترددات عالية. وبالتالي، فإن أي تقرير يناقش الإجراء الذي يؤدي إلى فهم تأثير ضجيج الاحتراق، والذي يمكن أن يتولد عن تلك الاهتزازات الغير المرغوب فيها، يمكن أن يفيد المجتمعات العلمية والشركات الصناعية للعثور على التقنية المثلى التي تؤدي إلى زيادة في عمر محركات الاحتراق. ان الهدف الرئيسي من هذا العمل هو التحقق من تأثير استخدام بطانات مثقبة أسطوانية مزدوجة على فقدان الانبعاث الصوتي لتوربينات الغاز. حيث تم التحقق من تأثيرات تكوين البطانات على الخصائص الصوتية، من خلال حساب معامل خسارة الارسال الصوتي من البيانات التي تم الحصول عليها باستخدام نفق الرياح الصوتي الكبير الحجم مع سياق عينات البطانة المثقبة الفردية والمزدوجة واسعة النطاق، بدون سرعة (٠ م / ث) ومع استخدام سرعات تدفق مختلفة تتراوح بين ١٠ م / ث إلى ٢٥ م / ث وبفاصل ٥ م / ث. تم إنشاء التجارب باستخدام نفق الرياح الصوتية الفريد من نوعه في مركز هال للأبحاث الصوتية. لإكمال جميع هذه المهام، تم استخدام مخطوطات MATLAB لمحاكاة وتحليل ورسم جميع البيانات التجريبية التي تم جمعها باستخدام نفق الرياح مع سياق طبقة واحدة ومزدوجة مثقبة. أوضحت التجارب بأنه إذا تم استخدام المعالجة الصوتية باستخدام التثقيب، فسوف يتسبب في انخفاض معامل الارسال الصوتي الفعال، ولا سيما عند الترددات العالية، ومع زيادة حجم الثقب، فإن التأثير ليس دراميًا كما هو الحال عند الثقب الابتدائي الأولي، وهذا واضح بشكل خاص عند الترددات الأعلى. أوضحت النتائج أن نفق الرياح الهوائي مع سياق البطانة المزدوجة يعطي نتائج أفضل من حيث فقدان الارسال الصوتي.
