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IMPEDANCE EDUCTION OF ACOUSTIC LINERS USING THE MAINE FLOW FACILITY

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ABSTRACT

MAINE Flow (for Multimodal Acoustic ImpedaNce Eduction with Flow) is a large-scale duct permitting the study of the acoustic properties of liners with flow and acoustic conditions typically found in nacelles of aircraft engines. In particular, the incident acoustic level can go up to 150 dB and the flow velocity up to Mach 0.63. Compared to other large-scale experiments, this facility permits a precise control of the modal content and amplitude, as well as the measurement of the scattering matrix of the liner. In this paper, we describe an inverse method implemented to allow impedance eduction. It is based on a 3D Multimodal Method that computes the sound field for uniform flow. Then, the impedance is found by minimising the difference between the experimental and numerical values of the multi-modal scattering matrix. In this paper, the method is applied to the characterisation of a Double Degree of Freedom liner without flow. The educed impedance corresponds greatly to the one of the same concept evaluated in a small test bench with only plane wave.

Keywords: *Duct Acoustics, Liner Characterisation, Impedance eduction.*

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1. INTRODUCTION

Most of duct aeroacoustic studies focus on small section facilities where plane wave propagation is assumed both upstream and downstream the tested sample [1, 2]. These studies are crucial as they provide valuable insights into the complex physics of liners in flow ducts. However, when it comes to aeronautic applications like optimizing a liner for a turbo-engine nacelle, the conditions deviate significantly from plane wave configurations. Thus, it becomes important to investigate how the tested liner performs with specific high-order modes. Moreover, the overall sound pressure level in these applications is extremely high (exceeding 155 dB), and the flow velocity is substantial (up to Mach 0.7).

MAINE Flow has been built to investigate the acoustic properties of liners with grazing flow up to Mach 0.63 and incident acoustic levels up to 150 dB [3, 4]. Apart from accommodating these extreme conditions, this setup possesses a unique precise control over the modal content and amplitudes of the incident acoustic field. This allows measurements with complex and diverse modal contents, as well as fundamental research exploring the relationship between the incident wave propagation direction, interactions with the boundary layer, and the effective liner impedance perceived by the acoustic waves. Previous studies on impedance eduction [5] have indicated that measurement errors and uncertainties can be minimized when the liner adequately attenuates the acoustic field. Therefore, understanding and controlling the modal behavior can focus the energy on highly attenuated modes, thereby reducing uncertainties in impedance eduction.

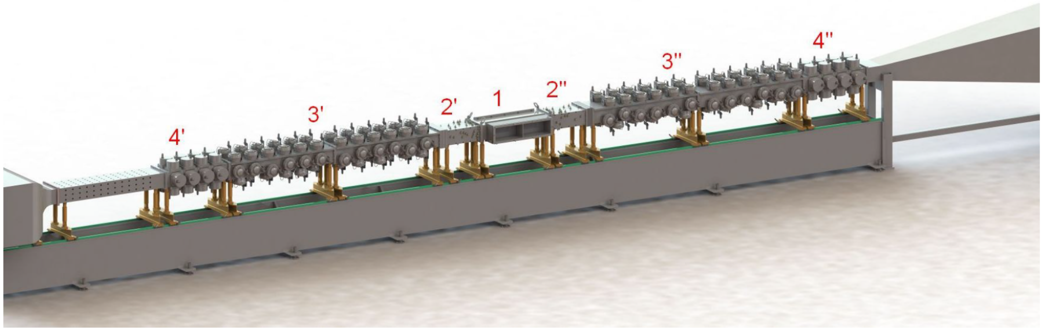

Figure 1. General view of the test section with (1) the sample support, (2' and 2") the upstream and downstream microphone sections, (3' and 3") the upstream and downstream High Frequency loudspeaker sections and (4' and 4") the upstream and downstream Low Frequency loudspeaker sections.

The present paper introduces an inverse method based on the minimisation of the difference between a liner measured scattering matrix and its computation by a multimodal model. The method is applied here for a Double Degree of Freedom (DDOF) liner without flow. The results are compared to the impedance of the same liner but measured in a much smaller duct. The very good agreement validates inverse impedance eduction in MAINE Flow and offers great perspective for further studies with flow.

2. SET-UP AND SCATTERING MATRIX MEASUREMENTS

2.1 Test facility

The MAINE Flow facility is a rectangular duct with a 150×280 mm^2 cross-section. It operates with a fan in suction mode, located downstream of the schematic view displayed in Fig. 1. The test section is 800 mm long and can accommodate one or two liner samples on its smaller sides. The mean flow velocity above the tested samples can reach up to Mach 0.63. To create the acoustic field, 24 loudspeakers are positioned on each side of the test section, generating a plane wave below 600 Hz. In addition, 66 compression chambers on each side can be used to generate the remaining acoustic field up to 10 kHz. These sources can be controlled using sine sweep excitation or broadband noise, with an incident level of up to 150 dB. Simultaneous acquisition of the incident, transmitted, and reflected sound fields is carried out using two sets of 60 flush-mounted microphones. These microphones are strategically placed in duct sections located upstream and downstream of the test section. It is important to note that the positioning of the microphones and acoustic sources has been optimized to ensure the generation and decomposition of the 24 modes capable of propagating at 4000 Hz [3].

2.2 Scattering matrix measurement

The amplitudes of the waves $\mathbf{p}^{out}$ scattered by an element mounted in the test section are linked to the vector of incident modes $\mathbf{p}^{in}$ by the multimodal scattering matrix $\mathbf{S}$. In other words, we write $\mathbf{p}^{out} = \mathbf{S} \cdot \mathbf{p}^{in}$ with

$$\mathbf{S} = \begin{bmatrix} \mathbf{R}^+ & \mathbf{T}^- \\ \mathbf{T}^+ & \mathbf{R}^- \end{bmatrix}, \tag{1}$$

where $\mathbf{T}$ and $\mathbf{R}$ are respectively the transmission and reflection matrices for waves coming from upstream (exponent $+$, waves in the direction of the flow) and from downstream (exponent $-$, waves against the flow). When N modes are cut-on in the rigid parts of the duct, the scattering matrix $\mathbf{S}$ has dimensions $2N \times 2N$ and it can be identified using more than 2N independent excitation cases [6]. In practice, the excitation cases are provided by sending a unit signal to each of the upstream and downstream source channels [7].

Fig. 2 displays the upstream transmission matrix $\mathbf{T}^+$ extracted from the measurement of $\mathbf{S}$ for a typical DDOF liner. Only the first four modes, ranked by their cut-on frequency, are shown. The subscript 0 corresponds to the plane wave and the matrix diagonal represents the trans-

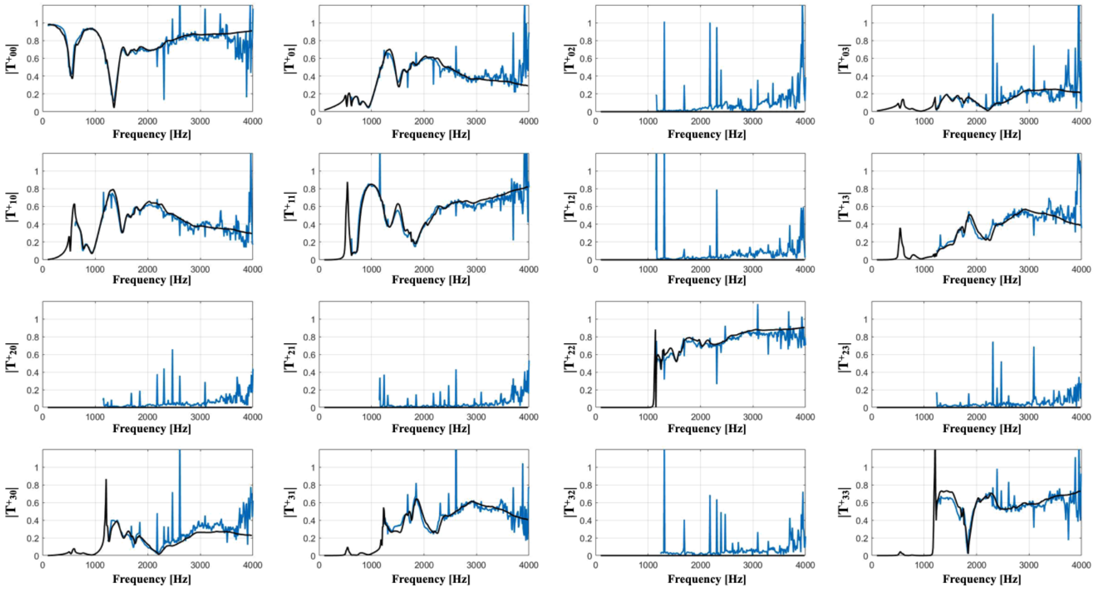

Figure 2. Transmission matrix $\mathbf{T}^{+}$ associated to an upstream acoustic excitation for a DDOF sample. Only the four first acoustic modes are shown. Blue lines: experimental measurements. Black lines: multimodal computation using the impedance measured in 50×40 mm^2 test bench.

mission of each mode on itself. Extra-diagonal terms describe energy transfers between modes caused by the presence of the liner. The black lines represent the scattering matrix calculated by the multimodal method introduced below, using the impedance of the same type of liner but measured in a 50×40 mm^2 duct facility where only plane wave propagates. The plane wave transmission to itself shows two transmission drops which are typical of the type of studied liner. The agreement between prediction and measurements is very good and validate the measurement procedure of the scattering matrix. Note that the peaks displayed on experimental curves are associated to the duct cut-on frequencies.

3. INVERSE METHOD FOR IMPEDANCE EDUCTION

3.1 Principle

Our inverse method for impedance eduction consists of the following steps. On one side are the measured transmission matrices $\mathbf{T}^{+}$ and $\mathbf{T}^{-}$. On the other side, given an initial impedance guess which is taken here as the impedance measured in the small test bench, the propagation in a 3D lined duct is calculated using a multimodal method adapted from the 2D version introduced and validated in [1]. Then, a cost function based on the difference between the experimental and the computed transmission matrices is built. The impedance that minimises this cost function is the liner impedance. In practice, since there are multiple modes, different cost functions can be built depending on the transmission coefficients taken into account.

3.2 Results

Fig. 3 displays the impedance results obtained by the inverse method. Two cases are considered here. For the impedance plotted in blue, only the first coefficient of $\mathbf{T}^{+}$ and $\mathbf{T}^{-}$ matrices contribute to the cost function. That is, the optimisation is only based on the transmission of the plane waves. For the second case (green lines) the cost function is based on the first four diagonal coefficients. In both cases, the expected impedance is retrieved, but the accuracy in multimodal context (highest frequencies) is improved by increasing the complexity of the cost function. Note that it has been verified that each coefficient independently taken leads to the same impedance. This was expected but this is less sure in presence of flow and will be of great interest in the future.

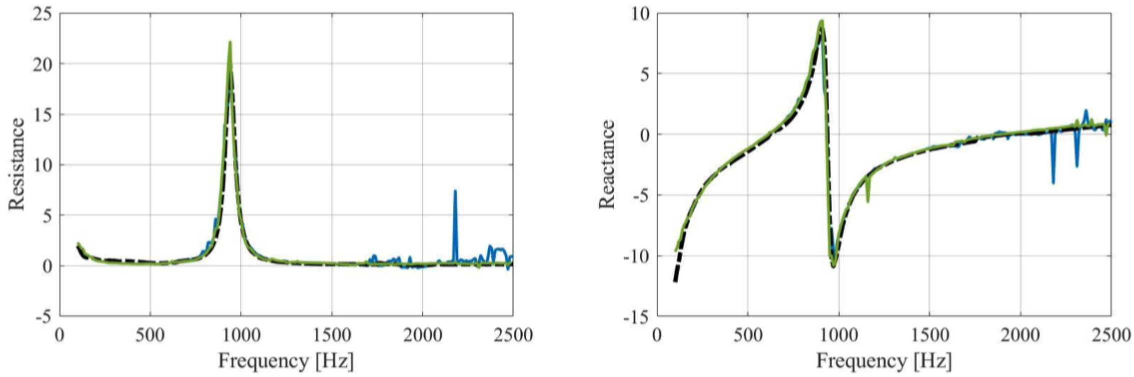

Figure 3. Real (Left) and imaginary (Right) parts of the non-dimensional DDOF impedance. The black lines correspond to the impedance measured in a small test bench. Blue lines: MAINE flow inverse results using only the first coefficient of $\mathbf{T}^{+}$ and $\mathbf{T}^{-}$ matrices. Green lines: the first four coefficients of $\mathbf{T}^{+}$ and $\mathbf{T}^{-}$ diagonal are used.

4. CONCLUSION

In this paper, an inverse method for impedance eduction has been introduced in the framework of a large duct permitting modal control and scattering matrix measurements. The method has been validated without flow by the characterisation of a DDOF liner. The benefit of taking into account high order modes is shown, since it increases the robustness of the eduction at high frequencies. Our future works will concern measurements with flow. In particular, it is not clear if all the modes are seeing the same impedance. Also, comparison with direct impedance eduction are planned.

5. ACKNOWLEDGEMENT

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