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PLASMA-BASED ACOUSTIC LINER FOR BROADBAND NOISE REDUCTION

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ABSTRACT

The recent developments in the aircraft industry, focusing on reducing fuel consumption, led to a significant decrease in fan rotation speeds in modern engines. Therefore, the associated tonal noises have shifted to lower frequencies. In order to cope with the "quarter-wavelength rule", active acoustic liner concepts are capable of addressing low frequency noise while having subwavelength dimensions. However, the use of electrodynamic loudspeakers as unit cells in active liners yields limited bandwidth of operation due to their resonant behaviour, as well as excessive weight for aircraft application. In this work, we propose a concept of plasma-based active acoustic liner, where the plasma actuators operate on the principle of atmospheric corona discharge. A liner prototype consisting of 4 active unit cells is designed and its acoustic performance is tested in a flow duct under grazing incidence. The noise reduction strategy is operated via local acoustic impedance control of each unit cell. Broadband noise attenuation is achieved with this concept. The limitations of the approach such as maximal sound pressure levels of operation and efficiency under mean flow are discussed.

Keywords: *acoustic liner, corona discharge, active control, acoustic impedance*

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1. INTRODUCTION

Acoustic liners are composite structures mounted on the internal walls of the aircraft engine nacelle with the objective of reducing acoustic noise emission from the engine. It typically consists of several perforated metallic sheets and honeycomb structures forming Helmholtz-type resonators which are tuned to absorb sound in a specific frequency range. However, frequencies of emitted noise vary at different stages of an aircraft flight [1]. Moreover, broadband low frequency noise, which is difficult to absorb with a compact structure, dominates in recent engine configurations. As a result, active concepts of acoustic liners are investigated.

Active acoustic liner concepts are represented by an array of controlled electroacoustic transducers. Different acoustic impedance control methods are employed to induce sound absorption [2–4]. Liners based on electrodynamic loudspeakers can be tuned and reconfigured in situ to absorb time-varying tonal noise as in aircraft engines. However, efficient broadband operation covering a frequency range up to a few kilohertz remains a challenge due to the resonant nature of the transducer restricting the bandwidth of control. In this work, we present a concept of the active liner where the impedance control is applied to plasma-based actuators to achieve a broadband noise reduction. Experimental assessments are performed in a flow duct facility.

2. ACTUATOR PRINCIPLE AND PROTOTYPE DESIGN

The plasma-based actuator operates on the principle of atmospheric corona discharge [5]. Its construction includes two electrodes separated by an air gap. The first electrode (emitter) typically has a small characteristic dimension.

The other electrode (collector) is significantly larger. If a positive constant high voltage (+HV) is applied to the emitter and the collector electrode is grounded, the ionization process starts around the emitter due to the locally high magnitude of the electric field. Produced positive ions drift towards the collector electrode in the external electric field. They further transfer their momentum through elastic collisions to air neutral particles, which mostly fill the entire volume between the electrodes. As a result, such a process generates a volumetric force that acts on neutral air. A small amount of heat is also constantly released in the ionization region. If an alternating high voltage component is added to the constant high voltage, the electric field magnitude changes accordingly creating fluctuation in the force acting on the air and released heat. This process leads to the generation of sound waves. The actuator can also be used to control sound, for example, create an impedance-matched condition for sound absorption or cancel out acoustic pressure or a specific location [6]. For noise reduction under grazing sound incidence, an array of four identical plasma actuators used as an active acoustic liner was tested in CAIMAN flow duct facility at Ecole Centrale de Lyon.

The duct has a cross-section of 70×110 mm^2. One lateral wall presents an interchangeable test section of 360×70 mm^2, hosting the active liner prototype composed of 4 identical plasma actuators. Two microphones on each side of the test section measure the transfer matrix. Fig. 1 shows how the section is covered with plasma actuators as well as their design. First, the treated surface is lined with a wire mesh of $0.25\rho c$ resistance. Plasma-based liner is placed on the wire mesh. Each active cell has an actively controlled area of 60×70 mm^2 (Fig. 1a). The emitter electrode is made out of a thin nichrome wire arranged in 6 parallel lines over the active area of the actuator with intervals of 10 mm. The collector electrode is made of a steel perforated plate, and placed behind the wire mesh (the emitter being behind the collector). The distance between the electrodes is 7 mm. A control microphone is inserted in the space between the wire mesh and collector electrode. The transducer is enclosed by a rectangular cavity with a depth of 15 mm. A 10 mm layer of melamine foam is fixed at the enclosure wall. The total thickness of the liner prototype is 48 mm. Fig. 1 shows all four active cells being partially disassembled. These actuators operate with a constant voltage bias of 8 kV.

The liner is controlled with a Speedgoat real-time controller. The sampling frequency is 50 kHz. Each cell represents an independent SISO control system. Control

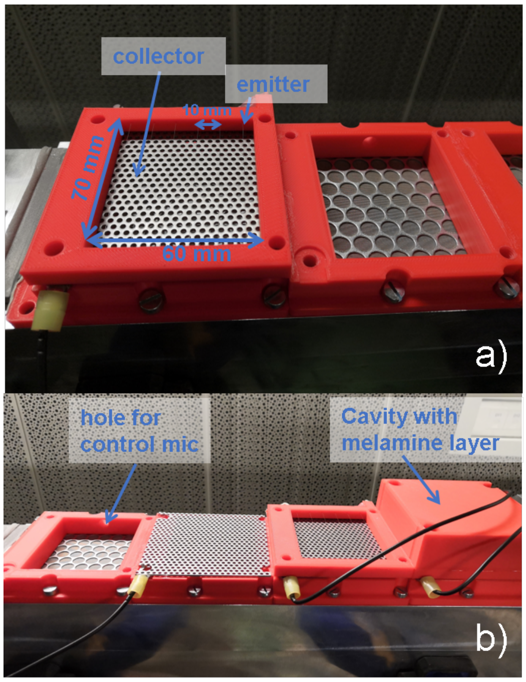

Figure 1. Active liner prototype where a) illustrates the construction of a plasma actuator and b) shows the assembly of 4 cells on the test section.

microphone senses the total pressure in front of the transducer and feeds the controller input. The output of the controller is amplified with a custom-made high-voltage amplifier that powers the actuators.

The control system targets a predefined acoustic impedance in front of the actuator. The methodology is described in [7]. A constant resistive impedance in the range of 0.5-1 ρc is targeted in the tests.

3. TEST RESULTS

Measurements were performed without mean flow. The duct was excited with a band-pass noise in the frequency range 50-1500 Hz at SPL of 105-110 dB. Measurements of the plasma liner prototype in passive and active regimes are presented in Fig. 2. The reduction of transmission by the duct itself is not taken into account since the transmission loss of the rigid duct was measured to not exceed 0.5 dB. The collector and emitter electrodes of the plasma transducer are almost transparent to sound. Therefore, the liner represents an array of four slightly damped cavities communicating with the duct through a wire mesh. The resonance frequency of a passive liner is around 1170 Hz. At this frequency, transmission losses reach 18.5 dB. At low frequencies below 600 Hz losses do not exceed 2-3 dB.

With the impedance control technique, it is possible to achieve high transmission losses in the range of 6-8 dB, from low frequencies (the actual low bound was not investigated but is obviously below 200 Hz) up to 1300 Hz (Fig. 2). This highlights a non-resonant operation of the plasma-based active liner. The lower target impedance $0.7\rho c$ results in better attenuation towards the lower frequencies (green line in Fig. 2) compared to a target of ρc (red line in Fig. 2). At the same time, lower target resistance requires higher output voltage of the transducer, lowering the highest SPL of operation. Therefore, lower targets than $0.5\rho c$ were not tested. The additional plots of absorption and reflection coefficient confirm that the transmission loss is indeed achieved due to sound absorption and not due to the reflection of sound back to the noise source. However, it would be useful to analyse the achieved impedance since it can be seen from targeting the two constant impedances that a frequency-dependent target could provide a better absorption in the whole frequency range. The impedance could be educed using, for example, the inverse method [8]. The measurements with the flow were not performed as the SPL of noise was higher than 110 dB and the actuator's output voltage exceeded its maximal value.

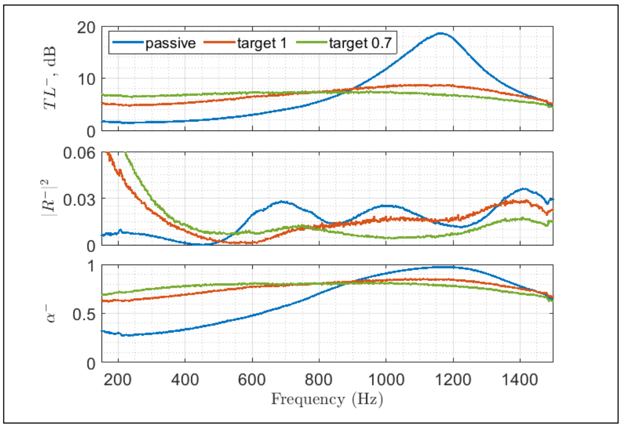

Figure 2. Transmission losses, reflection and absorption induced by active plasma liner prototype, targeting constant resistive impedance. The target values in the legend are normalised by the characteristic air impedance.

4. DISCUSSION

The proposed plasma-based liner prototype has proven its capability of reducing noise in a broadband manner with a considerably wider bandwidth of control compared to the other existing passive and active concepts. Broadband attenuation was achieved by targeting low resistive impedance. However, a frequency-dependent acoustic impedance can potentially lead to an even higher absorption performance. Broadband operation is more powerful in general since most real word tonal sound sources such as aircraft engines produce several higher-order harmonics which are difficult to attenuate if the bandwidth of control is limited.

However, the main and important limitation of the presented concept is the relatively low maximal level of noise that the plasma-based liner can attenuate which is strictly linked to the physics of the actuator. Higher sound pressure levels of noise require higher levels of driving voltage exceeding the dynamic range of corona discharge voltages. The geometry of the actuator and material selection can be optimized to push this limit further.

5. ACKNOWLEDGMENTS

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