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DESIGN AND EXPERIMENTAL VALIDATION OF AN ACTIVE ACOUSTIC LINER FOR AIRCRAFT ENGINE NOISE REDUCTION

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ABSTRACT

The use of acoustic liners in aviation industry is a quite common solution for reducing the engines acoustic emissions. Although the current solutions based on single or multilayer liners are efficient and compact for the mid and high frequencies, noise mitigation in the low frequencies would require large volumes, making the integration in the nacelle difficult. Moreover, the passive liners are tuned to attenuate fixed frequencies and are optimized for specific flights regimes. An active electroacoustic skin based on a distribution of loudspeaker and microphones is presented here. The acoustic impedance is controlled by an embedded electronic system and can be changed in real time. Compared to a conventional passive liner, it is shown that the resonance frequency of the active skin can be adjusted to better match the flight phase and that the performance is better at low frequency. An experimental campaign in a wind tunnel has been performed and is presented here.

1 INTRODUCTION

The reduction of noise pollution due to civil aviation has become a major challenge for aircraft manufacturers. The use of passive liners inside aircraft nacelles is commonly used to attenuate the acoustic emissions of aircrafts but the efficiency is not broadband and the attenuation in low frequencies is poor. Moreover, the optimum acoustic impedance of the liner evolves according to the flight phase. Active noise control strategies have already shown their effectiveness [1, 2]. The solution proposed here lies in the use of an active coating for acoustic impedance control. A prototype of this system is presented hereinafter.

2 ACOUSTIC IMPEDANCE CONTROL

The active skin presented here is made of an arrangement of unit cells used to synthesize a target acoustic impedance. A unit cell is the assembly of a speaker (actuator), four microphones (sensors) and an electronic control stage. The strategy consists in estimating the pressure at the center of the cell by averaging the signal of the four microphones and to act on the velocity field by the action of the membrane of the speaker.

The equation of control has been established in [3] and is based on the Thiele/Small speaker model [4]:

$$H_{loc}(p) = \frac{S_d}{Bl} \left(1 - \frac{M_{ms}p^2 + R_{ms}p + \frac{1}{C_{ms}}}{\mu_1 M_{ms}p^2 + S_d R_{at}p + \frac{\mu_2}{C_{ms}}} \right) \quad (1)$$

With :

- p : Laplace variable;
- S_d : Effective piston area;
- Bl : Electromechanical conversion factor ;
- M_{ms} : Mass of the mobile assembly;
- R_{ms} : Mechanical resistance;
- C_{ms} : Compliance of membrane suspensions;
- R_{at} : Target acoustic resistance of the mobile assembly;
- $\mu_1, \mu_2 \in [0; 1]$: Control parameters.

This control law is used to alter the dynamics of the electrodynamic actuator and would ideally synthesize a purely resistive acoustic impedance when $\mu_1 = \mu_2 = 0$. For stability considerations, these parameters can never be null, which would be equivalent to cancel the mass and the compliance of the loudspeaker. However μ_1 controls the apparent mass of the speaker and μ_2 its compliance.

3 EXPERIMENTAL DEVELOPMENTS

3.1 Prototype of active skin

The prototype is made of thirty 50x50mm cells. Each cell is the assembly of a speaker and each corner is equipped with a microphone (see figure 1). The current through the speaker is

controlled by a Howland current source [5]. A micro-controller computes the equation driving the dynamic of the electric current in the speaker reel depending on the average measured pressure. The output current is updated at a rate of 50kHz. The computations are performed locally but all the cells are connected to an interface card through a serial bus. Thus the parameters of all the cells can be changed and local features (RMS pressure and RMS current) are accessible from a computer.

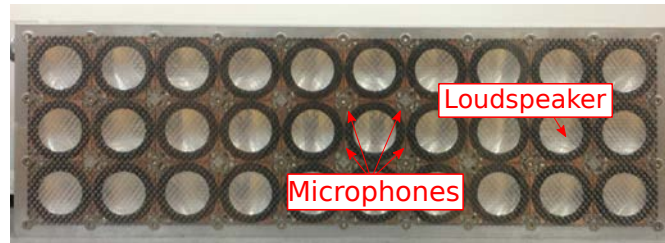


Figure 1: Picture of the active skin prototype comprising 30 loudspeakers and 120 microphones.

3.2 Power consumption

With the control off, the active skin has a power of 12.5W, including 0.2W per micro-controller. The electronics is able to feed each speaker with a current of 0.25A *i.e.* a power of 1.25W. The maximum electric power is then 50W. In practice, with a controlled noise of 110dB RMS, only 5mA are required per speaker so the overall power is 20W for 30 cells.

3.3 Wind tunnel

The active skin prototype has been wall mounted in the wind tunnel FDF of the Netherlands Aerospace Centre (NLR). The test bench is shown in figure 2. The difference of acoustic intensity between the upstream and the downstream reverberant rooms gives the IL (*insertion loss*). The IL evaluates the acoustic energy absorbed by the active skin. The acoustic source is placed in the upstream room (downstream configuration) or in the downstream room (upstream configuration). Tests have been run with air flow up to Mach 0.15. The flow noise has saturated the microphones for flows faster than Mach 0.15. The figure 3 shows the results with flow in downstream and upstream configuration and the results without flow for a target resistance of $\frac{\rho c}{2}$. Mitigations up to 16 dB have been measured. The resonance frequency of the speaker is denoted f_0 . The flow does not affect significantly the efficiency.

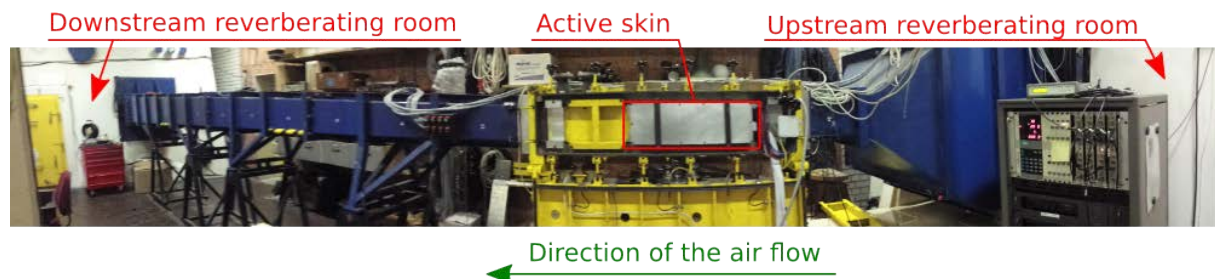


Figure 2. Experimental validation in a wind tunnel (NLR, the Netherlands).

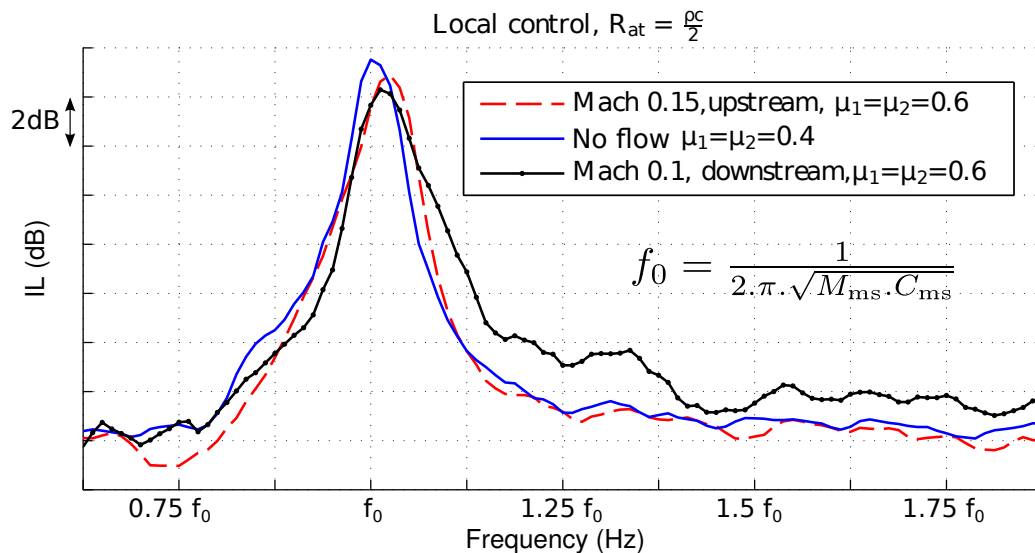


Figure 3. Insertion Loss for a target resistance $R_{at} = \frac{\rho c}{2}$ with and without flow.

4 CONCLUSION AND PERSPECTIVES

The prototype presented here is an active skin able to synthesize specified acoustic impedances. It aims at replacing passive liners in aircraft nacelles and has been tested in a wind tunnel with airflow up to Mach 0.15. *Insertion Loss* up to 16 dB have been measured. The acoustic impedance of the skin is re-programmable in real time so adaptive strategies can be implemented to best match the phases of flight.

5 ACKNOWLEDGEMENTS

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