Efficacy of perforated liners with different porosity: Lattice Boltzmann analysis

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Abstract Noise from jet combustion engines is often a source of noise pollution that could negatively impact the quality of living in areas around which such jet operations are present. One method of reducing the noise is through the use of perforated liners along the walls of jet engines which will generate vortical fluctuations dissipate the acoustic energy. This study presents a Lattice Boltzmann Method (LBM) to study the efficacy of such liners with different porosity.

Keywords: Aeroacoustics, Lattice Boltzmann Method, Acoustic liner

1 Introduction

Combustion engines generate noise that is often significant and can be a cause of unwanted disturbances [1]. One method of reducing such noise generated from combustion engines is the use of perforated liners. These liners are placed along the walls of the combustor and air is passed through the orifices to protect the integrity of the engine hull by lowering its temperature. Incidentally, the flow of air through these orifices (also called bias flow) serves to dampen the acoustic signatures generated by the engine. When air passes through the orifices, viscous dissipation effects from the unsteady jet that is generated will convert acoustic fluctuations into non-radiating vertical fluctuations [2]. A few factors could affect this mechanism's efficiency in achieving acoustic damping. Such includes the shape of the orifice [3], the thickness of the liner [4], and bias flow Mach number [5], amongst others. Here, a Lattice Boltzmann Method (LBM) based approach is applied to this problem to investigate the efficacy of liners with different porosity.

2 Simulation setup

The simulation problems are set up using open-source package Palabos. A grid dependency test is performed and the flow velocity profile is compared against measurements made on an experimental facility available on-site. The inlet of the 2.5m long impedance tube with a 5cm wide square cross-sectional area is defined with a randomly fluctuating inlet velocity simulating a turbulence intensity of 0.37%. A sinusoidally varying velocity inlet of 300Hz is applied to an area on the top surface of the impedance tube near the inlet. The acoustic signal is 100dB (re 20μPa). At the middle section of the tube, an other velocity inlet on all four sides is defined to simulate the liner's orifice and bias flow inlet. The orifice size in the simulation is varied to match the porosity of liners A to H of the experimental setup (A – 0.75%, B – 1.13%, C – 1.76%, D – 2.51%, E – 3.46%, F – 4.08%, G – 5.72%, H – 9.05%). A first-order non-reflecting boundary condition is applied for the outlet. Pressure data is recorded at various locations on the axis of the impedance tube for the duration of the simulations.

3 Results

Figure 1 presents the findings of the simulations across five liners (D through H). Liners A, B and C were not simulated due to a restriction of an insufficient number of cells across the liner orifice to resolve the flow. The left figure shows the amplitude of the acoustic pressure at different locations along the length of the impedance tube, obtained through a Fast-Fourier Transform (FFT) of the pressure data. The location of the bias flow inlet is immediately recognizable. Downstream of the bias flow, there is an apparent random fluctuation to the acoustic pressure amplitude. Note that the sinusoidal wave pattern from the inlet to outlet is due to the acoustic wave 'seeing' the inlet boundary condition as a reflective boundary, therefore, generating a pattern resembling that of a standing wave within the tube.

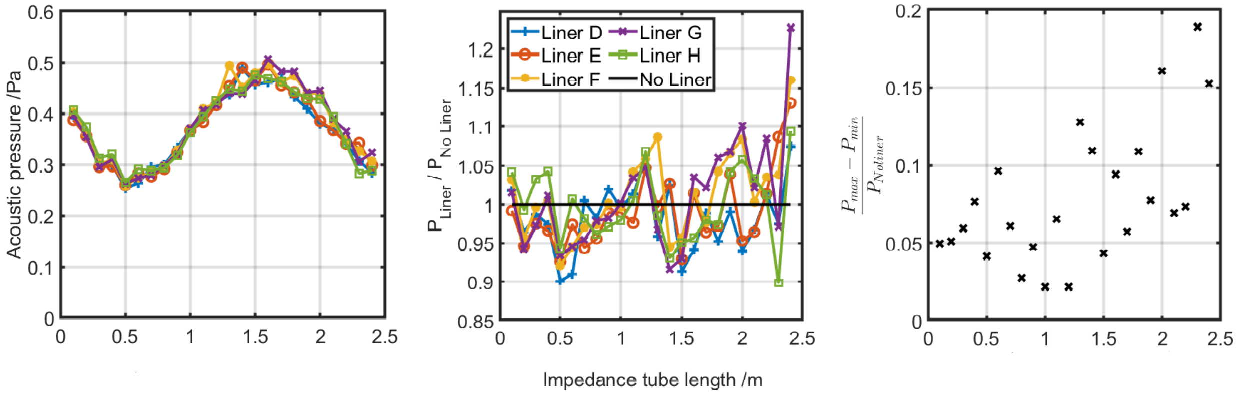

Figure 1 (Left) Acoustic pressure of 300 Hz signal across the length of the impedance tube for different liners. (Middle) Acoustic pressure normalized with control case in the absence of liners. (Right) Difference of maximum and minimum acoustic pressure as a percentage of control case.

The middle figure presents the same acoustic pressure amplitude normalized against a control simulation that is performed without any liner and bias flow. When compared against the control case, there is no clear indication of a constant reduction in acoustic pressure amplitude for any particular liner. Alternating amplification and reduction are observed for the range of liners simulated. Lastly, the right figure presents the difference between the maximum and minimum acoustic pressure amplitude recorded across all the liners as a percentage of that from the control case. It is again apparent that after the liner orifice, there is a marked increase in the fluctuations of acoustic pressure amplitude with a high value of 18.8%.

4 Conclusion

The simulation results show that a bias flow applied to the liner orifice contributes an effect to the acoustic pressure amplitude. However, the effectiveness of this liner orifice – bias flow configuration in achieving a reduction to the acoustic pressure is not obvious. Currently, there is no clear winner of any particular liner simulated and no reliable conclusion could be drawn without a statistical analysis across a larger data set. Further investigations are in place. Examples of which are the effects of bias flow Mach number, acoustic frequency and also the effects of a Helmholtz cavity backed liner.

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