Acoustic Liners and their Aerodynamic Penalty

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Engines are the primary source of noise during aircraft take-off and landing. For this reason, the inside of the nacelle is coated with acoustic liners. Acoustic liners consist of a perforated top plate with a solid backplate and a honeycomb core in the middle. They resemble Helmholtz resonators and exhibit a natural frequency that can be tuned to the engine frequency for noise dissipation. An undesirable side effect of these surfaces, however, is that they increase the total aircraft drag, essentially behaving as distributed surface roughness. This increase in drag has been accepted as a necessary compromise so far. However, moving towards cleaner aviation requires a more in-depth understanding of the drag increase over these surfaces.

Acoustic liners are typically very hard to study due to how the diameter of the orifices scales with the boundary layer length scales. The diameter of the orifices d is significant with respect to the boundary layer thickness ($d/\delta \approx 0.1$) and much larger than the viscous length scale ($d^+ = d/\delta_v \approx 500$). It is computationally very expensive to satisfy both constraints from a numerical perspective. Furthermore, acoustic liners are permeable surfaces and permeable surfaces have been studied far less than canonical rough surfaces. As a result, the interaction of acoustic liners with turbulent flow and the origin of their aerodynamic penalty is not very well understood.

We perform, for the first time, Direct Numerical Simulations of turbulent flow interacting with acoustic liner arrays at bulk Mach number, $M_b = 0.3$. We consider a range of facesheet porosities and orifice diameter with respect to the viscous length scale and quantify the drag of an acoustic liner. We show that acoustic liners behave as a permeable substrate and the relevant roughness paramter is the non-linear permeability of the facesheet. We also show that the drag increase scales perfectly with the wall-normal velocity fluctuations emanating from the orifice, which increase if the porosity or viscous-scaled diameter increase.

Based on our results and our understanding of acoustic liner interaction with the flow, we propose several novel orifice geometries where we change the shape and orientation of orifices. We show that the aerodynamic penalty suffered by such geometries is strongly correlated to the orifice geometry. However, the acoustic noise attenuation is relatively less influenced by orifice geometry. As a result, we show that there is significant potential in improving the aerodynamic penalty of acoustic liners while maintaining or improving acoustic noise attenuation.