CAA simulation of sound generation by linear interaction of vorticity with a wedge

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The study of airframe noise is intimately connected with the interaction of flow with edges. In this context the question arises, whether linearized conservation equations describe such sources. Lilley's aeroacoustic wave equation states that in a subsonic parallel steady mean shear flow $\vec{u}^0 = [u_1, u_2, u_3]^0 = [u_1^0(x_2), 0, 0]$ sound is generated by nonlinear processes only, because the respective aeroacoustic source term $\frac{\partial u_i}{\partial x_l}\frac{\partial u_k}{\partial x_i}\frac{\partial u_l}{\partial x_k}$ vanishes upon linearization about the basic state $\vec{u}^0$. The linear dynamics of whatsoever small perturbations $\vec{u}'$, e.g. due to small fluctuations of the vorticity, will therefore not contribute to the generation of noise.
In order to verify the above statement a numerical simulation of the linear dynamics of a purely vortical perturbation evolving in a free parallel shearlayer was carried out using DLR's CAA code. The shearlayer is located in $-1.1 \le x_2 \le 1.1$; below there is no flow and above there is a constant flow of Mach number $M = 0.4$. Localized vorticity is introduced at simulation time $t = 0$ and position $x = x_1 = 2,\ y = x_2 = -0.5$. As a result a downstream convecting unstable wave packet evolves representing the classical Kelvin-Helmholtz instability. The left part of figure 1 shows the respective linear pressure field $p'(x, y, t = 70)$ which consists of purely hydrodynamic (i.e. non-propagating) components indicating complete silence and thus confirming the statement of Lilley's equation. The right part of figure 1 shows the pressure field if a sharp vertical wedge with vertex at $x = 10,\ y = -1.4$ is originally placed below the shearlayer. In this case sound is generated by scattering of the wave packet's linear hydrodynamic pressure field at the wedge although the mean flow does not even touch the wedge. The example shows that in the presence of edges the sound generation by vorticity becomes a linear problem even in the presence of a parallel shear flow.

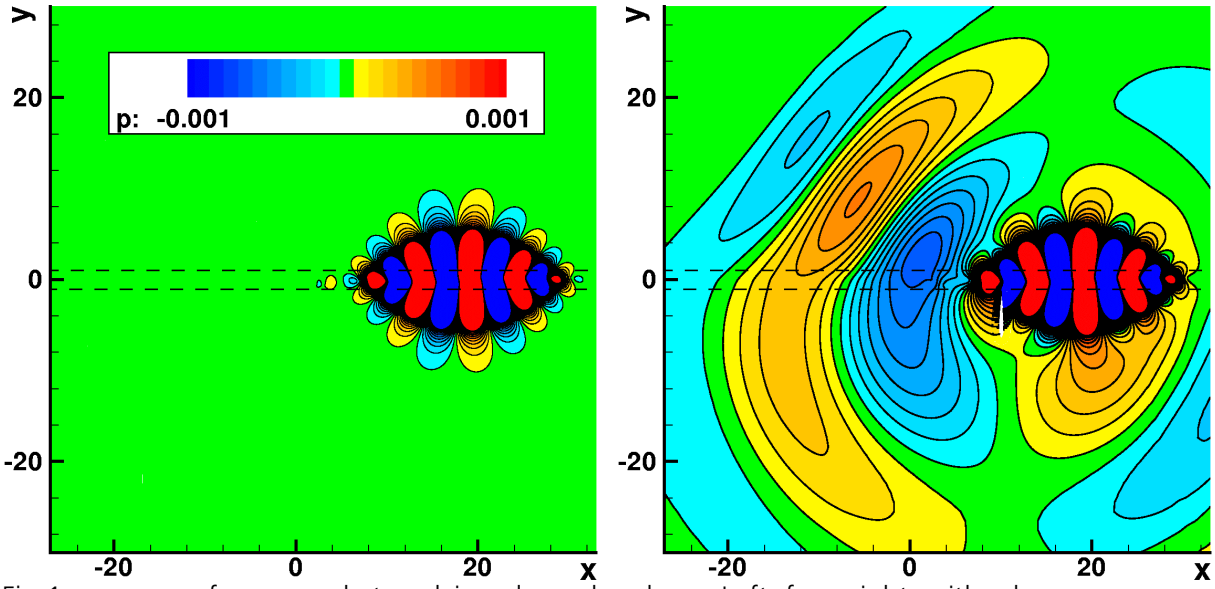

Fig.1: pressure of wave packet evolving along shearlayer. Left: free, right: with edge.

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