Hybrid computational aeroacoustics based on compressible flow data at low Mach numbers

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Lighthill's acoustic analogy transforms the compressible Navier-Stokes equation into an exact inhomogeneous wave equation. When extracting source terms from a compressible flow simulation, the results already incorporate acoustic wave propagation, corrupting the source term computation. Hence, acoustic analogies based on incompressible flow data are preferred at low Mach numbers. These methods implicitly describe a one-way coupling from flow structures to acoustic waves. However, some practical applications (e.g. a cavity with a lip[1] or resonator like structures) seek for compressible simulation, since acoustic feedback mechanisms excite flow structures. At low Mach numbers we identify the origin of the incompressible part of the velocity field as the incompressible solution of the flow field and the remaining part as a compressible disturbance.

Based on the compressible flow simulation, the acoustic propagation is computed in an extra step. At low Mach numbers, the incompressible flow structures are the main acoustic sources. Therefore, the compressible flow field is separated by the Helmholtz decomposition

$$\mathbf{u} = \mathbf{u}^{\mathrm{ic}} + \mathbf{u}^{\mathrm{c}} = \nabla \times \mathbf{A}^{\mathrm{ic}} + \nabla \phi^{\mathrm{c}} \,, \tag{1}$$

where $\mathbf{u}^{\mathrm{ic}}$ represents the solenoidal (incompressible) part and $\mathbf{u}^{\mathrm{c}}$ the irrotational (compressible) part. In this contribution we investigate the two possible computations of $\mathbf{u}^{\mathrm{ic}}$ and the effect on the calculation of the acoustic wave propagation. The scalar potential ϕ^{c} is associated with the compressible part and the property $\nabla \times \mathbf{u}^{\mathrm{c}} = 0$. The vector potential $\mathbf{A}^{\mathrm{ic}}$ describes the incompressible part of the velocity field satisfying $\nabla \cdot \mathbf{u}^{\mathrm{ic}} = 0$.

These properties lead to a scalar Poisson problem with the dilatation $\nabla \cdot \mathbf{u}$ as forcing, and to a curl-curl problem with $\nabla \times \mathbf{u}$ as right hand side, respectively. Both methods have been implemented in the finite element software CFS++[2] and are applied to the aeroacoustic benchmark problem of a flow over a cavity with a lip[3].

References

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