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Helmholtz-Hodge decomposition of compressible flow data on homologically trivial domains

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An unresolved problem of aeroacoustic, even for direct numerical simulation with a compressible media, is the accurate decomposition of the compressible flow field in a flow associated part and an acoustical part. At low mach numbers the incompressibility condition for the fluid dynamic part holds $\nabla \cdot \mathbf{u}^{\mathrm{ic}} = 0$. We assume that the compressible field is an irrotational field $\nabla \times \mathbf{u}^{\mathrm{c}} = 0$. These two properties give rise to a Helmholtz-Hodge decompositon of the velocity field. The investigation of homologically trivial domains (domains with holes) is of major importance in fluid dynamics. Realizations of such domains are e.g. components inside a domain, a cylinder or an airfoile in a crossflow.

Based on the compressible flow simulation, we extract a sequence of flow fields $u : \mathbb{R}^n \rightarrow \mathbb{R}^n$. At each realization we apply the Helmholtz-Hodge decomposition. Thus, the compressible flow field is separated in L^2 orthogonal components

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

where $\mathbf{u}^{\mathrm{ic}}$ represents the solenoidal (incompressible) part, $\mathbf{u}^{\mathrm{c}}$ the irrotational (compressible) part, and $\mathbf{u}^{\mathrm{h}}$ the divergence-free and curl-free part of the velocity field.

In this contribution we investigate the computations of the components and the effect of the calculation procedure on the acoustic wave propagation. Furthermore, a preliminary time filtering method is investigated on the decomposed velocity sequence. Both methods have been implemented in the finite element software CFS++[1] and are applied to a cylinder in a crossflow.

References

[1] M. Kaltenbacher. Numerical Simulation of Mechatronic Sensors and Actuators: Finite Elements for Computational Multiphysics, 3rd Edition. Springer (2015)