A Cut Finite-Element Method for Compressible Subsonic Flow with an Embedded Wake Approach for Coupled Aeroelastic Optimization of Flexible Wing Structures

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ABSTRACT

A cut finite element method for the solution of the full potential equation (FPE) with an embedded wake is presented. The flow outside of attached boundary layers of streamlined bodies flying at high Reynold numbers can be assumed to be irrotational and isentropic. This allows to reduce the Navier-Stokes equations to a single scalar nonlinear partial differential equation, namely the FPE. The FPE expresses conservation of mass in terms of the velocity potential. For subsonic flows, the FPE is elliptic and results in a boundary-value problem. In this work the FPE is discretized using a standard Galerkin finite element method and the nonlinear system of equations stemming from the discretization is solved using Newton's method [1].

In order to account for the effects of viscosity in the generation of lift, a model for the trailing wake needs to be introduced. In the presented method the wake is modeled as a straight surface in the free-stream direction [2]. This assumption is relaxed allowing mass flux across the wake. These modeling aspects are introduced in the FP formulation as further BCs on the wake interface. In order to capture the discontinuity in the velocity potential across the wake, a cut finite element method is employed. To allow for a jump in the potential, the degrees of freedom (dofs) belonging to the elements cut by the wake are duplicated and the dofs above the wake are decoupled from the dofs under the wake. The wake BCs are weakly applied on the duplicated dofs. Since the wake can cut through the wake elements arbitrarily, there might be elements with small cuts yielding an ill-conditioned system. To avoid this, a full integration method has been developed to stabilize the formulation. This implicit description of the wake within the mesh presents an effective approach to perform fluid-structure interaction computations and to apply aeroealstic optimization methods, where the position of the wake changes during consecutive iterations. The solver is implemented in Kratos Multi-Physics and verified for different angles of attack and free-stream conditions. Since the pressure does not change in the transverse direction of the boundary layer, the FPE yields accurate lift, induced drag and moment computations. This method is intended to be used for the analysis and design of flexible wind energy structures.

REFERENCES

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