Shape Sensitivity Analysis for Coupled Fluid-Solid Interaction Problems

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Abstract

In this paper, a robust continuum sensitivity formulation for the shape sensitivity analysis of weakly coupled aero-structural systems is derived. In this method, the solid boundaries are modelled using the immersed boundary approach. This simplifies the grid generation for the complex and deforming geometries since the computational mesh does not need to conform to the boundaries. The sensitivity analysis consists of differentiating the continuum form of the governing equations where the effect of the solid boundaries are modelled as additional forcing terms in these equations. By differentiating the governing equations, it is possible to reuse the operators utilized for solving the governing equations. Therefore, there is no need to develop new solvers for the solution of sensitivity response. This methodology is applied to different demonstration problems including flow over a cylinder and a simplified aeroelastic model of a wing. The wing structure is modelled as a beam with the lifting surface mounted at the tip where the load is transfered to the structure through the mounting point. The sensitivity results with this approach compares well with the complex step method results. Moreover, it is shown that the methodology is capable of handing complex shapes with high Reynolds numbers.

Chapter 1

Introduction

1.1 Motivation

Fluid-structure interaction (FSI) problems play important role in many scientific and engineering fields, such as automotive, aerospace, and biomedical industry. In all these cases, the engineers try to design the systems based on the coupling between the fluid and structural disciplines. Despite the application of FSI problems in different industries, a comprehensive study of such problems remains a challenge due to their strong nonlinearity and multidisciplinary nature. For most FSI problems, analytical solutions to are not available, and laboratory experiments are limited in scope. Therefore, to get more insight in the physics involved in the complex interaction between fluids and solids, numerical simulations are used. Nevertheless, the prohibitive amount of computations has been one of the major issues in the design of coupled FSI systems.

On of the root causes of this exesive computational cost is the computational mesh used to representing the complex and moving shape of the structure. The conventional approach discretize the domain with mesh that conforms to the boundary of the solid region. Hence, when the solid boundary moves, the mesh needs to be updated/deformed. The methods that are available add computational time to an already expensive computation. This will become a challenge specially When intended to design optimization for the large scale problems, because it is impractical to employ convectional finite difference sensitivity to perform shape design optimization of the coupled FSI problems.