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A CORRECTED NEAREST NEIGHBOR TRANSPOTATION METHOD OF AERODYNAMIC FORCE FOR FLUID-STRUCTURE INTERACTIONS

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Abstract. Aeroelastic analysis of the aircraft is a typical fluid-structure interaction problem. It is influenced by interactions between aerodynamic forces and deformations of elastic structures. The aerodynamic field and structural deformation are modeled by different physical equations, and the associated computational meshes do not match each other. Therefore, passing data from a mesh to the other one in a physically reasonable way is a challenging task. Current aerodynamic force transportation methods, such as virtual work conserved method (VWC), area weighted shape function method (AWSF), proximity minimum strain energy method (PMSE), and inverse distance weighted method (IDW), either destroy physical conservations or cause unreasonable distributions of structural forces. In this paper we propose a corrected nearest neighbor transportation method (CNNT) of aerodynamic force for the fluid-structure coupling analysis. The force transportation process is divided into two phases. First, the aerodynamic forces are allocated to the structural nodes initially using the conventional methods or, e.g., AWSF, IDW. Then, the initially allocated structural forces are corrected by solving an optimization problem with the physical conservations as its optimization target. The optimization problem is solved by a barrier interior point method efficiently.A sport airplane model is employed to verify effectiveness of CNNT. Comparisons with the VWC, AWSF, PMSE, IDW are also made. The numerical experiments show that the CNNT maintains the force, moment, and virtual work conservations, and exhibitsreasonable distributions of structural forces, indeed.

Key words. Aerodynamic force transportation, fluid-structure interaction, nearest neighbor method, and corrected algorithm.

1. Introduction

Aeroelastic analysis of the aircraft is a typical fluid-structure interaction problem. It is influenced by the interactions between deformations of elastic structures caused by fluid flows and aerodynamic forces decided by structure frameworks. Loose couplings adopt a three-field formulation, the aerodynamic model, structural model, and the coupling process. Such schemes have advantages that each component of coupling problems can be handled as an isolated identity. The aerodynamic field can be modeled by Navier-Stokes or Eular equations that can be solved for example by finite volume methods or panel methods, while the structural deformation is modeled by elasticity theory that can be solved in general by finite elements methods. These two models describe the interfaces of the aircraft using different resolutions so that the meshes they use don't match each other. Therefore, the challenging task is to pass data from a mesh to the other one in a physically reasonable way. Specifically, aerodynamic forces need to be transferred from fluid to structure, while structure displacements need to be interpolated form structure back to fluid. In the process of data exchange, five criteria should be satisfied [1, 2]: (1) global conservations of forces and moments; (2) accurate displacement interpolations; (3)

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global conservations of virtual works; (4) consistency of local loads; (5) stability and efficiency.

In aspect of the displacement interpolations, the interpolation accuracy rather than the conservations of physical quantities is a main focus. Therefore, various interpolation methods with high accuracies can be taken as choices. In general, the displacement interpolation methods are divided into local interpolation methods and global interpolation methods [3].The local interpolation methods, such as nodal projection method [4, 5],weighted residual method [6] and constant volume method [7], produces interpolation matrices that are sparse and can be solved quickly. However, it requires additional mesh information and searching process, which will increase the computational complexity. The global displacement interpolation methods are easily implemented, but yield full interpolation matrices, such as infinite panel spline (IPS) method [8], finite plate spline (FPS) [9], thin plate spline (TPS) [10], multi-quadric spline (MQ) [11], and Shepard method [12]. Compared with the methods above, radial basis function (RBF) spline methods [13, 14] perform the interpolation on various sub-regions of an aircraft, and show advantages in dealing with a large number of scatter data. The RBF spline interpolation methods have been widely used in fluid-solid coupling analysis in [15–18]. It was investigated in [19, 20] that the TPS and MQ are superior to the other RBF with the most robust, easily implemented, and accurate properties. In this paper, we adopt the TPS based radial basis function to fulfill the displacement interpolation.

On the other hand, the aerodynamic forces need to be transferred from fluid nodes to structure nodes. This process is significantly different from the displacement interpolation because the conservations of total forces, moments, virtual works, and reasonable distributions of forces are required. A generally used method for the force transportation is a so-called virtual work conserved method (VWC), which is embedded into conventional FE softwares, like the MSC-Nastran. The VWC derives the transportation formulation based on the law of virtual work conservation, and the associated transportation matrix is just the transpose of the displacement interpolation matrix [21]. The load is also globally conserved by the VWC. However, it usually causes unreasonable local force distributions in a sense that the transported forces may be opposite to the associated aerodynamic forces on some local structural nodes. Various local methods are also commonly used for the force transportation, and the main idea of these methods is to distribute an aerodynamic force to the structural nodes in its nearest neighborhood. For instance, an area weighted shape function method (AWSF) [22] finds the nearest three structural nodes of a fluid node to construct a triangle and distribute the aerodynamic force according to the area weights, a proximity minimum strain energy method (PMSE) [23]chooses the several nearest structural nodes to allocate the aerodynamic force by assuming the load conservation laws and minimizing a strain energy, an inverse distance weighted method (IDW) [12]also chooses the nearest structural nodes, but allocates the force using the inverses of Euclidean distances between structure node and fluid nodes as weights. Even though the load distributions of these local methods are relatively reasonable, compared with the VWC, the physical conservations are destroyed, such as the virtual works are not maintained by all three methods, while the moments are not preserved by the AWSF and IDW. Moreover, in the AWSF some structure nodes may get no force, and in the PMSE, local force deviations may appear in areas with high curvatures or irregular distributions of structure nodes. To our best knowledge, an aerodynamic