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DEVELOPMENT OF STRONGLY COUPLED FSI TECHNOLOGY INVOLVING THIN WALLED STRUCTURES

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SUMMARY

A strongly coupled finite volume-finite element fluid-structure interaction (FSI) scheme is developed. Both an edge-based finite volume and Galerkin finite element scheme are implemented and evaluated for modelling the mechanics of solids. The governing equations are formulated in a total Lagrangian configuration and large non-linear deformations are accounted for. An implicit matrix-free second-order accurate dual-time-stepping scheme is employed. The higher-order finite element scheme displays the most desirable results and is coupled with an in-house fluid-flow solver. The developed technology is evaluated on representative strongly coupled fluid-structure interaction test problems.

Key Words: finite volume, finite element, fluid-structure interaction

1. INTRODUCTION

Fluid-structure interaction (FSI) constitutes a branch of Computational Mechanics in which there exists an intimate coupling between fluid and structural or solid domains; the behaviour of the system is influenced by the interaction of a moving fluid and a deforming solid structure. The aim of this work is to develop the technology capable of solving complex FSI problems with thin structures subjected to large non-linear deformations. Examples of such problems include the prediction of wing flutter in aircraft [1] and arterial modelling in the human body [2].

2. RESULTS

Traditionally, finite element methods have been used extensively for modelling the mechanics of solids. On the other hand, for modelling of fluid flow phenomena finite volume methods have been more dominant. A stable and robust in-house fluid-flow solver, based on the compact edge-based finite volume approach, is available [3]. There are distinct advantages in applying an edge-based approach. It is applicable to arbitrary element shapes and is computationally efficient. An accurate finite volume structural solver would allow for FSI problems to be solved using a unified strongly coupled scheme.

The first part of this paper highlights the outcomes from investigating whether the same edge-based finite volume approach could be easily extended to accurately model the mechanics of solids. The governing equations for the solid domain are formulated in a total Lagrangian or undeformed configuration and are able to account for geometrically non-linear deformations of the structure. The set of equations are solved via a single-step Jacobi iterative scheme [4] which is implemented such as to ensure a matrix-free and robust solution. The standard finite element Galerkin method is then implemented. Linear four-node (Q4) and higher-order eight-node (Q8) isoparametric quadrilateral elements are used for spatial discretisation. Second-order-accurate temporal discretisation is achieved via dual-time-stepping [5], with both consistent and lumped mass matrices and with a Jacobi pseudo-time iteration method employed for solver purposes. The matrix-free approach makes the scheme particularly well suited for distributed memory parallel hardware architectures.

The finite volume and finite element schemes above are evaluated for modelling thin walled solids. For this purpose, a number of test-cases ranging from geometrically non-linear static analysis to dynamic stress analysis are considered. The finite volume approach is found to exhibit distinct advantages over the Q4 formulation, in that it is insensitive to element aspect ratio. This result is shown in Figure 1.

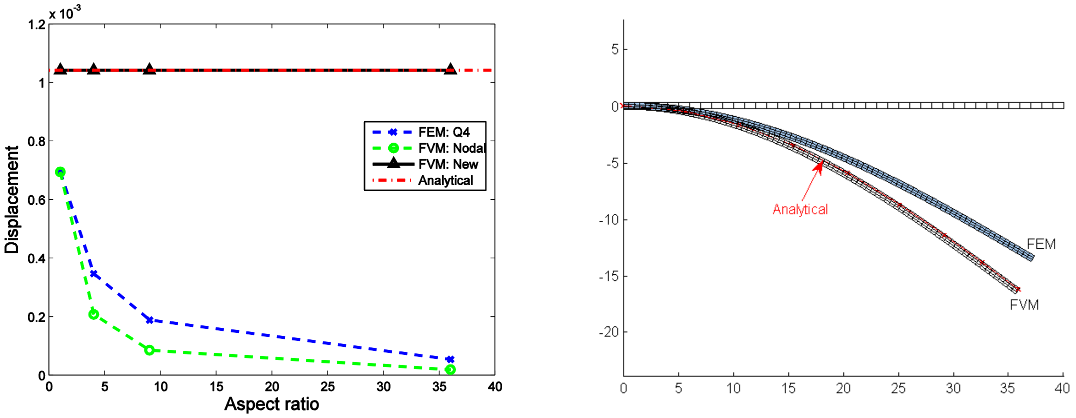

Figure 1 Left: Displacement as a function of element aspect ratio for a thin beam in pure bending. **Right:** Geometrically non-linear analysis using the finite-volume (FVM) and Q4 finite element (FEM) methods.

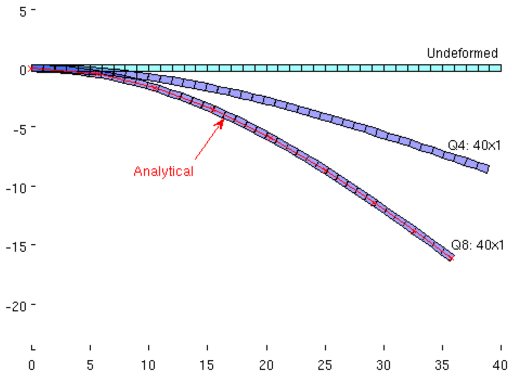

Figure 2: Geometrically non-linear analysis on a 40x1 mesh using the Q4 and Q8 finite element (FEM) methods.

The Q8 formulation displays greater accuracy, however, to the extent that only a single element is required through a thin wall, as shown in Figure 2. Next, the Q8 finite element method is implemented into a finite volume fluid flow solver. The coupling between the fluid and structural components is rigorously assessed. The developed technology is finally evaluated and benchmarked on representative two-dimensional strongly coupled large-displacement fluid-structure interaction test problems.

3. CONCLUSIONS

An edge-based finite volume method to model structures is investigated and compared with the traditional Galerkin finite element method in this work. Although the former approach exhibits distinct advantages over the Q4 formulation, the Q8 formulation displays the most desirable results. A strongly coupled FSI scheme is developed and evaluated on representative test problems.

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