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AC-CBS-Based Partitioned Semi-Implicit Coupling Algorithm for Fluid-Structure Interaction Using Stabilized Second-Order Pressure Scheme

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Abstract. We analyze in this paper the pressure splitting scheme of a partitioned semi-implicit coupling algorithm for fluid-structure interaction (FSI) simulation. The semi-implicit coupling algorithm is developed on the ground of the artificial compressibility characteristic-based split (AC-CBS) scheme that serves not only for the fluid subsystem but also for the global FSI system. As the dual-time stepping procedure recommended for quasi-incompressible flows is incorporated into the implicit coupling stage, the fluctuating pressure may be unusually susceptible to the AC coefficient. Moreover, it is not trivial to devise an optimal AC formulation for pressure estimation. Instead, we consider a stabilized second-order pressure splitting scheme in the AC-CBS-based partitioned semi-implicit coupling algorithm. Computer simulation of a benchmark FSI experiment demonstrates that good agreement is exposed between the available and present data.

AMS subject classifications: 35Q30, 65M22, 65M60, 74F10, 76M10

Key words: Fluid-structure interaction, semi-implicit coupling, CBS, artificial compressibility, second order.

1 Introduction

The numerical simulation of fluid-structure interaction (FSI) has long attracted vast interests from research community because of its scientific and practical importance. In

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consideration of FSI, people can moderately handle challenging problems, such as wind-induced vibrations of a skyscraper or super suspension bridge in civil engineering. Although an FSI problem can be solved in a monolithic manner [1, 2], partitioned solution technique under the arbitrary Lagrangian-Eulerian (ALE) description [3, 4] seems a prevailing strategy. Interested readers can refer to recent review articles [5, 6] for the representative numerical methods of FSI.

Apart from traditional explicit and implicit approaches, partitioned *semi-implicit* coupling algorithm has been proposed over the last decade. Fernández et al. [7] first proposed a projection semi-implicit coupling scheme for simulating FSI problems with strong added-mass effect [8–10]. The basis of this semi-implicit concept depends on the classical Chorin-Témam splitting [11, 12] which naturally offers an explicit-implicit treatment for the FSI resolution. In particular, the ALE-advection-diffusion step is explicitly treated with the predicted fluid mesh while the projection step is implicitly coupled with the structural motion on the previously frozen fluid mesh. Theoretical analysis indicated that the semi-implicit coupling algorithm exhibits the enhanced computational efficiency without affecting the stability condition significantly when compared to the implicit coupling algorithm [7]. Following this idea, a number of semi-implicit coupling methods have been presented over the past years. Quaini and Quarteroni [13] invented a semi-implicit coupling scheme on the ground of algebraic fractional step method. This is the first time that the algebraic fractional step method is applied to FSI. Unlike differential splitting, the algebraic fractional step method requires no auxiliary boundary conditions for differential subsystems divided by the original problem. Badia et al. [14] introduced the inexact block-LU factorization into several semi-implicit coupling schemes and discussed their own performances. Nitsche-based and Robin-based semi-implicit coupling schemes, as well as a couple of variants, were proposed for an incompressible viscous fluid interplaying with a thin-walled solid [15]. Better stability properties were achieved through these hybrid interface conditions. Astorino et al. [16] performed a convergence analysis for the projection-based semi-implicit coupling scheme [7] in a simplified FSI system. The error of time discretization was proved to be at least $\sqrt{\Delta t}$ in this scheme. Fernández [17] presented a comprehensive review for numerical simulation of blood flows in large arteries involving explicit, semi-implicit and implicit coupling schemes. The projection-based partitioned semi-implicit coupling strategy was successfully applied to a three-dimensional idealized abdominal aortic aneurysm for sequential parameter estimation by using reduced-order unscented Kalman filter [18].

A new partitioned semi-implicit coupling method was developed by the authors on the basis of the characteristic-based split (CBS) scheme, a general algorithm for fluid dynamics [19–21]. The resulting algorithm was termed the *CBS-based partitioned semi-implicit coupling method*. It is seen from [19] that a set of additional ordinary differential equations need to be solved on the constructed fluid-structure interface. Unlike [19], the traditional interface conditions were enforced in [20,21]. The first author's research work was briefly summarized in [20] by comparing different partitioned coupling schemes for two large-displacement FSI problems. Ref. [21] provided the details on carrying out the smoothed