Commun. Comput. Phys.
doi: 10.4208/cicp.291210.290411s

Vol. **12**, No. 2, pp. 337-377
August 2012

REVIEW ARTICLE

Numerical Methods for Fluid-Structure Interaction — A Review

Gene Hou[1], Jin Wang[2,*] and Anita Layton[3]

[1] *Department of Mechanical and Aerospace Engineering, Old Dominion University, Norfolk, VA 23529, USA.*
[2] *Department of Mathematics and Statistics, Old Dominion University, Norfolk, VA 23529, USA.*
[3] *Department of Mathematics, Duke University, Durham, NC 27708, USA.*

Received 29 December 2010; Accepted (in revised version) 29 April 2011

Available online 20 February 2012

Abstract. The interactions between incompressible fluid flows and immersed structures are nonlinear multi-physics phenomena that have applications to a wide range of scientific and engineering disciplines. In this article, we review representative numerical methods based on conforming and non-conforming meshes that are currently available for computing fluid-structure interaction problems, with an emphasis on some of the recent developments in the field. A goal is to categorize the selected methods and assess their accuracy and efficiency. We discuss challenges faced by researchers in this field, and we emphasize the importance of interdisciplinary effort for advancing the study in fluid-structure interactions.

AMS subject classifications: 65-02, 65Z05, 74F10

Key words: Fluid-structure interaction, conforming and non-conforming meshes, immersed methods.

Contents

*Corresponding author. *Email addresses:* ghou@odu.edu (G. Hou), j3wang@odu.edu (J. Wang), alayton@math.duke.edu (A. Layton)

1 Introduction

In fluid-structure interaction (**FSI**) problems, one or more solid structures interact with an internal or surrounding fluid flow. FSI problems play prominent roles in many scientific and engineering fields, yet a comprehensive study of such problems remains a challenge due to their strong nonlinearity and multidisciplinary nature (Chakrabarti 2005, Dowell and Hall 2001, Morand and Ohayon 1995). For most FSI problems, analytical solutions to the model equations are impossible to obtain, whereas laboratory experiments are limited in scope; thus to investigate the fundamental physics involved in the complex interaction between fluids and solids, numerical simulations may be employed.

With recent advances of computer technology, simulations of scientific and engineering systems have become increasingly sophisticated and complicated. For example, the speed requirement of a planing boat hull has advanced to such a degree and with such a speed that has outpaced the availability of testing data and existing design equations (Weymouth et al. 2006, 2008). To fill the technological gap, an efficient numerical algorithm can be used to investigate in detail the interaction between water waves and the motion of the boat. Such an investigation is typically multidisciplinary. In this example, the performance of the boat is a result of the interaction between water hydrodynamics and structural dynamics. Other FSI applications include, but are not limited to, sedimentation (Mucha et al. 2004, Tornberg and Shelley 2004, Wang and Layton 2009), particle assembly (Liu et al. 2006), aerodynamics (Haase 2001, Zhang, Jiang and Ye 2007), turbulence (Kaligzin and Iaccarino 2003, Yang and Balaras 2006), complex flows in irregular domains (Fadlun et al. 2000, Udaykumar et al. 1996, 2001), electro-hydrodynamics (Hoburg and Melcher 1976), magneto-hydrodynamic flows (Grigoriadis et al. 2009), biofluid and bio-mechanics (such as cell aggregation and deformation, blood-heart interaction, inner ear fluid dynamics, jellyfish swimming, sperm motility, cilliary beating, etc.).

The numerical procedures to solve these FSI problems may be broadly classified into two approaches: the *monolithic approach* and the *partitioned approach*. It is understood that the distinction between the monolithic and partitioned approaches may be viewed differently by researchers from different fields. In this paper, we intend to define these two approaches from the engineering application point of view. Fig. 1 illustrates the solution procedures of the monolithic and partitioned approaches.

The monolithic approach (Hubner et al. 2004, Michler et al. 2004, Ryzhakov et al. 2010) treats the fluid and structure dynamics in the same mathematical framework to form a single system equation for the entire problem, which is solved simultaneously by a unified algorithm. The interfacial conditions are implicit in the solution procedure. This approach can potentially achieve better accuracy for a multidisciplinary problem, but it may require substantially more resources and expertise to develop and maintain such a specialized code. In contrast, the partitioned approach treats the fluid and the structure as two computational fields which can be solved separately with their respective mesh discretization and numerical algorithm. The interfacial conditions are used explicitly to communicate information between the fluid and structure solutions. A motivation of