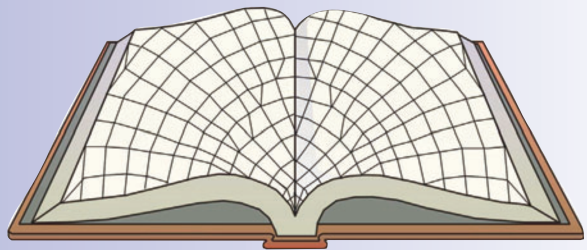
COMPUTATIONAL FLUID-STRUCTURE INTERACTION: METHODS AND APPLICATIONS



BOOK REVIEW

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ISBN: 978-0-470-97877-1, 384 pages, hard cover, £81.50 (List Price).
Contents: Preface; 1. Governing Equations of Fluid and Structural Mechanics; 2. Basics of the Finite Element Method for Nonmoving-Domain Problems; 3. Basics of the Isogeometric Analysis; 4. ALE and Space–Time Methods for Moving Boundaries and Interfaces; 5. ALE and Space–Time Methods for FSI; 6. Advanced FSI and Space–Time Techniques; 7. General Applications and Examples of FSI Modeling; 8. Cardiovascular FSI; 9. Parachute FSI; 10. Wind-Turbine Aerodynamics and FSI; References; Index.

I have always been impressed with the problems attacked and solutions obtained by the group of the third author, Tayfun Tezduyar, in Rice University. This group has been one of the leading groups that solve extremely complicated and important real life problems using sophisticated computational techniques. Their particular expertize has been Fluid-Structure Interaction (FSI) problems with moving boundaries and interfaces. Whenever I want to show students what computational mechanics can achieve today, I advise them to look up Tezduyar's web site. The second author has belonged to this group since 2007, and is also an independent researcher in Japan. The first author is an expert in isogeometric analysis, who is based in UCSD and has been collaborating with this group in recent years. Both are young researchers who already have a sophisticated and impressive volume of work under their names.

As expected, the book includes many impressive examples of this work. It can roughly be divided into three parts. Chapters 1 to 4 cover the infrastructure needed for the methods discussed. Chapters 5 and 6 present the computational techniques recommended for solving FSI problems. Chapters 7 to 10 discuss a variety of applications, including the process of balloon inflation, the flying of an insect, various cardiovascular problems, the behavior of parachutes of various kinds and wind turbine aerodynamics. These last chapters are scattered with results that exhibit a tour de force. Samples from the many beautiful figures that appear in these chapters are shown here. In fact, the entire book is very nicely edited, is full of illustrations, and has an extremely pleasing appearance.

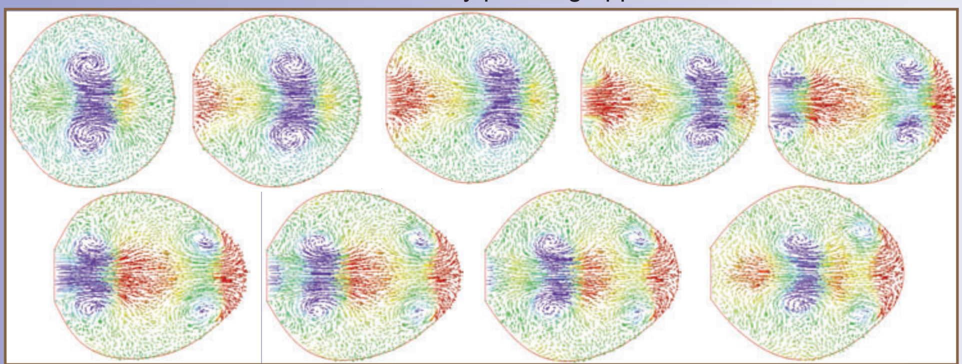
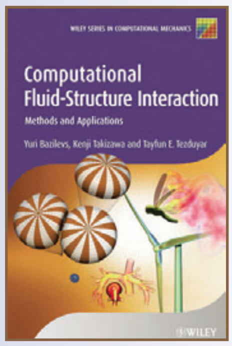


Figure 1:
Inflation of a balloon: velocity vectors colored by air pressure, from 2 to 4 sec. This figure appears as Fig. 7.12, p. 180, in the book



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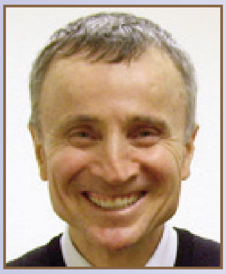

Tayfun Tezduyar

Figure 2:
Flight of an insect: vorticity at eight instants during the flapping cycle.
This figure appears as Fig. 7.26, p. 189, in the book

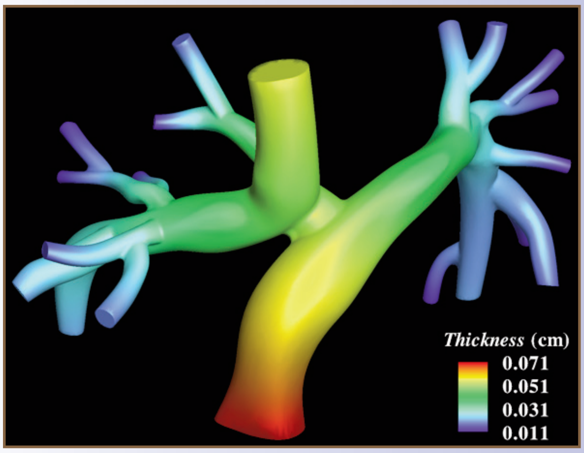

Figure 3:
Cardiovascular FSI analysis: reconstructed thickness distribution from inlet and outlet data for a patient-specific Fontan surgery configuration.
This figure appears as Fig. 8.3, p. 203, in the book

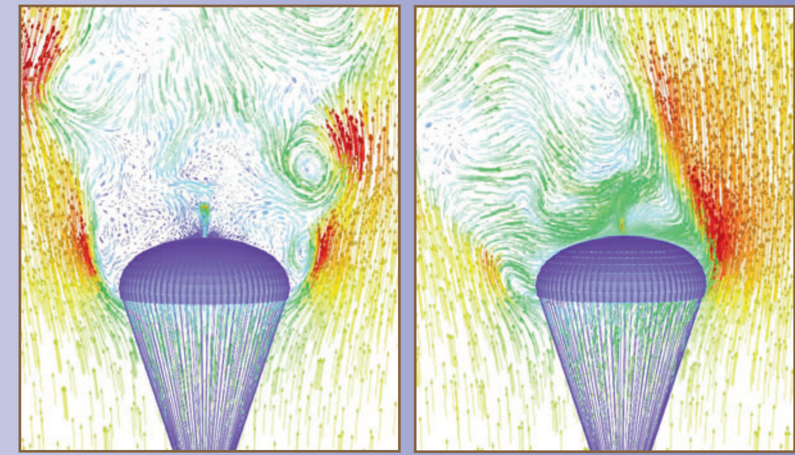

Figure 4:
Parachute shape and flow field at an instant during symmetric FSI (left) and asymmetric FSI (right).
This figure appears as Fig. 9.15, p. 276, in the book

The Preface summarizes very nicely the challenges entailed in computational FSI. It is remarked that the fluid mechanics modeling in this book is restricted to incompressible flows, due to the research interests of the authors. I have not found in the Preface a statement concerning whom this book is intended to and what background is needed. On the back cover it is stated that this book is a "comprehensive reference for researchers and practicing engineers…, (and a) text for graduate and senior-level undergraduate courses…"

My own judgment is that the reader is required to have basic knowledge of fluid mechanics (and the Navier-Stokes equations), of nonlinear solid mechanics (called here "structural mechanics"), of tensor notation (for example, the meaning of the tensor product symbol), and of the standard finite element method. It is true that Chapter 1 covers the "governing equations of fluid and structural mechanics,'' and that Chapter 2 covers the "basics of the finite element method.'' However, these chapters are written in a way that serves to *remind* the reader of these subjects, and to introduce the notation used later, rather than to *teach* these subjects to a reader who has never been exposed to them.

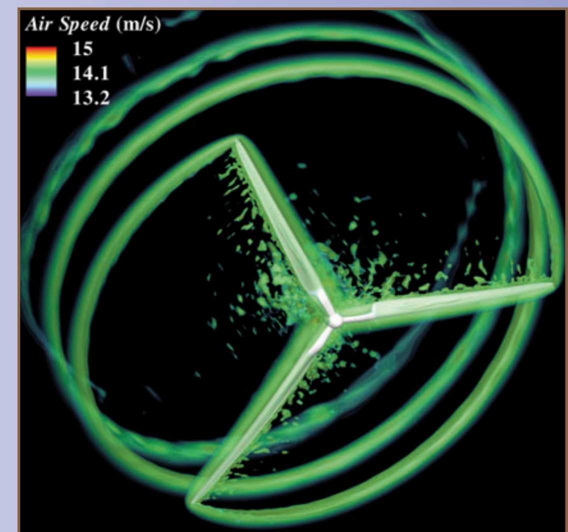

Figure 5:
Simulation of a wind turbine rotor: isosurfaces of air speed at an instant. This figure appears as Fig. 10.28, p. 344, in the book

I will give a couple of examples to demonstrate this. The symbol S appears first in the principle of virtual work, eq. (1.79), and the text states: "Here S is the second Piola-Kirchhoff stress tensor which is symmetric and work conjugate to E." I suspect that for a reader who has never studied continuum mechanics this sentence would be almost cryptic, and the need for introducing this "strange" stress tensor S, which seems to be different than the familiar Cauchy stress σ, would be unclear. A second example is the presentation of the weak form of the Navier-Stokes equations, on p. 11. The text simply says "To derive the weak form of the fluid mechanics equation, following the standard approach, we multiply Eqs. … by the linear-momentum and continuity equations test functions respectively, integrate over …, and add the equations to obtain…" The reader encounters the terms "weak form" and "test functions" for the first time in this book. It is clear from this phrasing and from the very quick way in which the weak form is derived, that the authors assume the reader to be somewhat familiar with these basic concepts.

The weak form for the solid mechanics problem, eq. (1.80), is called here the "variational formulation," and no attempt is made to point to the analogy between the "weak form" of the fluid mechanics problem and the "variational formulation" of the solid mechanics problem. The reader is trusted to be familiar with these concepts, and to understand that the variational form is in fact a weak form. In section 1.2.9 thin-walled structures such as shells and cables are discussed. Again the reader is assumed to know quite a lot about shell theory, and this section mainly serves as a reminder. In any case, it would have been helpful to provide the reader with references to excellent books devoted to fluid mechanics, nonlinear solid mechanics, shell theory, tensor analysis and the finite element method. For the beginner, these subjects should be studied before starting to read the present book.

Chapter 2 includes, beyond a brief coverage of the standard Galerkin FEM, some less standard material, like FE treatment of the advection-diffusion problem, with and without SUPG stabilization, various stabilization techniques for the Navier-Stokes equations, Variational MultiScale (VMS), and Dirichlet conditions enforced weakly. Incidentally, acronyms are used a lot in the book, and their meanings are not always defined clearly. Some of the acronyms are quite long, such as SSTFSI-VMST (p. 123), DSD/SST-SUPS (p. 102), and SENCT-FC-M1 (p. 164). A reader encountering a certain acronym on p. 123 would have a hard time locating where it has been defined. If a second edition of this book is ever to be published, I suggest that the authors include a table of acronyms at the beginning.

The authors concentrate in this book on a certain collection of techniques which they have developed, investigated and implemented themselves. These techniques are based on certain space-time FE formulations, Arbitrary Lagrangian Eulerian (ALE) methods, certain stabilization methods, isogeometric analysis, and certain FSI coupling methods. Together these constitute a powerful tool box which allows solving realistic and very complicated FSI problems. Some other possible approaches and tools receive less attention. These include, for example, time-stepping methods applied to semi-discrete FE formulations (except for some short segments in various chapters), the work of Roger Ohayon's group on FSI for wave problems, the particle FE methods for FSI a là Oñate and Idelsohn, etc. In fact, I think it would be fair to say that the book is not intended to offer a comprehensive review on all existing FSI-related methods. Its strength is in presenting a certain tool box for FSI problems. Moreover, this is not an accidental tool box, but one which has proved itself very clearly and consistently as extremely viable and robust in solving FSI problems of a very high level of complexity.

Chapter 3 provides the essentials of isogeometric analysis, and Chapter 4 covers the basics of ALE and space-time FE methods, with and without the presence of moving boundaries and interfaces. Efficient methods for mesh updating are also discussed. Chapter 5 shows how to employ the methodologies of Chapter 4 to FSI. Chapter 6 introduces advanced FSI and space-time methods, developed mainly by the authors. These include advanced techniques for solving the nonlinear algebraic equations resulting from the discretization, the treatment of time using NURBS, space-time mesh control using NURBS, and a technique for contact between solids, that is relevant, e.g., to parachute problems.

As mentioned above, Chapters 7-10 provide a plethora of examples where the techniques covered by the previous chapters are employed in various applications. Whether the reader is interested in one of these applications or in another application not discussed here, she will definitely find here a clear demonstration to what these sophisticated techniques can achieve today.

In summary, this book is an excellent source to a reader who wants to get serious about solving realistic FSI problems, using a set of techniques that have proved themselves as powerful and robust.