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Book Review

Prosperetti, A., Tryggvason, G. Computational methods for multiphase flows, Cambridge University Press, 481 pp., 95$ (hardback)

Multiphase flows are ubiquitous in nature and engineering. Efforts to compute them started in the 1960s, motivated in good part by nuclear safety problems. The subject has become a topic of increasing scientific interest within the last two decades which have seen the flowering of various dedicated computational techniques. In addition to the usual difficulties encountered in the computation of single-phase incompressible flows (consequences of the nonlinearity of the momentum equation, divergence-free condition, problem of outflow conditions in open flows...), two-phase flows offer many new challenges. Dealing with the matching conditions to be satisfied on a generally unknown boundary, with the specific nature of surface tension forces and the fact that the shape or even the topology of the two phases may change in time requires the development of specific numerical techniques which are now considered as a intrinsic part of the ongoing research in multiphase flows. The field is now so vast and so active that getting a unified vision of its main developments requires the reading of hundreds of technical papers disseminated in many different journals. This makes the present book, where fourteen authoritative authors in the field provide a thorough view of the specific problems encountered in the computation of a wide range of two-phase flows and how they are dealt with by modern computational techniques, particularly timely.

The book starts with two introductive chapters: chapter 1 describes the basic governing equations and the most widely used dimensionless numbers while chapter 2 summarizes the best established numerical techniques used to solve single-phase incompressible Navier–Stokes equations.

The first of the two main parts of the book is built on chapters 3–7 which deal with direct numerical simulation of two-phase flows where no assumption beyond the validity of Navier–Stokes equations and Laplace's law is involved. Each of these chapters focuses on a specific method or group of methods, namely immersed boundary techniques, structured grid techniques, the finite element approach (restricted to particulate flows), lattice Boltzmann approaches and boundary integral techniques for Stokes flow, respectively. All chapters present interesting applications of the concerned method to physical problems that were considered by the corresponding authors in some of the papers to which they personally contributed. Several of these chapters offer a significant amount of key details on the technique they describe and may be used as a guide when developing a new code based on the corresponding approach (I found this especially true in chapters 5 and 7). In contrast chapter 3 rather provides an overview of what I prefer to call "fixed-grid techniques" to keep the terminology "immersed boundary technique" to the approach initiated by Peskin (Peskin, 1977) some thirty years ago, which is now becoming increasingly popular (this approach is nicely discussed in Section 4.2). Actually, the focus of chapter 3 is on the well-known Volume Of Fluid, Front Tracking and Level Set approaches. I found this chapter rather sketchy and was a bit disappointed to see that several important topics are not addressed. For instance the difficult issue of mass conservation which frequently prevents long term phenomena from being fruitfully studied using the Front Tracking or the Level Set approach because the mass of each phase fails to be rigorously conserved as time proceeds is not mentioned at all. Similarly, the subtleties related to viscosity interpolation in interfacial regions is only mentioned in a couple of sentences. Also the Ghost Fluid interpolation approach now increasingly used in conjunction with the Level Set method is not discussed. I found the content of chapter 6 devoted to the lattice Boltzmann approach also somewhat unbalanced. While the central issue of thermodynamical consistency is discussed with care, the treatment of capillary effects is totally ignored. The implementation of some types of boundary condition is described in its main lines but little is said on many other technical aspects of this method.

The last part of the book, made of chapters 8–11, considers two-phase flow computations in situations where some level of modelling is involved. This part of the book opens with chapter 8 which presents the theoretical foundations of averaged models, starting with the technique of volume averaging and the popular homogeneous and drift flux models widely used in industrial codes. A section of this chapter also considers the specific case of dispersed flows in which the main closure issue is the specification of hydrodynamic forces acting on the particulate phase. Expressions for these forces are reviewed both in the dilute limit and in the dense case (expression (8.67), later reproduced as equation (9.10), is only correct in the zero-Reynolds-number limit (Magnaudet et al., 1995)). This chapter ends with a substantial and clear discussion of well-posedness and hyperbolicity of averaged Eulerian models which is a key mathematical issue that needs to be addressed before the numerical implementation of any new such model.

Chapter 9 discusses the important approach of point-particle methods in which the dispersed phase is treated in a Lagrangian way, each particle being considered as a point with respect to the resolved fluid scales. In my view this chapter could have been included in the first part of the book, since the structure of the equations under consideration for the fluid phase is still that of the Navier–Stokes system. The chapter rightly insists on the crucial technical aspect of interpolation of fluid characteristics at the instantaneous particle location. I was a little worried that the applications discussed later in the chapter are restricted to gas–solid flows in which only the fluid velocity has to be interpolated while applications to liquid–liquid and bubbly flows also require the fluid acceleration and vorticity to be interpolated, which imposes more stringent constraints on the interpolation procedure. It is not clear to me why section 9.4 which describes the numerical treatment of the fluid phase was included in this chapter, since this treatment is not specific to the point-particle approach and a close algorithm is described in chapter 2. In contrast the subsection

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discussing the difficulties encountered to define properly the undisturbed fluid velocity in this type of computations is welcome. It could profitably be complemented by a discussion of physical problems which cannot be addressed using this type of approach, namely most of those governed by small-scale flow features. Examination of the literature indicates that this limitation is quite frequently ignored...

The last two chapters focus on fully averaged models in which the interfaces are not explicitly localized any more, in direct connection with the concepts developed in chapter 8. Chapter 10 is concerned with the so-called segregated methods in which the two phases are solved in sequence, as is suitable when their interaction is weak enough such as in fluidized beds. In contrast, chapter 11 discusses coupled methods which are used in situations of strong interaction, such as those encountered in thermohydraulic safety and oil transportation problems. Chapter 10 insists on the difficulties related to advection, with the frequent need to use slope limiters, and on the strategies employed to evaluate the pressure field, either from the averaged continuity equation or from the conservation of the sum of the volume fractions. In the case of coupled methods, a certain level of implicitness is required to avoid excessive stability constraints. Several first-order strategies routinely used in industrial codes are discussed, all of which are characterized by a substantial numerical diffusion. This is why the second part of the chapter adopts a more prospective point of view and concentrates on higher-order schemes, essentially based on the TVD approach. The issues discussed in this second part have much in common with gas dynamics, since most ills and remedies are shared by the two fields.

The whole book is well written, in a clear and efficient general style. Obviously each chapter follows a slightly specific approach, having been written by a different group of authors. Nevertheless a noticeable effort was made by the editors to harmonize notations and refer to results discussed in another chapter when necessary. I found only a few misprints (e.g. Eq. (3.18)) and some references quoted in the text which are not included in the reference list. These details will easily be fixed in the second edition.

A characteristics of this book is that it covers two different types of computational techniques: those used in fundamental research on two-phase flows (broadly speaking, based on the Navier–Stokes equations) as well as those employed in full engineering applications (based on some form of averaged equations). This is an ambitious choice, the benefit of which is that both aspects are treated in a unified perspective and with the same level of mathematical description. Nevertheless I wonder whether two separate books would not have been more appropriate, given that the two communities of potential users are quite distinct. In particular, this would have allowed the first part of the book to be expanded so as to include a discussion of several important additional computational approaches. I have particularly in mind the force coupling technique developed by Maxey's group (Lomholt and Maxey, 2003; Climent and Maxey, 2003) which is a promising extension of the point particle approach based on a truncated multipole expansion, the second gradient and phase field techniques based on the specification of a free energy function which allows the description of complex interfacial rheologies and physical processes, and the boundary integral techniques for irrotational flows which have proved to be extremely powerful, for instance in studies of surface wave breaking, and were initiated by Longuet-Higgins and Cokelet (1976) at the same time Youngren and Acrivos created the boundary integral technique for Stokes flows (Youngren and Acrivos, 1975).

Beyond these personal remarks, the authors and the editors have to be warmly thanked for having produced the first comprehensive book entirely devoted to computational approaches for multiphase flows. This book will be extremely useful for graduate and PhD students developing or using a multiphase flow code as well as for academics and research engineers involved in multiphase flow research. It may be used as a self-consistent document to get a detailed idea of the potentialities and difficulties of a given method or as a guide toward more specialized papers when focusing on a specific point. All this makes *Computational Methods for Multiphase Flow* useful to and enjoyable by the whole multiphase flow community and I strongly recommend any member of this community to have this volume in his bookshelves!

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