DIRECT NUMERICAL SIMULATIONS OF GAS–LIQUID MULTIPHASE FLOWS

Accurately predicting the behavior of multiphase flows is a problem of immense industrial and scientific interest. Using modern computers, researchers can now study the dynamics in great detail, and computer simulations are yielding unprecedented insight. This book provides a comprehensive introduction to direct numerical simulations of multiphase flows for researchers and graduate students.

After a brief overview of the context and history, the authors review the governing equations. A particular emphasis is placed on the "one-fluid" formulation, where a single set of equations is used to describe the entire flow field and interface terms are included as singularity distributions. Several applications are discussed, such as atomization, droplet impact, breakup and collision, and bubbly flows, showing how direct numerical simulations have helped researchers advance both our understanding and our ability to make predictions. The final chapter gives an overview of recent studies of flows with relatively complex physics, such as mass transfer and chemical reactions, solidification, and boiling, and includes extensive references to current work.

GRÉTAR TRYGGVASON is the Viola D. Hank Professor of Aerospace and Mechanical Engineering at the University of Notre Dame, Indiana.

RUBEN SCARDOVELLI is an Associate Professor in the Dipartimento di Ingegneria Energetica, Nucleare e del Controllo Ambientale (DIENCA) of the Università degli Studi di Bologna.

STÉPHANE ZALESKI is a Professor of Mechanics at the Université Pierre et Marie Curie (UPMC) in Paris and Head of the Jean Le Rond d'Alembert Institute (CNRS UMR 7190).

DIRECT NUMERICAL SIMULATIONS OF GAS–LIQUID MULTIPHASE FLOWS

GRÉTAR TRYGGVASON
University of Notre Dame, Indiana

RUBEN SCARDOVELLI
Università degli Studi di Bologna

STÉPHANE ZALESKI
Université Pierre et Marie Curie, Paris 6

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE UNIVERSITY PRESS
Cambridge, New York, Melbourne, Madrid, Cape Town,
Singapore, São Paulo, Delhi, Tokyo, Mexico City

Cambridge University Press
The Edinburgh Building, Cambridge CB2 8RU, UK

Published in the United States of America by Cambridge University Press, New York

www.cambridge.org
Information on this title: www.cambridge.org/9780521782401

First published 2011

Printed in the United Kingdom at the University Press, Cambridge

A catalogue record for this publication is available from the British Library

ISBN 978-0-521-78240-1 Hardback

Contents

Cambridge University Press
978-0-521-78240-1 - Direct Numerical Simulations of Gas-Liquid Multiphase Flows
Gretar Tryggvason, Ruben Scardovelli and Stephane Zaleski
Frontmatter
More information

Preface

Progress is usually a sequence of events where advances in one field open up new opportunities in another, which in turn makes it possible to push yet another field forward, and so on. Thus, the development of fast and powerful computers has led to the development of new numerical methods for direct numerical simulations (DNS) of multiphase flows that have produced detailed studies and improved knowledge of multiphase flows. While the origin of DNS of multiphase flows goes back to the beginning of computational fluid dynamics in the early sixties, it is only in the last decade and a half that the field has taken off. We, the authors of this book, have had the privilege of being among the pioneers in the development of these methods and among the first researchers to apply DNS to study relatively complex multiphase flows. We have also had the opportunity to follow the progress of others closely, as participants in numerous meetings, as visitors to many laboratories, and as editors of scientific journals such as the *Journal of Computational Physics* and the *International Journal of Multiphase Flows*. To us, the state of the art can be summarized by two observations:

- Even though there are superficial differences between the various approaches being pursued for DNS of multiphase flows, the similarities and commonalities of the approaches are considerably greater than the differences.
- As methods become more sophisticated and the problems of interest become more complex, the barrier that must be overcome by a new investigator wishing to do DNS of multiphase flows keeps increasing.

This book is an attempt to address both issues.

The development of numerical methods for flows containing a sharp interface, as fluids consisting of two or more immiscible components inherently do, is currently a "hot" topic and significant progress has been made by a number of groups. Indeed, for a while there was hardly an issue of the *Journal of Computational Physics* that did not contain one or more papers describing such methods. In the present book we have elected to focus mostly on two specific classes of methods: volume of fluid (VOF) and front-tracking methods. This choice reflects our own background, as well as the fact that both types of method have been very successful and are responsible for some of the most significant new insights into multiphase flow dynamics that DNS has revealed. Furthermore, as emphasized by the first bullet point, the similarities in the different approaches are sufficiently great that a reader of the present book would most likely find it relatively easy to switch to other methods capable of capturing the interface, such as level set and phase field.

The goal of DNS of multiphase flows is the understanding of the behavior and properties of such flows. We believe that while the development of numerical methods is important, it is in their applications where the most significant rewards are to be found. Thus, we include in the book several chapters where we describe the use of DNS to understand specific systems and what has been learned up to now. This is inherently a somewhat biased sample (since we elected to talk about studies that we know well – our own!), but we feel that the importance of these chapters goes beyond the specific topics treated. We furthermore firmly believe that the methods that we describe here have now reached sufficient maturity so that they can be used to probe the mysteries of a large number of complex flows. Therefore, the application of existing methods to problems that they are suited for and the development of new numerical methods for more complex flows, such as those described in the final chapter, are among the most exciting immediate directions for DNS of multiphase flows.

Our work has benefitted from the efforts of many colleagues and friends. First and foremost we thank our students, postdoctoral researchers and visitors for the many and significant contributions they have made to the work presented here. GT would like to thank his students, Drs. D. Yu, M. Song, S.O. Unverdi, E. Ervin, M.R. Nobari, C.H.H. Chang, Y.-J. Jan, S. Nas, M. Saeed, A. Esmaeeli, F. Tounsi, D. Juric, N.C. Suresh, J. Han, J. Che, B. Bunner, N. Al-Rawahi, W. Tauber, M. Stock, S. Biswas, and S. Thomas, as well as the following visitors and postdoctoral researchers: S. Homma, J. Wells, A. Fernandez, and J. Lu. RS would like to thank his students, Drs. E. Aulisa, L. Campioni, A. Cervone, and V. Marra, as well as his collaborators S. Manservisi, P. Yecko, and G. Zanetti. SZ would like to thank his students, Drs. B. Lafaurie, F.-X. Keller, J. Li, D. Gueyffier, S. Popinet, A. Leboissetier, L. Duchemin, O. Devauchelle, A. Bagué, and G. Agbaglah, as well as his collaborators, visitors, and postdoctoral researchers, G. Zanetti, A. Nadim, J.-M. Fullana, C. Josserand, P. Yecko, M. and Y. Renardy, E. Lopez-Pages, T. Boeck, P. Ray, D. Fuster, G. Tomar, and J. Hoepffner. SZ would also like to thank his trusted friends and mentors, Y. Pomeau, D.H. Rothman, and E.A. Spiegel, for their invaluable advice. We also thank Ms. Victoria Tsengué Ingoba for reading the complete book twice and pointing out numerous typos and mistakes. Any errors, omissions, and ambiguities are, of course, the fault of the authors alone.

And last, but certainly not least, we would like to thank our families for unerring support, acceptance of long working hours, and tolerance of (what sometimes must have seemed) obscure priorities.

Grétar Tryggvason
Ruben Scardovelli
Stéphane Zaleski