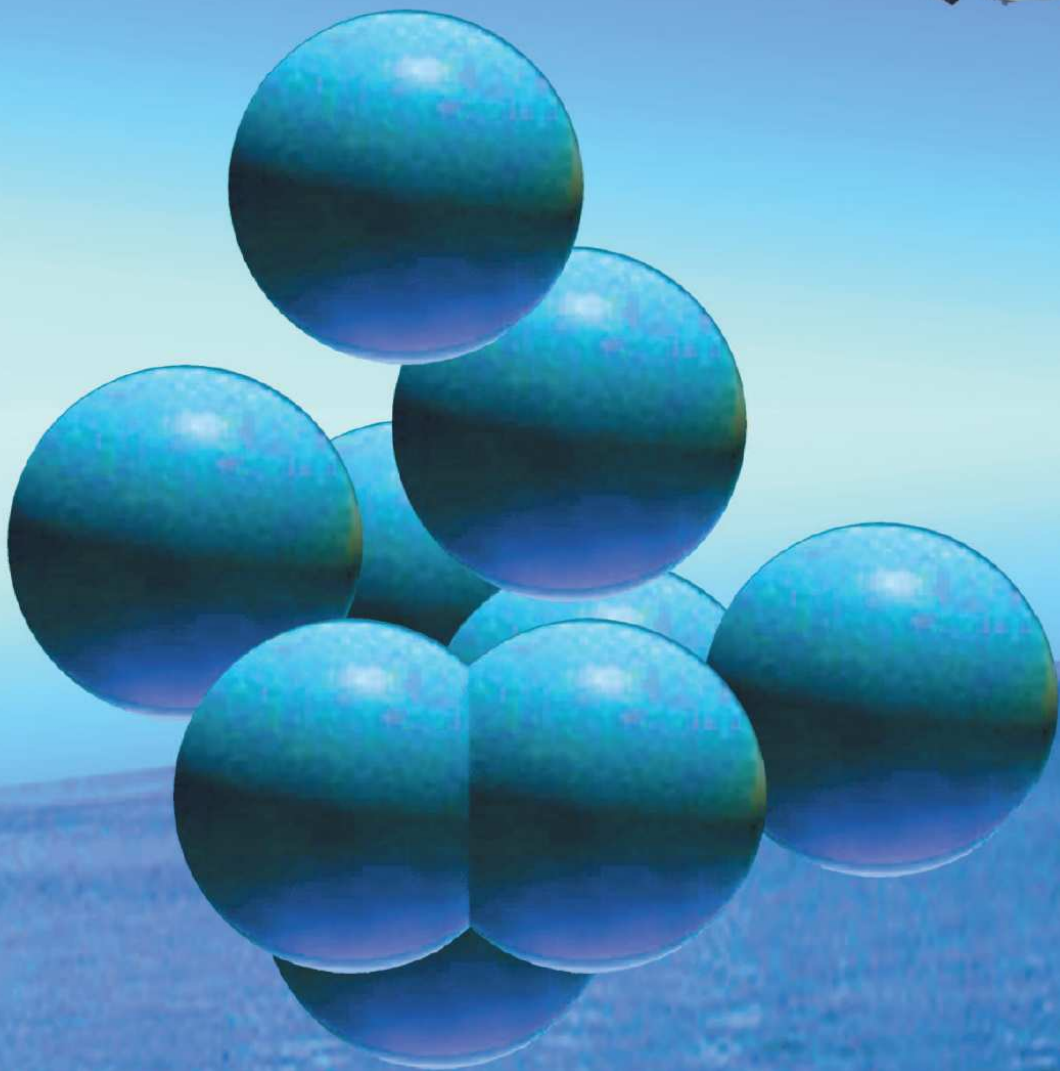


Fluids, Materials & Microgravity

Numerical Techniques and Insights into the Physics



Marcello Lappa

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ELSEVIER

*To my sons Francesco Romano and Arianna,
To my wife Maria Lucia, to my Parents
and to the memory of Natale Lappa*

Preface

Gravity dominates everything on Earth, from the way life has developed to the way materials interact. But aboard a spacecraft orbiting the Earth, the effects of gravity are barely felt. In this “microgravity environment”, scientists can conduct experiments that are all but impossible to perform on Earth. In this virtual absence of gravity as we know it, space flight gives scientists a unique opportunity to study the states of matter (solids, liquids and gases), and the forces and processes that affect them.

In practice, microgravity or near-weightlessness corresponds to a free-fall situation and in this condition various phenomena are significantly altered, in particular convection, buoyancy, hydrostatic pressure and sedimentation. When microgravity conditions are attained, fluids do “incredible” things.

Scientific disciplines affected include fluid physics and transport phenomena, combustion, crystal growth and solidification, biological processes and biotechnology.

Microgravity is instrumental in unraveling processes that are interwoven or overshadowed in normal gravity. It can therefore be regarded as an important tool for improving models of complex phenomena and hence manufacturing processes on Earth. Critical knowledge gained from microgravity experiments, in fact, is validating new, more complex models, accelerating the current trend towards predictable and reproducible phenomena, and enabling the development of new industrial processes (i.e. a commercial return from space research activities based on the application on the ground of the knowledge obtained in space).

Within this context the present book develops working engineering models that can be easily employed in applications, while providing a rigorous mathematical and numerical framework for deeper understanding and effective treatment of phenomena encountered in microgravity and/or unmasked by this environment.

Mathematical modeling is the art and craft of building a system of equations that is both sufficiently complex to do justice to physical reality and sufficiently simple to focus on the most significant aspects of the given situation. Numerical simulation is the art of solving these equations. In this book, a comprehensive study of fundamental concepts and simulation methods is presented. Partial differential equations are used as the basis for the methods. However, the analysis is not limited to these aspects. A number of prototype applications, in fact, is presented.

This means that the reader is taken beyond the theoretical to demonstrate how multiphase flow equations can be solved to provide applied, practical, predictive solutions to a variety of technological problems both on Earth and in space. Along these lines, a significant effort is provided throughout the volume to show how the prototype numerical examples fit the corresponding experimental processes. The consistency of numerical predictions with experimental data suggests, in fact, that rate-controlling steps are taken into account, that simplifications do not distort actual behavior and finally provides validation for the theoretical models and techniques.

It is also worthwhile to stress how the proposed simulations, exhibiting significant capabilities to predict and elucidate experimental observations, in turn lead to identify cause-and-effect relationships, i.e. they are propaedeutical to discerning heretofore unknown physical mechanisms. Thus the book can also be regarded as an additional step in the evolutionary progress towards the full understanding of the “physics of microgravity” and related processes.

New material is included along with a compilation of published material. The text gains information from fifty of the author’s relevant and recent papers to illustrate the philosophy of modeling, the practical applications and the insights into the physics. It is conceived in order to be a useful reference guide for other specialists in these disciplines as well as an advanced level text for students taking part in courses on CFD (computational fluid dynamics), or on numerical methods for materials engineering and similar techniques. It is directed at readers already engaged or starting to be engaged in these topics. Engineers, designers and students will find the necessary numerical techniques and the revealing insights into the behavior of many phenomena usually overlooked and/or obscured by gravity (including historical developments and very recent contributions). Often a deductive approach is followed with systems of growing complexity being treated as the book progresses.

Numerical methods are important since they are a decisive tool to reduce the number of expensive space experiments. They are propaedeutical to plan and improve the experimental setups and to optimize the new production techniques suggested by the amount of knowledge obtained in space.

Superimposed on this is the fact that most of the scientists carrying out research on Earth (as well as the undergraduate and the Ph.D. students) cannot directly access microgravity platforms. For this reason the use of numerical computations is of paramount importance (often it is the only way) for the investigation of the properties of materials and fluids in the zero-g (simulated) environment, for the understanding of forces and processes affecting them (hidden or undervalued in normal gravity) and finally for the design of the aforementioned new manufacturing methods to be used on Earth.

The volume provides a rich learning environment covering inorganic, organic and living (tissues) materials and therefore could be used, in principle, by different groups

of readers:

- (1) Professionals and students in the metallurgy and foundry field; the text, in fact, covers the latest developments in the understanding of some still poorly known phenomena controlling the properties of cast materials, and indeed the properties of final solidified alloys;
- (2) Researchers and scientists looking for new high-quality semiconductor crystals and related new production techniques needed to help advance progress in computer science and technology;
- (3) Organic chemists and materials scientists who are now coordinating their efforts in designing macromolecular crystals for a variety of physical and chemical applications; organic crystal growers will also find in this book the detailed analysis of the various effects governing the morphological evolution of the crystals.
- (4) Scientists, clinicians and engineers working in the new field of tissue engineering; the text offers many novel mathematical approaches including a detailed coverage of cell-tissue interactions at cellular and molecular levels; tissue surface kinetics, biochemical, and fluid-mechanical environments, etc.

The book is wide-ranging since the coverage reflects the multidisciplinary nature of space research.

Some unexpected theoretical kinships existing among the different subjects are elucidated and emphasized (for instance, those dealing with the presence of moving and/or interacting interfaces). Despite the very different genesis (inorganic, organic, biological, etc.), many problems are treated within the common framework of Volume of Fraction and Level-Set numerical methods and other similar Eulerian or Lagrangian techniques. This is an example of the fact that herein a large amount of information is transmitted from one field to the others in terms of models and numerical strategies. This philosophy is also used in the attempt to build a common source made available for the scientific community under the optimistic idea that the contacts established among the different fields will develop into an ongoing, mutually beneficial dialogue.

Napoli, 03 March 2004

Marcello Lappa

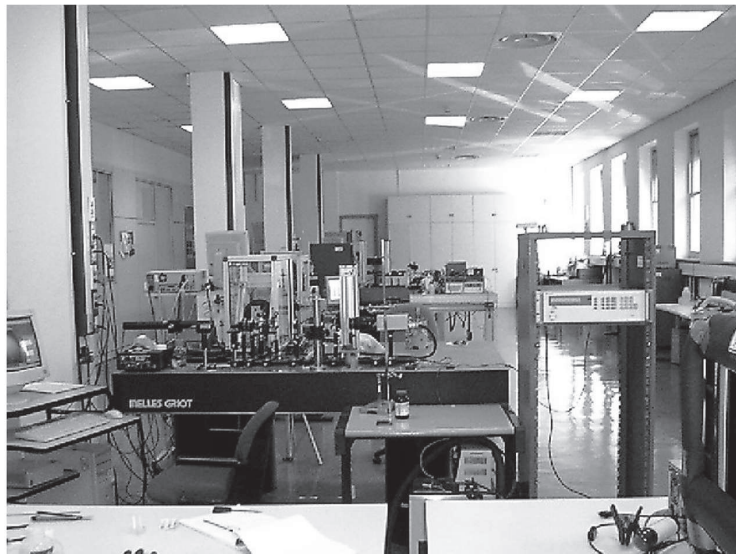
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Microgravity Advanced Research and Support Center – Laboratories

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