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Book reviews

Fluid Dynamics and Transport of Droplets and Sprays
W.A. Sirignano, Cambridge University Press, 1999, $80, ISBN 0 521 63036 3

This book, written by one of the leading experts in the field of fluid dynamics of droplets and sprays, is addressed to scientists, engineers and graduate students dealing within the topics related to multiphase flow. It generalizes the results of a number of investigations (including original researches by the author and his collaborators) related to the mechanics of gas-droplet systems. The book is very well written. The basic approaches to studying the complex phenomena are outlined in a straightforward manner and illustrated by the results of the computations for single droplets and sprays.

The book can be divided into three parts accordingly to the subjects covered: (i) foundations of dynamics of droplets and sprays — basic ideas; mass, momentum and heat transfer (chapters 2–5); (ii) computational aspects of problems on sprays (chapter 6); (iii) special problems of the theory of gas-droplet flows and its applications, namely droplet/turbulence interaction, behavior of droplets in a high pressure environment, spray ignition, and combustion wave propagation (chapters 7–9). Three appendices deal with the equations of fluid mechanics, with models of pure liquid droplets and multicomponent droplets undergoing heating and vaporization, as well as with principles of two- and multi-continua formulation.

The preface and the first introductory chapter outline the range of the problems considered and present brief comments concerning droplet-size distribution, mechanism of droplet formation via instability of liquid jets and disintegration of thin liquid sheets, etc.

Chapter 2 "Theory of Isolated Droplet Vaporization, Heating and Acceleration" covers the problems connected with the behavior of an isolated droplet in a high temperature environment. The author concentrates attention on droplets in gas at rest, or gas flow. In connection with that, the transport processes in gaseous and liquid phases are discussed. The consideration includes analysis of various approximate flow models in the vicinity and within the evaporating droplets (the boundary layer approximation, etc.), as well as the direct numerical simulation of the problem. At the same time, a number of important questions arising in the theory of droplet vaporization, such as the effect of radiative heat transfer, oscillations of gaseous phase, etc. are also considered in Chapter 2. Some of these problems (e.g. modeling of behavior of burning droplet under conditions when chemical reaction rate is very low or very fast compared with the rate of diffusion) are touched only briefly and a number of details seem to be missing.

Vaporization and combustion of multicomponent liquid droplets are treated in chapter 3, "Multicomponent Liquid Droplets". It includes a clear exposition of the specific peculiarities

of the phenomenon taking place when rates of vaporization of various components are different. The analysis accounts of mass transfer in liquid phase as well as treatment of vaporization and combustion of droplets of slurry fuels with high volumetric heat release. The author has contributed in this area and a systematic exposition of these results is of considerable interest.

Dealing with transport phenomena in multicomponent droplets (gas and liquid mass diffusion) the author pays great attention to vaporization and combustion of metal-slurry droplets. In this connection the burning of fuel droplet containing a single or a number of fine metallic particles are considered. The mechanism of the process and its modeling are discussed.

The approaches developed to describe metal-slurry droplets present significant interest. Unfortunately, chapter 3 (like the other ones) contains only a limited experimental data related to combustion of multicomponent droplets, in particular, to metal-slurry droplets. The latter makes difficult to judge in agreement of theoretical predictions with experimental data and on the fields of possible applications the theoretical models.

Chapter 4, ''Droplets and Groups'', discusses behavior of droplets in gas–liquid systems containing many fine droplets. The intensity of heat and mass transfer and combustion in such systems depends not only on physico-chemical properties of gaseous and liquid phases and regime parameters of flow, but also on structural characteristics of multiphase media: spacing between neighboring droplets, their sizes, etc. The results included in chapter 4 characterize burning arrays and clouds of fine droplets and demonstrate the effect of different factors (spacing, droplet size, the Prandtl and Reynold's numbers, etc.) on hydrodynamic structure of multiphase flow, intensity of heat and mass transfer, etc. The problems of droplet–droplet and droplet–wall collisions are discussed briefly in the last section of chapter 4.

Some aspects of theoretical description of spray evolution are treated in chapter 5. The author concentrates on one of the possible ways of solution of the problem, namely, on the modeling heterogeneous multiphase media as a number of interpenetrating and interacting continua characterized by ''effective'' density of each phase. The problem reduces to a system of balance equations containing sources accounting for the mass, momentum and energy transition from a given phase to the other ones. The system of governing equations is closed by using correlations accounting for particle/fluid interaction (the discrete particle formulation). It should be noted that the two (multi)-continua approximation does not reflect the multi-step character of heat transfer in particle-laden flows; through particle/liquid interphase, then through carrier liquid and then through liquid/particle interphase. The multi-step heat transfer determines the mechanism of particle ignition and propagation of combustion wave in particle-laden mixture. This problem requires a special consideration of the combustion processes.

The computational aspects related to droplet and spray computations are discussed in chapter 6, ''Computational Issues''. The efficient algorithms for droplet computations and numerical schemes for spray computations are considered in this chapter.

The seventh chapter, ''Spray Application'', deals with application of the spray theory for solution of a number of problems related with vaporization and combustion in gas-droplet systems, such as spray ignition, combustion wave propagation, etc. These results present a two-fold interest. First, they allow one to reveal peculiarities of combustion process developing under conditions of strong interaction of heat and mass transfer phenomena with the chemical reaction processes. They also demonstrate the progress which has been made in the theory of

sprays during the last 20 years and its applicability in a number of important problems. At the same time, it should be noticed that the author almost everywhere uses only the results of numerical simulations of spray combustion and practically does not consider the results obtained using theoretical analysis of the phenomena in the framework of the classical methods of combustion theory: the thermal regimes of combustion, critical states of reactive multiphase systems, etc. Such an approach restricts the scope of the consideration.

The following two-chapters, "Droplet Interactions with Turbulence and Vortical Structures" and "Droplet Behavior at Near-Critical, Transcritical, and Supercritical Conditions" contain the results of investigation of droplet/turbulence interaction (the unsteady droplet motion, vortex/spray interaction, etc.) and droplet behavior under the conditions of a wide pressure variation.

The monograph of Sirignano is a substantial generalization of numerous researches dealing with the dynamics of droplets and sprays. The book exposes state of the art of this problem. It is of interest for a readership working in the field of gas-droplet flows.

L.P. Yarin
Deaprtment of Mechanical Engineering,
Technion — Israel Institute of Technology,
3200, Haifa,
Israel

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Droplets and sprays appear in a wide range of engineering applications. The primary focus of this monograph is on the theoretical and computational aspects where liquid fuel droplets and combustion applications are emphasized, an area in which the author has published extensively. Major attention is given to the works of the author's research team. Specifically, there are 421 papers listed in the reference, of which, 89 (~21%) are contributed by the author and his co-workers. The author undertook this writing because no previous treatise exists that broadly addresses theoretical and computational issues related to both spray and droplet behavior. Since this field is still developing in terms of both science and technology, he has undertaken a critical review. Among topics covered are transient heating and vaporization, multicomponent liquid droplet vaporization, near-critical and supercritical ambient conditions, interaction of droplets with turbulent or vortical structures, distortion of the spherical shape, secondary atomization of the droplets, and computational issues.

The book has nine chapters and three appendices. An overview of spray atomization and some comments about droplet-size determination are given in Chapter 1. In Chapter 2, the vaporization of individual droplet is discussed. Attention is given to the behavior of isolated