AIAA JOURNAL
Vol. 45, No. 11, November 2007

Book Reviews

BOOK REVIEWS published in this section reflect the opinions of their individual authors. They are not necessarily the opinions of the Editors of this journal or of AIAA.

Combustion Physics

Law, C. K., Cambridge University Press, New York, 2006, 722 pp., $95.00

DOI: 10.2514/1.33347

COMBUSTION occurs in a broad range of important engineering technologies and is a topic of primary societal and environmental concern. It involves the transport of matter and energy in multicomponent and often multiphase systems in which chemical reactions with significant energy liberation take place. It is a multidisciplinary science that relies on understanding fluid mechanics, thermodynamics, transport phenomena, and chemical kinetics. In the past four decades, significant advances have been made along three fronts: 1) theoretical advances driven by the increase and sophistication of mathematical techniques such as the use of asymptotic methods and methods of nonlinear analyses, 2) advances in simulation enabled by the accessibility of computers and the efficiency of numerical tools, and 3) advances in experimental methods, in particular, laser diagnostic techniques. Professor C. K. Law has taken part in this tremendous growth in combustion science and has made significant contributions to the field in several areas that have been incorporated in this exciting text.

The book addresses the new developments in combustion in a comprehensive and unified manner. It reflects the fundamental approach that is characteristic of the author's work reported in his numerous publications and is best described by its title *Combustion Physics,* in that it provides an understanding of the basic physical mechanisms underlying combustion processes. As stated in the Preface, combustion science has evolved from a discipline "that was largely empirical to one that is quantitative and predictive." Indeed, there is a strong emphasis throughout the book on the intimate interplay between experiment, theory, and computation. Integrating this level of understanding in advanced numerical codes promotes what may be considered the ultimate goal of combustion: to increase the predictive capabilities of the performance of combustion devices such as reciprocating engines, gas turbines, industrial furnaces, or fluidized beds.

Writing a comprehensive text on combustion involves many challenges. Because of the evolving state of the subject, one needs first to make difficult choices concerning the selection of topics and the depth of coverage of each topic. Second, because of the multidisciplinary nature of the subject, the accessibility of the material must be carefully tailored to the expected mathematical, physical, and chemical backgrounds of the students. Third, because of the recent advances in the field, it is important to present the material in a simple and unified manner so that newcomers can easily follow and to guide interested readers toward further exploration of the literature. Last, a useful text needs to provide ample challenging problems and exercises. *Combustion Physics* admirably meets these challenges and, as such, is highly recommended to serve as a graduate-level text with essentially no prerequisites beyond the standard undergraduate curriculum in engineering and the physical sciences.

The Introduction and the following 14 chapters span 691 pages, excluding references. The Introduction highlights the importance of combustion in daily life and in technology. It lists and briefly discusses some important practical combustion problems, summarizes the disciplines comprising combustion, and provides several common classifications of combustion processes. It ends with a useful list of books and journals covering various aspects of the subject.

Chapters 1–4 cover the topics of equilibrium thermodynamics, including calculation of the adiabatic flame temperature and equilibrium composition; chemical kinetics; oxidation mechanisms of practical fuels, including various strategies for mechanism reduction; and transport phenomena. In chapter 5, the general conservation laws are derived based on control volume considerations. The isobaric assumption is then discussed, leading to simplified, yet fairly general, equations valid for deflagrative combustion. The remainder of the chapter covers a number of simplifications often used in theoretical studies, such as the Shvab–Zel'dovich and the mixture-fraction formulations, and introduces general nondimensional numbers used in the remainder of the book. This important chapter ends with a list of nomenclature that is kept consistent throughout the book and can be consulted whenever necessary.

The next three chapters are devoted to properties of laminar flames. Nonpremixed, or diffusion, flames are discussed in chapter 6 through a variety of examples, each identifying some unique characteristics. These include the one-dimensional chambered flame, the

Burke–Schumann configuration, condensed fuel vaporization from a planar surface, droplet vaporization and combustion, and the counterflow flame. The discussion in this chapter is based on the reaction-sheet limit (infinite Damköhler number) and uses the general formulations developed in the preceding chapter as a demonstration of their effectiveness. Chapters 7 and 8 are dedicated to premixed combustion. After a brief discussion of the two distinct combustion waves, deflagration and detonation, the focus is on deflagrations. A substantial part of chapter 7 deals with the structure of the steady, planar, premixed flame and the associated laminar flame speed, first based on a phenomenological approach and then using a number of approximations that have been adopted in laminar flame analysis. The most rigorous results, obtained using the large activation energy asymptotic (AEA) approach, are discussed in great detail for pedagogical reasons. In the rest of this chapter, experimental techniques for measuring the laminar burning velocity are discussed and numerical and experimental results are presented and analyzed, including a discussion on the chemical structure of flames. Chapter 8 is concerned with the stabilization of premixed flames and phenomena associated with ignition and extinction.

Chapter 9 provides a mathematical description of a number of canonical structures of reactive–diffusive zones that appear in asymptotic studies, which the more mathematically inclined readers will find useful. These generalized results could have been applied in some of the problems discussed in the following chapters (the counterflow flame in chapter 10 and flames in boundary layers in chapter 12), but the author chose instead to present these subsequent analyses in a self-contained manner, ostensibly recognizing that chapter 9 may not necessarily be included as part of a standard course. Interested readers will find the presentation useful for further exploration of asymptotic flame studies before consulting the literature and facing the technical difficulties that may be encountered in more complex problems, such as those that come across when applying the AEA methodology to unsteady and multidimensional flames.

Chapter 10 covers the hydrodynamic aspects of premixed flames. Most of the chapter deals with the effects of flame stretch on flame properties, frequently using the stagnation flame as an example, and includes the AEA treatment as well as experimental and numerical results. The last section is devoted to flame-front instabilities, describing various possible mechanisms leading to cellular, polyhedral, and pulsating flames. The stability analysis presented in this chapter sensibly uses a simplified Markstein-type approach that can be followed by most readers with moderate effort, rather than the more rigorous extensive analysis that is certainly out of place in this text.

The next three chapters are devoted to flame–flow interactions. Chapter 11 provides an overview of the modeling strategies of turbulent flames using results of laminar flames as building blocks. Chapter 12 examines the structure of flames in boundary-layer flows, including jet flames and the associated concepts of liftoff, stabilization, and blowout, and the development of tribrachial flames. Chapter 13 deals with two-phase flows and presents a detailed discussion of droplet and carbon particle combustion as an introduction to spray and condensed-phase flames. The text concludes with chapter 14 on supersonic combustion, with the first part devoted to the effects of sound waves in chemically reacting flows and the second part devoted to the structure and dynamics of detonation waves.

The list of references appearing at the end of the book includes over 400 citations to the most relevant entries in the literature. The references are sorted alphabetically and the full title appears in every entry. This makes it convenient to find and identify a reference when reading the book without the need to go over the entire list or attempting to locate the reference to find out what exactly is cited. Finally, although a few typographical errors were detected, the book has been carefully edited and has an overall attractive layout.

Combustion Physics is an excellent text that is comprehensive in coverage, rigorous yet expeditious in the analytical developments, insightful in the physical descriptions, and above all, very readable. It is not only an invaluable reference for combustion researchers, but its emphasis on clarity and logical presentation makes it particularly attractive for classroom adoption for a graduate course on combustion in aerospace, mechanical, or chemical engineering, and the physical sciences. Specifically, no prerequisite is expected, the mathematical approach avoids unnecessary complications, theoretical considerations are always related to experimental observations, photographs of combustion phenomena and illustrations of physical concepts appear in almost every chapter, and the book contains a large number of nontrivial and challenging problems and exercises. The author is to be congratulated for having made this valuable, lasting contribution to combustion literature and education.

Moshe Matalon
University of Illinois at Urbana–Champaign