

Combustion Theory

Second Edition

Forman A. Williams

ABP

Combustion Theory

Combustion Science and Engineering Series

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To Th. von Kármán,
the founder of aerothermochemistry

Combustion Theory

*The Fundamental Theory of
Chemically Reacting Flow Systems*

Second Edition

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The Advanced Book Program

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Preface to the Second Edition

Truly remarkable progress has been achieved in combustion theory during the 20 years since the completion of the first edition of this book. Because of this progress, when the first edition went out of print about 5 years ago, it was clear that a reprinting could no longer serve to bring readers to the frontiers of the subject. Revision of the entire text was needed, and I undertook the revision without realizing that it would require as much time as writing the first edition. Although it is regrettable that the book has been unavailable during the preparation of the second edition, it seemed best to try to complete as good a revision as possible instead of rushing into print. Thus consideration has been given to changes throughout; none of the chapters survived without modification, and outdated chapters have disappeared entirely and have been replaced by chapters devoted to new material of importance in the subject.

Nevertheless, the general format of the book and the philosophy of the presentation remain the same. The necessary background material still appears in the same five appendixes. These appendixes needed less revision than the rest of the volume; a few of the sections survived intact. Among the specific changes in the appendixes are updating of the discussion of thermochemical equilibrium calculations to take account of the revolutionary advances in computational power of electronic computers, presentation of clarifications that have been achieved in the concepts of steady-state and partial-equilibrium approximations in chemical kinetics, amplification of the discussions of branched-chain and thermal explosions on the basis of insights developed from ideas of asymptotic methods, presentation of newly available information on the chemical kinetics of hydrocarbon oxidation and of the production of oxides of nitrogen in flames, and augmentation of the treatment of transport processes to include additional aspects of radiant energy transfer. The first chapter, in which the basic mathematical formulations are presented, remains just as formidable to the faint-hearted as it was in the first edition. There are still 12 chapters, but the later ones, especially, exhibit modifications in coverage as a consequence of the progress made in the field.

The titles of the first six chapters remain essentially the same as in the first edition. Chapter 7 of the first edition, which was devoted mainly to a discussion of experiments on turbulent flames, has been deleted and replaced by a considerably more extensive chapter (Chapter 10) that develops turbulent-flame theory from first principles; noteworthy advances in the theory during the past 20 years have made this possible. Presentation of material on turbulent combustion, formerly in Chapter 7, is postponed until Chapter 10 because the new knowledge relies in part on various results that have been obtained in studies of laminar-flame instabilities (now

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Nevertheless, the general format of the book and the presentation remain the same. The necessary changes appear in the same five appendixes. These changes are more than the rest of the volume; a few of the second edition are specific changes in the appendixes are updated. The chemical equilibrium calculations to take account of advances in computational power of electronic computers.

covered in Chapter 9) and in investigation (included in Chapter 8). Monopropellant droplets are the subject of Chapter 10 of the first edition, which played a prominent role in combustion in the intermediate edition, covered only briefly now, specifically at the end of the chapter that includes detailed discussions of the burning of droplets. Of the first edition addressed both the theory and theories of combustion instability; such progress was made in these subjects that two chapters are devoted to this material properly, Chapter 7 on combustion instabilities, Chapter 9 on combustion instabilities. The subject of ignition, extinction, and flammability limits, which was the subject of Chapter 11, spray combustion, and thrust of Chapter 12 remains approximately the same, with a title change, from "Chemical Reactions in Combustion" to "Attachment and Flame Spread," introducing new areas of application.

To delineate more thoroughly the modifications introduced, it seems desirable to discuss briefly the changes. The basic formulations in Chapter 1 and the jump conditions across combustion waves are the same as in the first edition. Therefore, the following discussion of the new chapters.

Chapter 2 on diffusion flames and droplets

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The material in Chapter 4, on finite-rate gaseous molecular transport, has been amplified and its presentation in the first edition. The discussion of the well-stirred reactor have been expanded somewhat and phase nozzle flow has been added, while corrections in the writing have been restricted.

The chapter on laminar-flame theory, where finite-rate chemistry first enters simultaneously with transport, in the light of advances in our conceptual foundations. Asymptotic methods in mathematical analysis, nonequilibrium energy asymptotics, have provided us with a new set of the elements of laminar-flame propagation. Some of the material that were detailed in the first edition are deleted. The development of activation-energy asymptotics and its application are employed to explain many previously puzzling features of flame structure and flame speeds. In addition, the treatment of flames with multiple-step chemistry and detonation flames, on the basis of both asymptotic concepts and the computational abilities of electronic computers.

Because of rapid progress in detonation research since the first edition on detonations was published, before it appeared in print. In contrast, many new developments in this subject seem now to have been brought to the attention of reviewers. Therefore, the extensive revision

reviews. Therefore, the extensive revision preparation of the second edition, appears longer period of time. The major changes discussion of effects of three-dimensional str tion. Consideration is given to the relevance instability, to triple-shock interactions and addition, new analyses of detonability limits are included, and criteria for direct initiation along with a discussion of processes of detonation.

Chapter 7, on solid-propellant combustion deflagration of homogeneous solids. Considered controlled by interface, condensed-phase, and reactions, now with utilization of concepts examples mentioned include the combustion ammonium perchlorate; attention is paid to sensitivities of burning rates of propellant current status of theories of combustion of the combustion of black powder is addressed theoretical problem involving the oldest pr