PREFACE

The basic premise of this book is that a few fundamental physical principles, rightly applied, can provide students of mechanical and aeronautical engineering with a deep understanding of all modes of aircraft and spacecraft propulsion. More—that they can lead directly to usefully quantitative assessments of performance; and still more—that they can illuminate possibilities for improvement. Doubtless, it is only at a fundamental level that one can properly address not only the questions of how and why things work but also the more challenging questions of why and how they can be improved.

It would not do, of course, to stress fundamental principles exclusively; only in application do the basic ideas really come alive to stimulate both analysis and invention. It is sometimes astonishing to see how a few basic ideas can reduce what would otherwise be an overwhelming mass of information into easily understood and manageable categories. Application of basic principles to specific engineering objectives can reward the student not only with a valuable appreciation of their practical significance but also with a much deeper understanding of the principles themselves.

The first edition of this book has been used by thousands of engineering students over the last twenty-five years, but it is now high time for a new edition. Not that the basic principles of propulsion have changed, but over this period the practical development of aircraft and spacecraft propulsion has been truly spectacular. The subject is now more richly interesting than it ever was before. It therefore seems appropriate to offer a new edition that can not only reflect on the great achievements of the recent past but also assess the reasons why we may yet expect great developments.

In preparing the second edition, one objective has been to provide a wide range of new illustrative material on modern aircraft and rocket engines. A second has been to present clearer explanations of pertinent physical phenomena. A third, to provide a much greater range of problem statements at the end of each chapter and a fourth, to introduce preliminary design procedures.

Today students have marvelous computers and graphics with which to calculate and display the implications of ideas that should control new designs. Realistic treatment of physical properties and mechanisms is quite easily possible within an appropriate time allotment. Hence this new edition encourages students, through design examples and problem statements, to consider the possibilities of preliminary design so as to identify physical possibilities and limitations as clearly as possible and to determine the consequences of uncertainty. This is not to say that in an introductory propulsion course one can use the complete Navier-Stokes equations to design turbomachinery, for example. But it does mean that the fluid mechanics of turbomachinery can be treated in realistic, albeit more approximate, simple ways that provide insight into how turbomachines work and how they can be designed.

Among the resources now available to students of propulsion are computer codes that they can use knowledgeably and critically to display the characteristics of specific important phenomena. One of these is the STANJAN code developed by W. C. Reynolds of Stanford University, for fast, versatile determination of the high-temperature equilibrium composition of combustion products. Treatment of boundary layer separation (which places such an important limitation on turbomachine behavior) is now quite easy, in the two-dimensional approximation, with the aid of a personal computer and the equations presented in the text. One can also readily use elementary computer procedures to take into account the effects of high-temperature variations on the specific heat of gases. Thus the power of the student to explore physical phenomena and design possibilities has in recent years been greatly enhanced.

The essentially difficult problem is that within a given course there is only so much time to take up new ideas. The book contains more than any one course can contain, so a choice must be made.

Part 1 of this text consists mainly of a review of those topics in thermodynamics, combustion, and fluid mechanics that are of vital importance to propulsion engines. One chapter reviews the thermodynamics of flow through control volumes with or without chemical reaction. Because of the prime significance of high-speed flows, a brief chapter is devoted entirely to review of compressible flows, Mach number, and shock waves. Because of the extremely important design limitation due to boundary layers, one chapter is concerned with boundary layer growth, separation, and heat transfer.

Part 2 of the text focuses on air-breathing turbine engines exclusively. First come analyses of propulsion efficiency, cycle performance, and the rationale for various types of turbine engines. This is followed by description and analysis of the ways in which successful flow behavior can be obtained in inlets, burners, and nozzles, then by detailed examination of the aerodynamics and performance of compressors and turbines. The development of high-flow-rate, high-efficiency compressors has for long been one of the most important challenges in turbine engine development, so these chapters present the topics of axial and centrifugal compressor (as well as turbine) aerodynamics in some depth. In each case the first section of the chapter deals mainly with the questions of why and how this turbomachine works; the second, with the physical factors that limit its performance and with how these may be quantified; and the third, with a compact preliminary design procedure. The first section of each chapter would make a reasonably complete unit if there is no time to take up the second and third sections. (If one wishes to include both rockets and air-breathing engines in a one-term course, this kind of selection might be essential.)

Part 3 of the text is devoted to rocket propulsion. Chapter 10 presents an elementary treatment of rocket vehicle dynamics to demonstrate the significance of specific impulse and other variables and also to show how to decide on propulsion requirements for space missions. The latter requires some attention to the trajectories of space vehicles and the conditions under which the propulsion system may be optimized. Chemical rockets are the subject of Chapters 11, 12, and 13. Chapter 11 takes up those fundamental matters that govern the design and optimization of rocket nozzles; aerodynamics and heat transfer are two of the most important concerns. The next chapter analyzes the important features of liquid- and solid-propellant combustion. Key topics here include product mixture dissociation and equilibrium or nonequilibrium (or even two-phase) expansion processes. Chapter 13 focuses on the turbomachinery for a rocket vehicle and shows how one can make preliminary design decisions about system configuration, size, and speed for specified propellant flow rates and pressure rises.

Chapter 14 is devoted to the special feature of electrical propulsion, taking up fundamental considerations of why and how electrostatic, electrothermal, and electromagnetic propulsion can be used to best advantage.

A one-term course on rockets might consist of appropriate review of material in Chapters 2, 3, and 4 and a treatment of selected topics from Chapters 10 through 14.

A substantial effort has been made to improve the number and quality of problem statements at the end of each chapter. Objectives have been that each problem statement should refer to a substantial exercise that will illuminate an important question; that each problem should be doable (and that the average student should not be left baffled on how to start); that certain problem statements should, with guidance, take the student beyond what is clearly spelled out in the text; and that certain of them should be directed to preliminary design calculations feasible on a personal computer. However, no student should feel obliged to solve all the problems in a given chapter.

The mathematical portions of the text assume a knowledge of calculus, but mathematical complication has been minimized so that the reader can clearly discern physical principles. So much can be learned from steady-flow control volume analyses that these have been used again and again in the study of one- and two-dimensional compressible and incompressible viscous and inviscid flows.

To make the text as readable as possible, the equation sets derived for preliminary design have been relegated to the appendixes. The equations provided should be sufficient to allow exploration of many more design options than are specifically discussed in the text.

Referring back to the preparation of the first edition, the authors again would like to record our indebtedness to the late Edward S. Taylor, who was our teacher, critic, and friend during our years of association in the M.I.T. Gas Turbine Laboratory. We originally wrote the text largely as a result of his encouragement, and his influence will still be recognizable in some of the sections.

Throughout the text are several references to the work of J. H. Keenan and A. H. Shapiro. Their expositions of thermodynamics and fluid mechanics were so enlightening to us as students that they have heavily influenced our whole approach.

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