HIGH SPEED AERODYNAMICS AND JET PROPULSION

VOLUME II

COMBUSTION PROCESSES

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HIGH SPEED AERODYNAMICS

AND JET PROPULSION

COMBUSTION PROCESSES

EDITORS

B. LEWIS · R. N. PEASE

H. S. TAYLOR

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COMBUSTION PROCESSES

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FOREWORD

On behalf of the Editorial Board, I would like to make an acknowledgement to those branches of our military establishment whose interest and whose financial support were instrumental in the initiation of this publication program. It is noteworthy that this assistance has included all three branches of our Services. The Department of the Air Force through the Air Research and Development Command, the Department of the Army through the Office of the Chief of Ordnance, and the Department of the Navy through the Bureau of Aeronautics, Bureau of Ships, Bureau of Ordnance, and the Office of Naval Research made significant contributions. In particular, the Power Branch of the Office of Naval Research has carried the burden of responsibilities of the contractual administration and processing of all manuscripts from a security standpoint. The administration, operation, and editorial functions of the program have been centered at Princeton University. In addition, the University has contributed financially to the support of the undertaking. It is appropriate that special appreciation be expressed to Princeton University for its important over-all role in this effort.

The Editorial Board is confident that the present series which this support has made possible will have far-reaching beneficial effects on the further development of the aeronautical sciences.

Theodore von Kármán

PREFACE

Rapid advances made during the past decade on problems associated with high speed flight have brought into ever sharper focus the need for a comprehensive and competent treatment of the fundamental aspects of the aerodynamic and propulsion problems of high speed flight, together with a survey of those aspects of the underlying basic sciences cognate to such problems. The need for a treatment of this type has been long felt in research institutions, universities, and private industry and its potential reflected importance in the advanced training of nascent aeronautical scientists has also been an important motivation in this undertaking.

The entire program is the cumulative work of over one hundred scientists and engineers, representing many different branches of engineering and fields of science both in this country and abroad.

The work consists of twelve volumes treating in sequence elements of the properties of gases, liquids, and solids; combustion processes and chemical kinetics; fundamentals of gas dynamics; viscous phenomena; turbulence; heat transfer; theoretical methods in high speed aerodynamics; applications to wings, bodies and complete aircraft; nonsteady aerodynamics; principles of physical measurements; experimental methods in high speed aerodynamics and combustion; aerodynamic problems of turbo machines; the combination of aerodynamic and combustion principles in combustor design; and finally, problems of complete power plants. The intent has been to emphasize the fundamental aspects of jet propulsion and high speed aerodynamics, to develop the theoretical tools for attack on these problems, and to seek to highlight the directions in which research may be potentially most fruitful.

Preliminary discussions, which ultimately led to the foundation of the present program, were held in 1947 and 1948 and, in large measure, by virtue of the enthusiasm, inspiration, and encouragement of Dr. Theodore von Kármán and later the invaluable assistance of Dr. Hugh L. Dryden and Dean Hugh Taylor as members of the Editorial Board, these discussions ultimately saw their fruition in the formal establishment of the Aeronautics Publication Program at Princeton University in the fall of 1949.

The contributing authors and, in particular, the volume editors, have sacrificed generously of their spare time under present-day emergency conditions where continuing demands on their energies have been great. The program is also indebted to the work of Dr. Martin Summerfield who guided the planning work as General Editor from 1949–1952. The cooperation and assistance of the personnel of Princeton University Press and of the staff of this office has been noteworthy. In particular, Mr. H. S.

Bailey, Jr., the Director of the Press, and Mr. R. S. Snedeker, who has supervised the project at the Press and drawn all the figures, have been of great help. Special mention is also due Mrs. H. E. H. Lewis and Mrs. E. W. Wetterau of this office who have handled the bulk of the detailed editorial work for the program from its inception.

Joseph V. Charyk
General Editor

PREFACE TO VOLUME II

This volume is concerned with combustion processes in their various aspects, encompassing chemical kinetics, the kinetics of transport processes, fluid dynamics, and thermodynamics. It deals, therefore, with rate processes in chemical reactions, with the propagation of chemical reaction by the mechanisms of combustion waves and detonation waves, with the effect of turbulence on combustion waves, with processes of simultaneous mixing and combustion of fuels and oxidants, and with chemical equilibria. These subjects are basic for an understanding of the role of combustion in propulsion processes. After a survey of basic principles the presentation continues with oxidation and flame propagation in gaseous systems, and the combustion of liquid and solid fuels and propellants. Final sections of the book are devoted to detonation processes and the principles of energy production by nuclear reaction.

The volume editors express their appreciation of the cooperation received from the authors. The bulk of the first drafts of the several sections were received in 1951, and revised copy late in 1952 and early 1953. Delays unfortunately occurred in securing the necessary permission to publish certain manuscripts. This delayed the publication date and the position of this volume in the publication sequence. The volume editors believe that the difficulties arising from these delays have been minimized as far as is possible, but emphasize these aspects in defining the book as a presentation of current science.

The duties of General Editor of the present volume have largely been discharged by Professor Irvin Glassman of Princeton University. His assistance to us is deeply appreciated. Mr. R. S. Snedeker has continued to render his conspicuous service in the preparation of all the figures and in the supervision at Princeton University Press. The volume will reveal the same high quality of typography and arrangement that have been observed in the earlier volumes. To all, authors and collaborators, we extend our sincere thanks.

B. Lewis
R. N. Pease
H. S. Taylor

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PART ONE

THERMODYNAMICS OF COMBUSTION

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