

HIGH SPEED  
AERODYNAMICS AND  
JET PROPULSION

VOLUME II

COMBUSTION  
PROCESSES

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VOLUME II  
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.

## PREFACE

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

# CONTENTS

## PART 1. THERMODYNAMICS OF COMBUSTION

EDITOR: B. LEWIS

A. High Temperature Equilibrium	3
James M. Carter, Aerojet Engineering Corporation, Azusa, California	
David Altman, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California	
1. Problems in Combustion	3
2. Determination of Equilibrium Composition and Thermodynamic Properties	4
3. Determination of Heat Release and Flame Temperature	15
4. Gas Imperfection	17
5. Failure to Maintain Equilibrium in Combustion	22
6. Cited References and Bibliography	24
B. Expansion Processes	26
David Altman, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California	
James M. Carter, Aerojet Engineering Corporation, Azusa, California	
1. Classification of Flow Processes	26
2. Thermodynamic Relations for Flow Processes	28
3. Determination of Performance Parameters for Isentropic Flow	40
4. Nonequilibrium Effects	45
5. Two-Phase Flow	52
6. Cited References	62
C. Computational Methods in Combustion Calculations	64
Stuart R. Brinkley, Jr., Combustion and Explosives Research, Inc., Pittsburgh, Pennsylvania	
1. Introduction	64
2. Calculation of the Equilibrium Composition	65
3. Calculation of the Thermodynamic Properties at Equilibrium	84
4. Evaluation of Performance Factors of Fuel-Oxidant Systems	97
5. Cited References	97

## CONTENTS

### PART 2. CHEMICAL KINETICS OF COMBUSTION

EDITORS: H. S. TAYLOR AND R. N. PEASE

D. Fundamentals of Chemical Kinetics	101
Hugh S. Taylor, Department of Chemistry, Princeton University, Princeton, New Jersey	
1. Introduction	101
2. General Considerations	102
3. The Half Life of a Reaction	105
4. The Order of Simultaneous Reactions	105
5. Temperature and the Velocity of Chemical Reaction	110
6. The Potential Energies of 2-, 3-, and 4-Atom Systems	113
7. Potential Energy and Activation Energy	116
8. Statistical Treatment of the Activated Complex	118
9. Absolute Rate Theory and Collision Theory. A Comparison	120
10. The Theory of First Order Processes	124
11. The Theory of Third Order Processes	126
12. The Reaction of Molecules with Atoms or Radicals	127
13. Chain Mechanisms	130
14. Branching Chains and Explosions	132
15. Wall Reactions	135
16. Gas Reactions at Surfaces. General Principles	137
17. Adsorption	138
18. Adsorption Equilibrium. The Adsorption Isotherm	139
19. Desorption Phenomena	139
20. Kinetics of Chemical Reactions at Surfaces	140
21. Adsorption and Desorption as Rate-Determining Processes	142
22. Transport to and from the Surface as Rate-Determining Steps	143
23. Kinetics of Reactions in Solid and Solid-Gas Systems	144
24. Fast Reactions: Introduction	147
25. Rates of Fast Reactions	147
26. Experimental Methods	148
27. Nonequilibrium and Nonequipartition Systems in Fast Reactions	153
28. The Persistence of Nonequilibrium Conditions	156
29. Cited References	156
E. Kinetics of Several Oxidation Reactions	160
Robert N. Pease, Department of Chemistry, Princeton University, Princeton, New Jersey	
1. The Hydrogen-Oxygen Reaction	160
2. The Carbon Monoxide-Oxygen Reaction	175

## CONTENTS

3. The Oxidation of Paraffin Hydrocarbons	179
4. Some Other Exothermic Reactions	191
5. Cited References and Bibliography	197

### PART 3. FLAME PROPAGATION IN GASES

EDITOR: B. LEWIS

F. Mechanics of Reaction Continua	203
-----------------------------------	-----

John M. Richardson, The Ramo-Wooldridge Corporation, Los Angeles, California

Stuart R. Brinkley, Jr., Combustion and Explosives Research, Inc., Pittsburgh, Pennsylvania

1. Fundamental Equations	203
2. Application of the Phenomenological Theory of Irreversible Processes	211
3. Cited References and Bibliography	214

G. Combustion Waves in Nonturbulent Explosive Gases	216
-----------------------------------------------------	-----

Bernard Lewis and Guenther von Elbe, Combustion and Explosives Research, Inc., Pittsburgh, Pennsylvania

#### *Chapter 1. Theory of Combustion Waves*

1. Description and General Equations	216
2. Special Solutions for One-Dimensional Steady State Propagation	223
3. Wave Near a Heat Sink. Dead Space and Quenching Distance	227
4. Curved Waves	231
5. Principles of Stabilization of Combustion Waves in Gas Streams	233
6. Calculation of Wave Shape and Gas Flow Pattern	238
7. Momentum Change and Thrust Pressure	244
8. Propagation in Channels	245
9. Thermal Model of Combustion Wave. Excess Enthalpy	249
10. Principles of Ignition	251
11. Simplified Equations for Calculations Involving Heat Transport Across the Combustion Wave	271

#### *Chapter 2. Experimental Phenomena of Combustion Waves*

12. Ignition: Experiments and Comparison with Theory	287
13. Observations on the Propagation of Combustion Waves	296
14. Stability and Quenching Limits, and Structure of Burner Flames	298

## CONTENTS

### *Chapter 3. Combustion Waves in Closed Vessels*

15. Dependence of Pressure Rise and Temperature Distribution on Fraction of Gas Burned	305
16. Correlation of Rate of Pressure Rise with Burning Velocity	306
17. Cited References	310
 H. Combustion Waves in Turbulent Gases	 312
Béla Karlovitz, Combustion and Explosives Research, Inc., Pittsburgh, Pennsylvania	
1. Phenomenological Description of Turbulent Flames	312
2. The Work of Damköhler	314
3. The Work of Shelkin	317
4. Turbulent Burning Velocity Measurements of the National Advisory Committee for Aeronautics	320
5. Turbulent Flames Confined in Channels	324
6. Turbulent Flame Measurements at California Institute of Technology	331
7. Other Experimental Studies of Turbulent Flames	333
8. Turbulence	334
9. Turbulent Diffusion	337
10. Theory of Flame Propagation by Large Scale Turbulence	339
11. Experimental Measurement of the Turbulent Burning Velocity	342
12. Turbulence Generation by the Turbulent Flame	346
13. Pressure Drop Across the Flame, Diffusion of Turbulence, Thickness of the Turbulent Flame	351
14. Propagation of Flames in Turbulent Explosive Mixtures	353
15. Stability of Turbulent Flames	359
16. Numerical Data of Turbulent Flames	360
17. The Status of Turbulent Flame Research	362
18. Cited References	363
 I. Diffusion Flames	 365
K. Wohl and C. W. Shipman, Department of Chemical Engineering, University of Delaware, Newark, Delaware	
1. Introduction	365
2. Laminar Diffusion Flames	367
3. Transition Region Between Laminar and Turbulent Diffusion Flames	381
4. Turbulent Flames	386
5. Cited References	404

## CONTENTS

### PART 4. COMBUSTION OF LIQUIDS AND SOLIDS

EDITOR: R. N. PEASE

J. Combustion of Liquid Fuels	407
J. P. Longwell, Esso Research and Engineering Company, Linden, New Jersey	
1. Atomization	407
2. Mixing and Precipitation of Fuel Sprays	415
3. Evaporation of Fuel Drops	425
4. Combustion of Fuel Drops	438
5. Cited References	443
K. Combustion of Solid Fuels	444
Melvin Gerstein and Kenneth P. Coffin, Lewis Flight Propul- sion Laboratory, National Advisory Committee for Aero- nautics, Cleveland, Ohio	
1. Introduction	444
2. Properties of Solid Fuels and Combustion Products	444
3. Fuel and Air Contact	446
4. Oxidation Mechanisms	448
5. Ignition	451
6. Combustion Processes	458
7. Exhaust	466
8. Concluding Remarks	467
9. Cited References	468
L. Combustion of Liquid Propellants	470
David Altman and S. S. Penner, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California	
<i>Chapter 1. Ignition Phenomena in Bipropellant and Monopropellant Systems</i>	
1. Introduction	470
2. Experimental Methods Used for Measuring Ignition Delay in Bipropellant Systems	474
3. Representative Ignition Delay Measurements on Spon- taneous Bipropellant Systems	481
4. Ignition of Representative Nonspontaneous Bipropellants	487
5. Ignition of Monopropellants	488
<i>Chapter 2. Motor Performance of Selected Monopropellants</i>	
6. General Characteristics of Monopropellants	489
7. Classification of Monopropellants	490
8. Performance Characteristics of Monopropellants	492

## CONTENTS

### *Chapter 3. Combustion of Selected Bipropellant Systems*

9. Classification of Oxidizers and Fuels	503
10. Combustion of Bipropellants in Rocket Engines	504
11. Performance Characteristics of Several Bipropellant Combinations	507
12. Modern Trends in Combustion Research on Liquid-Fuel Rocket Engines	511
13. Cited References	512
M. Combustion of Solid Propellants	514
Clayton Huggett, Rohm and Haas Company, Philadelphia, Pennsylvania	
1. General Characteristics of Solid Propellants	514
2. Thermal Decomposition of Propellant Components	518
3. The Burning of Double-Base Propellants	532
4. The Burning Rate of Propellants	541
5. Theories of the Burning of Propellants	554
6. The Mechanism of Burning of Composite Propellants	564
7. The Ignition of Solid Propellants	568
8. Cited References	572

## *PART 5. DETONATION PROCESSES IN GASES, LIQUIDS, AND SOLIDS*

*EDITOR: R. N. PEASE*

N. Detonation Processes in Gases, Liquids, and Solids	577
-------------------------------------------------------	-----

A. R. Ubbelohde, Department of Chemistry, Queen's University, Belfast, Ireland  
 John Copp, Department of Chemistry, University College, Dundee, Scotland

### *Chapter 1. Experimental Methods for Observing Detonation*

1. Introduction	577
2. Measurement of Detonation Velocities	578
3. Detonation Temperatures	582
4. Flow Velocities	582
5. Other Experiments	583

### *Chapter 2. The Physical Chemistry of Detonation Processes in Gases, Liquids, and Solids*

6. Some Characteristic Differences Between Detonation and Explosion	583
7. Equations of State for Detonation	585
8. A Finite Time of Energy Release in Detonation	586

## CONTENTS

9. The Finite Time of Energy Release in Relation to Lateral Venting	587
10. Data on Energy Release in Stable Regimes	591
11. Mechanisms of Activation in the Propagation of Detonation	594
<i>Chapter 3. Limiting Conditions for Stable Detonation</i>	
12. The Decay and Failure of Detonation	596
13. Macroinitiation of Detonation. Graded Detonative Impulses	598
14. The Transition from Macrocombustion to Detonation	600
15. Microinitiation of Detonation. The Sensitiveness of Explosives	603
<i>Chapter 4. The Development of Research in the Physical Chemistry of Detonative Processes</i>	
16. Basic Detonation Parameters	606
17. Studies on the Marginal Propagation of Detonation	606
18. Direct Microinitiation	607
19. Cited References	607
 <i>PART 6. ENERGY PRODUCTION BY NUCLEAR REACTIONS</i> <i>EDITOR: R. N. PEASE</i>	
O. Energy Production by Nuclear Reactions	613
H. Soodak, Department of Physics, The College of the City of New York, New York	
1. Introduction	613
2. Nuclei	614
3. Nuclear Energies	617
4. Nuclear Reactions	623
5. Summary and Conclusions	645
6. Cited References and Bibliography	652
Index	653

PART ONE

*THERMODYNAMICS OF COMBUSTION*

