

HIGH SPEED
AERODYNAMICS AND
JET PROPULSION



PHYSICAL
MEASURE-
MENTS IN GAS
DYNAMICS
AND
COMBUSTION



VOLUME IX
HIGH SPEED AERODYNAMICS
AND JET PROPULSION

*PHYSICAL
MEASUREMENTS IN
GAS DYNAMICS
AND COMBUSTION*

EDITORS

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*PHYSICAL MEASUREMENTS IN
GAS DYNAMICS AND COMBUSTION*

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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

PREFACE TO VOLUME IX

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 of this office who has handled the bulk of the detailed editorial work for the program from its inception.

Joseph V. Charyk
General Editor

PREFACE TO VOLUME IX

This volume is concerned with physical measurements in gas dynamics and with the corresponding measurements in combustion processes. It records the varying techniques which can be employed to measure density, pressure, velocity, and temperature in gaseous systems. It deals with the measurements of shock waves, turbulence, condensation studies, and analogue methods. The second half of the volume is concerned with techniques and the measurement of properties in materials undergoing combustion processes.

The first 340 pages of the present volume represent the original proposal for a single volume. To secure a greater uniformity in the size of each volume in the series the second part was added to the first. Professor R. Ladenburg, with a rare editorial initiative and skill, assembled his contributors' material more rapidly than any other editor. Unhappily, he did not live to see the fruits of his effort through the processes of printing and publication. That duty has been most efficiently discharged by his former pupil and colleague Professor Daniel Bershader. Together they have provided an authoritative document in the field of measurement in gas dynamics. The list of their authors and the articles are at once a guarantee of the authority of the work and a tribute of devotion to their late editor. The volume becomes in this way a memorial to Professor Ladenburg's unique abilities in the area in which he so conspicuously excelled.

The second part of the volume will, it is hoped, not be found unworthy to be included with the material assembled by Professor Ladenburg. It has been the writer's responsibility mainly to secure this in respect to Part 2, and to provide a summary of the techniques and measuring tools that can be employed in flames and in combustion processes generally.

The results achieved would not have been possible without the loyal effort and cooperation of some twenty-two authors, the General Editor and his staff, and the Princeton University Press. To them I extend sincere appreciation and thanks.

Hugh Taylor
Volume Editor

CONTENTS

PART 1. PHYSICAL MEASUREMENTS IN GAS DYNAMICS

EDITOR: R. LADENBURG

A. DENSITY MEASUREMENTS

A,1. Analysis of Optical Methods	3
F. Joachim Weyl, Office of Naval Research, Department of the Navy, Washington, D.C.	
1.1. Introductory Remarks	3
1.2. The Principal Systems	4
1.3. Quantitative Evaluation	8
1.4. Analysis of Shadowgraphs	20
1.5. Conclusions	23
1.6. Cited References	24
A,2. Shadow and Schlieren Methods	26
J. W. Beams, Department of Physics, University of Virginia, Charlottesville, Virginia	
2.1. Introduction	26
2.2. Schlieren Systems	27
2.3. Shadow Methods	38
2.4. Light Sources, Optical Parts, and Photography	40
2.5. Comparison of Schlieren and Shadow Methods	43
2.6. Cited References	44
A,3. Interferometry	47
R. Ladenburg, Department of Physics, Princeton University, Princeton, New Jersey	
Daniel Bershader, Department of Aeronautical Engineering, Princeton University, Princeton, New Jersey	
3.1. Introduction	47
3.2. Theory of the Mach-Zehnder Interferometer	49
3.3. Construction of the M-Z Interferometer	56
3.4. Evaluation of Interferograms	61
3.5. Applications	69
3.6. Cited References	75

CONTENTS

A,4. Electrical Discharge and Afterglow Technique	79
Eva M. Winkler, Aeroballistic Division, Naval Ordnance Laboratory, Silver Spring, Maryland	
4.1. Introduction	79
4.2. Nitrogen Afterglow	79
4.3. Air Afterglow	82
4.4. Experimental Aspects of Afterglow Methods	83
4.5. Glow Discharge in Nitrogen and Air	86
4.6. Experimental Aspects of the Discharge Technique	86
4.7. Cited References	87
A,5. Spectral Absorption Method	89
Eva M. Winkler, Aeroballistic Division, Naval Ordnance Laboratory, Silver Spring, Maryland	
5.1. Introduction	89
5.2. Oxygen Absorption Method	90
5.3. Ozone Absorption Method	92
5.4. Mercury Vapor Absorption Method	93
5.5. Concluding Remarks	95
5.6. Cited References	96
A,6. X-Ray Technique	97
Eva M. Winkler, Aeroballistic Division, Naval Ordnance Laboratory, Silver Spring, Maryland	
6.1. Principle and Accuracy of the Method	97
6.2. Apparatus	100
6.3. Application of the X-Ray Technique	103
6.4. Use of Corpuscular Rays	103
6.5. α Particles and Protons	104
6.6. Electrons	105
6.7. Concluding Remarks	106
6.8. Cited References	107
B. PRESSURE MEASUREMENTS	
B,1. The Impact Tube	111
P. L. Chambré, Department of Mathematics, University of California, Berkeley, California S. A. Schaaf, School of Engineering Science, University of California, Berkeley, California	
1.1. Introduction	111
1.2. Viscous Effects	112
1.3. Tolerances in Alignment. Effects of Transverse Velocity Gradient and Free Stream Turbulence	119

CONTENTS

1.4. Impact Tube Theory in Free Molecule Flow	120
1.5. Cited References	122
B,2. Pressure Measuring Manometers and Gauges	124
Walker Bleakney, Department of Physics, Princeton University, Princeton, New Jersey	
Arnold B. Arons, Department of Physics, Stevens Institute of Technology, Hoboken, New Jersey	
2.1. Introduction	124
2.2. Important Characteristics	124
2.3. Low Frequency Gauges	126
2.4. High Frequency Gauges	127
2.5. Mechanical Peak Pressure Gauges	133
2.6. Cited References	134

C. VELOCITY MEASUREMENTS

C,1. Velocity Measurements Using Ions as Tracers	139
Willoughby M. Cady, Physics Division, Naval Ordnance Test Station, Pasadena, California	
C,2. Velocity Measurements by Illuminated or Luminous Particles	142
Willoughby M. Cady, Physics Division, Naval Ordnance Test Station, Pasadena, California	
C,3. Electric Discharge Anemometry	146
Willoughby M. Cady, Physics Division, Naval Ordnance Test Station, Pasadena, California	
C,4. Acoustic Mach Meters	152
Willoughby M. Cady, Physics Division, Naval Ordnance Test Station, Pasadena, California	
Cited References and Bibliography (C,1-C,4)	
C,5. Velocity of Shock Waves by the Light Screen Technique	159
Walker Bleakney, Department of Physics, Princeton University, Princeton, New Jersey	
Cited References (C,5)	163

D. TEMPERATURE MEASUREMENTS

D,1. Wall Temperature Determination	167
Gerhard R. Eber, Holloman Air Development Center, Holloman Air Force Base, New Mexico	
1.1. Introduction	167
1.2. On the Principle of Wall Temperature Measurements	168
1.3. Thermocouples	169

CONTENTS

1.4. Infrared Radiation	170
1.5. Phosphor Luminescence	173
1.6. Applications	176
1.7. Cited References	184
D,2. Shielded Thermocouples	186
Gerhard R. Eber, Holloman Air Development Center, Holloman Air Force Base, New Mexico	
2.1. Introduction	186
2.2. Theoretical Considerations	187
2.3. The Influence of Conduction and Radiation	188
2.4. Design of Temperature Probes	189
2.5. Miscellaneous Temperature Measuring Devices	195
2.6. Cited References	196
D,3. Temperature Measurement by Sound Velocity Methods	198
Willoughby M. Cady, Physics Division, Naval Ordnance Test Station, Pasadena, California	
Cited References	200
E. SHOCK FRONT MEASUREMENTS	
BY LIGHT REFLECTIVITY	
Donald F. Hornig, Metcalf Research Laboratory, Brown University, Providence, Rhode Island	
E,1. Introduction	203
E,2. Theory of the Method	204
E,3. Experimental Technique	205
E,4. Results. The Thickness of Shock Fronts and Rotational Equilibrium	207
E,5. Cited References	210
F. TURBULENCE MEASUREMENTS	
Leslie S. G. Kováshnay, Department of Aeronautical Engineering, The Johns Hopkins University, Baltimore, Maryland	
F,1. Methods to Distinguish between Laminar and Turbulent Flow	213
1.1. Velocity Profile Measurement	215
1.2. Diffusion Methods	215
1.3. Optical Methods	217
1.4. Glow Discharge Anemometer	218
F,2. Hot Wire Method	219
2.1. Introduction	219

CONTENTS

2.2. Hot Wire Probe	223
2.3. Heat Loss in Steady Flow (King's Formula)	228
2.4. Heat Loss of Wire at Supersonic Velocities	233
2.5. Effect of Finite Wire Length on Heat Loss	237
2.6. Angle of Attack	239
2.7. Hot Wire Response to Unsteady Flow	241
2.8. Electronic Equipment (Thermal Lag Compensation, Amplification)	253
2.9. Statistical Processing of the Hot Wire Anemometer Output Signal	263
F,3. Optical Techniques	277
3.1. Introduction	277
3.2. Turbulence Measurements from Shadow Pictures	278
3.3. Interferometer Measurement of Density Fluctuations	282
F,4. Cited References (F,1-F,3)	283

G. CONDENSATION STUDY BY ABSORPTION OR SCATTERING OF LIGHT

Eva M. Winkler, Aeroballistic Division, Naval Ordnance
Laboratory, Silver Spring, Maryland

G,1. Introduction	289
G,2. Theoretical Considerations of Light Scattered by Spherical Particles	289
G,3. Measurements	295
G,4. Application to Measurements of Condensation Particles in High Speed Flow	302
G,5. Cited References	304

H. ANALOGUE METHODS

H,1. Free Surface Water Table	309
Ascher H. Shapiro, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts	
1.1. Introduction	309
1.2. The Basis of the Analogy	309
1.3. Experimental Methods	311
1.4. The Validity of the Analogy	314
1.5. Some Typical Results	319
1.6. Appraisal of Water Channel as Experimental Tool	320
1.7. Cited References	321

CONTENTS

H,2. Electrolytic Plotting Tank	322
L. Malavard, ONERA, Châtillon-sous-Bagneux (Seine), Paris, France	
2.1. General Principles	322
2.2. The Experimental Method	324
2.3. The Experimental Apparatus	325
2.4. Representation of the Circulation around an Obstacle	327
2.5. Study of a Cascade of Profiles	329
2.6. Representation of Axially Symmetric Flows	329
2.7. Fulfillment of Boundary Condition	330
2.8. Lifting Surfaces	332
2.9. Study of Compressible Flows by the Method of G. I. Taylor	333
2.10. The Hodographic Tank	335
2.11. Conical Flows	337
2.12. Conclusions	339
2.13. Cited References	339

PART 2. PHYSICAL MEASUREMENTS IN COMBUSTION

EDITORS: H. S. TAYLOR, B. LEWIS, AND R. N. PEASE

I. MEASUREMENT OF FLAME TEMPERATURE, PRESSURE, AND VELOCITY

F. P. Bundy and H. M. Strong, General Electric Company,
Schenectady, New York

I,1. Introduction	343
I,2. Spectral Line Reversal Techniques	346
I,3. Absolute Radiation Methods	359
I,4. Spectral Energy Distribution Methods	361
I,5. Thermocouple and Compensated Hot Wire Methods of Flame Temperature Measurement	364
I,6. Gas Temperature from Pneumatic Apparatus	369
I,7. Temperature from Velocity of Sound	372
I,8. Gas Velocity in Supersonic Flames	376
I,9. Gas Pressure in Supersonic Flames	382
I,10. Cited References and Bibliography	385

J. FLAME PHOTOGRAPHY

William T. Reid, Battelle Memorial Institute, Columbus,
Ohio

J,1. Introduction	389
J,2. Direct Photography	389
J,3. Interferometry	396
J,4. Schlieren Photography	398

CONTENTS

J,5. Shadow Photography	401
J,6. Solids in Flames	402
J,7. Comparison of Photographic Methods of Locating Flame Front	404
J,8. Cited References	405

K. MEASUREMENT OF BURNING VELOCITY

Ernest F. Fiock, National Bureau of Standards, Washington, D.C.

K,1. Introduction	409
K,2. Effects of the Structure of the Combustion Wave	410
K,3. Burning Velocities from Stationary Flames	412
K,4. Burning Velocities from Moving Flames	422
K,5. Effects of Operating Parameters on Burning Velocity	428
K,6. Summary of Recent Determinations	430
K,7. Cited References	436

L. MASS SPECTROSCOPY

John A. Hipple, Atomic Physics Section, National Bureau of Standards, Washington, D.C.

Chapter 1. Methods of Mass Analysis

L,1. Introduction	441
L,2. Types of Analyzers of Current Interest to Chemists	442
L,3. The Production and Detection of Ions	446

Chapter 2. Application to Chemical Analysis

L,4. Ionization and Dissociation Processes	447
L,5. Special Requirements for Analysis	453
L,6. Recent Developments	453

Chapter 3. Applications to Flames

L,7. Early Studies of Chemical Reactions	456
L,8. Flame Studies with the Mass Spectrometer at Johns Hopkins Applied Physics Laboratory	458
L,9. Cited References	462

M. SPECTROSCOPY OF COMBUSTION

G. H. Dieke, The Johns Hopkins University, Baltimore, Maryland

M,1. Introduction	467
M,2. Instrumentation	468
M,3. Identification of Flame Constituents	482
M,4. Absorption	486
M,5. Data on Equilibrium Conditions	491
M,6. Departure from Equilibrium Conditions	514
M,7. Cited References and Bibliography	522

CONTENTS

N. ANALYSIS OF THE COMBUSTION WAVE BY PRESSURE EFFECTS AND SPECTROSCOPY

Nigel Thomas, Princeton University, Princeton, New Jersey

N,1. Introduction	527
N,2. Burner Design and Characteristics	528
N,3. Reaction Zone Structure	531
N,4. Spectroscopic Temperature Measurements	534
N,5. Free Radical Concentration Measurements	544
N,6. Pressure Effects and Burning Velocity	553
N,7. Discussion	561
N,8. Cited References	565
Index	567

SECTION A

DENSITY MEASUREMENTS

F. JOACHIM WEYL

J. W. BEAMS

R. LADENBURG

DANIEL BERSHADER

EVA M. WINKLER