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**This book focuses on the combustion performance and application of innovative energetic materials for solid and hybrid space rocket propulsion. It provides a comprehensive overview of advanced technologies in the field of innovative energetic**

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materials and combustion performance, introduces methods of modeling and diagnosing the aggregation/agglomeration of active energetic metal materials in solid propellants, and investigates the potential applications of innovative energetic materials in solid and hybrid propulsion. In addition, it also provides step-by-step solutions for sample problems to help readers gain a good understanding of combustion performance and potential applications of innovative energetic materials in space propulsion. This book serves as an excellent resource for

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researchers and engineers in  
the field of propellants,  
explosives, and  
pyrotechnics.

Despite significant  
developments and widespread  
theoretical and practical  
interest in the area of  
Solid-Propellant Nonsteady  
Combustion for the last  
fifty years, a comprehensive  
and authoritative text on  
the subject has not been  
available. Theory of Solid-  
Propellant Nonsteady  
Combustion fills this gap by  
summarizing theoretical  
approaches to the problem  
within the framework of the  
Zeldovich-Novozhilov (ZN-)  
theory. This book contains  
equations governing unsteady

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combustion and applies them systematically to a wide range of problems of practical interest. Theory conclusions are validated, as much as possible, against available experimental data. Theory of Solid-Propellant Nonsteady Combustion provides an accurate up-to-date account and perspectives on the subject and is also accompanied by a website hosting solutions to problems in the book. Written with both postgraduate students and researchers in academia and industry in mind, this reference covers the chemistry behind metal nanopowders, including

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production,  
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and combustion. The  
Aeronautics  
contributions from renowned  
international scientists  
working in the field detail  
applications in  
technologies, scale-up  
processes and safety aspects  
surrounding handling and  
storage, showing how  
versatile these materials  
can be. Contains a Foreword  
by Prof. Dr.-Ing. George  
Manelis, Institute of  
Problems of Chemical  
Physics, Russian Academy of  
Science, Chernogolovka,  
Russia and Prof. Dr.-Ing.  
Hiltmar Schubert, Fraunhofer  
Institute of Chemical  
Technology, Pfinztal,

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Germany.

**Nano-Energetic Materials**

**Nanomaterials in Rocket**

**Propulsion Systems**

**Solid Fuel Chemistry**

**Innovative Energetic**

**Materials: Properties,**

**Combustion Performance and**

**Application**

**Propellants and Explosives**

Developed and expanded

from the work presented at

the New Energetic

Materials and Propulsion

Techniques for Space

Exploration workshop in

June 2014, this book

contains new scientific

results, up-to-date

reviews, and inspiring

perspectives in a number

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of areas related to the energetic aspects of chemical rocket propulsion. This collection covers the entire life of energetic materials from their conceptual formulation to practical manufacturing; it includes coverage of theoretical and experimental ballistics, performance properties, as well as laboratory-scale and full system-scale, handling, hazards, environment, ageing, and disposal. Chemical Rocket Propulsion is a unique work, where a selection of

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accomplished experts from the pioneering era of space propulsion and current technologists from the most advanced international laboratories discuss the future of chemical rocket propulsion for access to, and exploration of, space. It will be of interest to both postgraduate and final-year undergraduate students in aerospace engineering, and practicing aeronautical engineers and designers, especially those with an interest in propulsion, as well as researchers in



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energetic materials.  
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Chemical and thermal  
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structure of flame of

solid propellants based on  
nitramine (HMX or RDX) and  
azide polymer (GAP or BAMO-  
AMMO) has been  
investigated at pressure  
of 0.5 and 1.0 MPa by  
method of molecular-beam  
mass spectrometry and  
microthermocouple.

Chemical flame structure  
of pure nitramines at  
atmospheric pressure has  
been obtained too. Burning  
rate has been measured.

The probe method of  
sampling of species from  
flame allowing to detect

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products of propellant decomposition (including nitramine vapor) in the zone adjacent to the burning surface has been developed. Eleven species, including nitramine vapor, have been detected in the zone adjacent to the burning surface in the case of nitramine/GAP propellants. Experiments showed that there are two zones of chemical reactions in flame of nitramine/GAP propellants and one zone in flame of nitramine/BAMO-AMMO propellants. Species concentrations have been

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determined at different distances from the burning surface. Temperature profiles in the combustion wave of solid propellants have been measured. An extensive plateau on the temperature profiles was not observed. Data obtained can be used for creation and validation of combusting model for propellants on the basis of nitramine and azide polymer.

The book is a treatise on solid propellants in nine chapters, covering the history, chemistry, energetics, processing and

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characterization aspects of composite solid propellants, internal ballistics, advanced solid propellants, safety, quality and reliability and homogenous or double base propellants. The book also traces the evolution of solid propellant technology in ISRO for launch vehicles and sounding rockets. There is a detailed table of contents, expanded index, glossary, exhaustive references and questions in each chapter. It can be used as a textbook for science and engineering

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students, as a reference book for researchers and as a companion to scientists and engineers working in the research, development and production areas of solid propellants.

NASA Thesaurus

A Meeting Organised by the  
AGARD Combustion and  
Propulsion Panel

A Study of the Gas Phase  
Chemistry of Solid  
Propellants Using a  
Microprobe Mass  
Spectrometer (MPMS)  
System: Preliminary  
Results for Solid Fuels  
(HTPB/Zecorez and

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BAMO/NMMO) Single-Base  
Propellant (M10) and an  
RDX-Based Propellant  
(BLX-9).

Boron-Based Fuel-Rich  
Propellant

Combustion Chemistry of  
Composite Solid

Propellants Based on  
Nitramine and High  
Energetic Binders

*This book presents the latest research on the area of nano-energetic materials, their synthesis, fabrication, patterning, application and integration with various MEMS systems and platforms. Keeping in mind the applications for this field in aerospace and defense sectors, the articles in this volume contain*

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contributions by leading researchers in the field, who discuss the current challenges and future perspectives. This volume will be of use to researchers working on various applications of high-energy research.

This document is the final report of the Caltech Multidisciplinary University Research Initiative (MURI), "Investigations of Novel Energetic Materials to Stabilize Rocket Motors," ONR Contract No. N00014-95-1-1338. With a one-year no-cost extension, the program covered the period 1 October 1995 to 30 September 2001 and involved Principal Investigators at nine Universities. In addition, for three years, funds from another source supported

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research by seven Russian research groups. Participants in the Caltech MURI provided technical oversight of that work. A second MURI devoted to the same general subject was carried out at the University of Illinois at Urbana- Champaign (UIUC). The two programs were largely complementary. Some of the sections in this report have been co-authored by representatives of both MURIs. Similarly, the final report of the UIUC MURI will contain some duplication of material covered in this document. The Caltech MURI was a multidisciplinary program devoted to research on fundamental problems of the chemistry, combustion and gas dynamics of novel energetic



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*propellants and their unsteady  
Ballistics in rocket motors. This  
program achieved significant  
progress towards the ultimate  
overall objective of research in  
this field, to identify and quantify  
the influences of propellant  
composition on the stability of  
motions in a solid propellant  
rocket motor. To attain that  
objective it is essential to support  
cross-disciplinary effort between  
propellant chemists and  
researchers; combustion  
researchers; and researchers  
concentrating on the dynamics of  
solid rocket combustors. This  
MURI program was the first  
sustained effort to accomplish the  
necessary collaborations among  
faculty and students in  
universities, with participation by*

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*representatives of government laboratories and industry; in the many respects described in this report the program has been highly successful.*

*The development of an erosive burning model for solid rocket motors using direct numerical simulation* Brian A. McDonald 93 Pages Directed by Dr. Suresh Menon. *A method for developing an erosive burning model for use in solid propellant design-and-analysis interior ballistics codes is described and evaluated. Using Direct Numerical Simulation, the primary mechanisms controlling erosive burning (turbulent heat transfer, and finite rate reactions) have been studied independently through the development of models using finite rate*

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chemistry, and infinite rate chemistry. Both approaches are calibrated to strand burn rate data by modeling the propellant burning in an environment with no cross-flow, and adjusting thermophysical properties until the predicted regression rate matches test data. Subsequent runs are conducted where the cross-flow is increased from  $M=0.0$  up to  $M=0.8$ . The resulting relationship of burn rate increase versus Mach Number is used in an interior ballistics analysis to compute the chamber pressure of an existing solid rocket motor. The resulting predictions are compared to static test data. Both the infinite rate model and the finite rate model show good agreement when compared to

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*test data. The propellant considered is an AP/HTPB with an average AP particle size of 37 microns. The finite rate model shows that as the cross-flow increases, near wall vorticity increases due to the lifting of the boundary caused by the side injection of gases from the burning propellant surface. The point of maximum vorticity corresponds to the outer edge of the APd-binder flame. As the cross-flow increases, the APd-binder flame thickness becomes thinner ; however, the point of highest reaction rate moves only slightly closer to the propellant surface. As such, the net increase of heat transfer to the propellant surface due to finite rate chemistry affects is small. This*

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*leads to the conclusion that augmentation of thermal transport properties and the resulting heat transfer increase due to turbulence dominates over combustion chemistry in the erosive burning problem. This conclusion is advantageous in the development of future models that can be calibrated to heat transfer conditions without the necessity for finite rate chemistry. These results are considered applicable for propellants with small, evenly distributed AP particles where the assumption of premixed APd-binder gases is reasonable.*

*A Study of the Gas Phase Chemistry of Solid Propellants Using a Microprobe Mass Spectrometer (MPMS) System:*

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*Initial Development of the MPMS  
System*

*The Development of an Erosive  
Burning Model for Solid Rocket  
Motors Using Direct Numerical  
Simulation*

*Nonsteady Burning and  
Combustion Stability of Solid  
Propellants*

*Applications of Turbulent and  
Multiphase Combustion*

*Rocket Propulsion Elements*

***Detailed knowledge of the gas-phase reactions which occur during propellant ignition and combustion are required to understand and model these processes. If detailed models were available, modification of propellant formulations for***

***improved combustion behavior could be achieved with much less trail-and-error testing. Furthermore, detailed models could be used to generate simplified kinetics schemes for use in propellant models. Without a firm basis for these simplified kinetic schemes, the kinetic parameters are often adjusted to fit burning rate and ignition data; thus the propellant models are reduced to sophisticated curve fits to experimental data. The present research program, centers around the development and application of a microprobe,***

***mass spectrometer (MPMS) system to study the gas phase chemistry of solid propellant ingredients and solid propellants during heating by a CO<sub>2</sub> laser and during steady combustion. The MPMS system uses quartz microprobes with orifice sizes of 100 microns or less to withdraw gases from the region above the sample material. Through a two stage pumping system, the sample is delivered to a quadrupole mass spectrometer for analysis. Sampling is continuous throughout the combustion event so that***



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**species profiles of stable intermediates above the sample are obtained during the experiments.**

**The Chemistry of Propellants is a collection of papers and comments presented at the meeting on “The Chemistry of Propellants , held in Paris, France on June 8-12, 1959, organized by the AGARD Combustion and Propulsion Panel. This book is organized into six parts encompassing 25 chapters that serve as an introduction to the broad and important subject of propellant chemistry and propulsion applications. The first part**

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***deals with the sources, availability, and comparative costing of propulsion system. The second and third parts discuss the theoretical, thermodynamic, and experimental aspects of liquid and solid propellants. The fourth part examines the main problems concerning preparation, storage, and use of propellants for ramjet, while the fifth part looks into the factors leading to deposits in jet engines and some of the consequences of their existence. The sixth part covers the advantages of the high energy chemical***

***propellants, including fluorine and hydrogen. Combustion and propulsion scientists and researchers will find this book beneficial.***

***This up-to-date overview provides the latest information on the performance, sensitivity, strength and processability aspects of propellants and explosive formulations, with the nature of polymer binder/plasticizer as the variable factor. Apart from applications, this monograph explores the principles behind energetic polymers, while discussing the synthetic routes and***

***energetic characteristics of individual family of energetic polymers. Furthermore, a number of case studies illustrate the role of energetic polyerms on enhancing the performance of formulations as compared to their inert counterparts. The emphasis is on safety throughout, with practical guidance on how to safely handle and formulate energetic polymer based formulations. With the advent of a new generation of energetic polymers, this book is relevant to industry and defense organizations as well as for academic research.***

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***The Chemistry of Propellants  
Science and Technology  
Challenges***

***Energetics of Propellant  
Chemistry***

***A History of Jet Propulsion,  
Including Rockets***

***Properties, Combustion, and  
Technology Aspects***

Detailed knowledge of the gas-phase reactions which occur during propellant ignition and combustion are required to understand and model these processes. If detailed models were available, modification of propellant formulations for improved combustion behavior could be achieved with much less trial-and-error testing. Furthermore, detailed models could be used to generate simplified

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kinetics schemes for use in propellant models. The present research program, centers around the development and application of a microprobe, mass spectrometer (MPMS) system to study the gas phase chemistry of solid propellant ingredients and solid propellants during heating by a CO<sub>2</sub> laser and during steady combustion. The MPMS system uses quartz microprobes with orifice sizes of 100 microns or less to withdraw gases from the region above the sample material. Through a two stage pumping system, the sample is delivered to a quadrupole mass spectrometer for analysis. Sampling is continuous throughout the combustion event so that species profiles of stable intermediates above the sample are obtained during the experiments. In addition to the MPMS system, existing

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experimental methods to be used in the work include high speed direct photography, high speed schlieren photography, microthermocouple probes and photodiodes (for first visible light).

## Solid Propellant Rocket Research

This reference work treats the basic chemistry of high energy materials and offers an overview of current research. Both civilian and military uses of high-energy compounds are presented.

## Chemical Rocket Propulsion

Solid Propellant Chemistry,  
Combustion, and Motor Interior  
Ballistics, Volume 185

## Solid Propellant Rocket Research

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Ballistics 1999

## Metal Nanopowders

**This third edition of the classic on the**

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**thermochemical aspects of the combustion of propellants and explosives is completely revised and updated and now includes a section on green propellants and offers an up-to-date view of the thermochemical aspects of combustion and corresponding applications. Clearly structured, the first half of the book presents an introduction to pyrodynamics, describing fundamental aspects of the combustion of energetic materials, while the second part highlights applications of energetic materials, such as propellants, explosives and pyrolants, with a focus on the phenomena occurring in rocket motors. Finally, an appendix gives a brief overview of the fundamentals of aerodynamics and heat transfer, which is a prerequisite for the study of pyrodynamics. A detailed reference for readers interested in**



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**rocketry or explosives technology. Solid propellant is the most important energy source for rocket, missile and other weapons to launch, and is the key material to realize the firing range and damage effect of weapons. In order to meet the requirements of weapon application, the overall requirements for the energy performance, combustion performance, mechanical performance, storage performance, safety performance and process performance of solid propellant are put forward. Therefore, there are many challenges to fully meet the requirements of solid propellant and apply it to weapons. In recent years, with the development of material science, computational science and experimental technology, there are many reports about the composition, structure, performance research and prediction of solid propellants. This**

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**book reviews the research progress in solid propellant binder, energy performance prediction and thermodynamic calculation, combustion gas flow and combustion performance regulation, material storage performance research and safety performance simulation, and discusses the key development direction. The summary and prospect of this paper are expected to provide guidance, reference and inspiration for relevant researchers to carry out the research of solid propellant. This book is suitable for researchers, technicians and students who are engaged in solid propellant, weapons, chemistry and other work to read, for reference in specific research work. Due to the limited level of editors and short time, some problems are inevitable. We regret for some problems.**

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**In the last decade, there has been an influx in the development of new technologies for deep space exploration. Countries all around the world are investing in resources to create advanced energetic materials and propulsion systems for their aerospace initiatives. Energetic Materials Research, Applications, and New Technologies is an essential reference source of the latest research in aerospace engineering and its application in space exploration. Featuring comprehensive coverage across a range of related topics, such as molecular dynamics, rocket engine models, propellants and explosives, and quantum chemistry calculations, this book is an ideal reference source for academicians, researchers, advanced-level students, and technology developers seeking innovative research**

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**in aerospace engineering.**

**Chemistry and Combustion Instability  
in Solid Propellant Rocket Motors**

**Raketentreibstoffe**

**Theory of Solid-Propellant Nonsteady  
Combustion**

**A Comprehensive Survey of Energetic  
Materials**

**Proceedings of the Fourth Symposium  
on Naval Structural Mechanics, Purdue  
University, Lafayette, Indiana, April  
19-21, 1965**

*A hands-on, integrated approach to  
solving combustion problems in  
diverse areas An understanding of  
turbulence, combustion, and  
multiphasereacting flows is essential  
for engineers and scientists in  
many industries, including power  
generation, jet and rocket  
propulsion, pollution control, fire  
prevention and safety, and*

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material processing. This book offers a highly practical discussion of burning behavior and chemical processes occurring in diverse materials, arming readers with the tools they need to solve the most complex combustion problems facing the scientific community today. The second of a two-volume work, *Applications of Turbulent and Multiphase Combustion* expands on topics involving laminar flames from Professor Kuo's bestselling book *Principles of Combustion, Second Edition*, then builds upon the theory discussed in the companion volume *Fundamentals of Turbulent and Multiphase Combustion* to address in detail cutting-edge experimental techniques and applications not covered anywhere else. Special features of this book

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*include: Coverage of advanced applications such as solid propellants, burning behavior, and chemical boundary layer flows A multiphase systems approach discussing basic concepts before moving to higher-level applications A large number of practical examples gleaned from the authors' experience along with problems and a solutions manual Engineers and researchers in chemical and mechanical engineering and materials science will find Applications of Turbulent and Multiphase Combustion an indispensable guide for upgrading their skills and keeping up with this rapidly evolving area. It is also an excellent resource for students and professionals in mechanical, chemical, and aerospace engineering.*

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*Propellants contain considerable chemical energy that can be used in rocket propulsion. Bringing together*

*information on both the theoretical and practical aspects of solid rocket propellants for the first time, this book will find a unique place on the readers' shelf providing the overall picture of solid rocket propulsion technology. Aimed at students, engineers and researchers in the area, the authors have applied their wealth of knowledge regarding formulation, processing and evaluation to provide an up to date and clear text on the subject.*

*Boron-Based Fuel-Rich Solid Rocket Propellant Technology is a professional book that systematically introduces the latest research progress for boron-based fuel-rich solid propellants. It covers surface*

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*modifications, coating and agglomerating techniques, granulation, and characterization of amorphous boron powders, and its application to fuel-rich solid rocket propellants. Technologies for controlling the processing methods and combustion performance of fuel-rich propellants are examined, and the book concludes with a summary of the research progress in boron-based fuel-rich solid propellants and a look forward to the foreseeable development trends of military applications.*

*An Introduction to Propellants*

*Energetic Polymers*

*Thermochemical Aspects of*

*Combustion*

*Production, Characterization, and*

*Energetic Applications*

*Proceedings*



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Nanomaterials in Rocket Propulsion Systems covers the fundamentals of nanomaterials and examines a wide range of innovative applications, presenting the current state-of-the-art in the field. Opening with a chapter on nano-sized energetic materials, the book examines metal nanoparticles-based fuels, ballistic modifiers, stabilizers and catalysts as the components of rocket propellants. Hydrogen storage materials for rocket propulsion based on nanotubes are then discussed, as are nano-porous materials and metal organic frameworks, nano-gelled propellants, nano-composite ablators and ceramic nano-composites. Other applications examined include high thermal conductivity metallic nano-composite nozzle liners, nano-emitters for Coulomb propulsion of space-crafts, and highly thermostable nano-ceramics for rocket motors. The book finishes with

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coverage of combustion of nano-sized rocket fuels, nano-particles and their combustion in micro- and nano-electromechanical systems

(MEMS/NEMS), plasma propulsion and nano-scale physics. Users will find this to be a valuable resource for academic and government institutions, professionals, new researchers and graduate students working in the application of nanomaterials in the aerospace industry. Provides a detailed overview of different types of nanomaterials used in rocket propulsion, highlighting different situations in which different materials are used Demonstrates the use of new nanomaterial concepts, allowing for an increase in payload capacity or a decrease in launch mass Explores a range of applications using metal nanopowders, presenting a panorama on cutting-edge, technological developments

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The definitive text on rocket propulsion—now revised to reflect advancements in the field. For sixty years, Sutton's Rocket Propulsion Elements has been regarded as the single most authoritative sourcebook on rocket propulsion technology. As with the previous edition, coauthored with Oscar Biblarz, the Eighth Edition of Rocket Propulsion Elements offers a thorough introduction to basic principles of rocket propulsion for guided missiles, space flight, or satellite flight. It describes the physical mechanisms and designs for various types of rockets' and provides an understanding of how rocket propulsion is applied to flying vehicles. Updated and strengthened throughout, the Eighth Edition explores: The fundamentals of rocket propulsion, its essential technologies, and its key design rationale. The various types of rocket propulsion

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systems, physical phenomena, and essential relationships. The latest advances in the field such as changes in materials, systems design, propellants, applications, and manufacturing technologies, with a separate new chapter devoted to turbopumps. Liquid propellant rocket engines and solid propellant rocket motors, the two most prevalent of the rocket propulsion systems, with in-depth consideration of advances in hybrid rockets and electrical space propulsion. Comprehensive and coherently organized, this seminal text guides readers evenhandedly through the complex factors that shape rocket propulsion, with both theory and practical design considerations. Professional engineers in the aerospace and defense industries as well as students in mechanical and aerospace engineering will find this updated classic indispensable for its scope.

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of coverage and utility.

Both Jet-engine propelled aircraft and long-range rockets were first successfully flown during World War II. This led to rapid post-war improvements in both, and within two decades we had supersonic airplanes, communication satellites, and trips to the moon. Unmanned probes to Mars and the outer planets followed, as well as the International Space Station. The technology behind these advances is described, along with short biographies of key pioneers. Problems at high Mach numbers are reviewed. Possible future developments are discussed. More technical details, including mathematics, are in an appendix.

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Chemie der hochenergetischen

Materialien

High Energy Propellants

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Mechanics and Chemistry of Solid  
Propellants 1999 Progress In  
A Continuing Bibliography

**Mechanics and Chemistry of Solid Propellants is a collection of papers presented at the Fourth Symposium on Naval Structural Mechanics, held in Purdue University, Lafayette, Indiana on April 19-21, 1965 under the joint sponsorship of the Office of Naval Research and Purdue University. The contributors consider the development and utilization of solid propellants. This book is composed of 22 chapters**

**that cover the many branches of studies that touch upon the science and technology of solid propellants. Some chapters present the mathematical and physical theories underlying the behavior of solid propellants, such as nonlinear and linear theories of viscoelasticity. Other chapters are devoted to advances in solid propellant binder chemistry; combustion and its effects on the structural integrity of the solid propellant grain; and design and other engineering problems. This**

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**book will be of value to  
scientists, engineers, and  
researchers who are  
interested in the diverse  
applications of solid  
propellants.**

**THE DEFINITIVE  
INTRODUCTION TO ROCKET  
PROPULSION THEORY AND  
APPLICATIONS** The recent  
upsurge in global  
government and private  
spending and in space flight  
events has resulted in many  
novel applications of rocket  
propulsion technology.  
**Rocket Propulsion Elements**  
remains the definitive guide  
to the field, providing a



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**comprehensive introduction to essential concepts and applications. Led by industry veteran George P. Sutton and by Professor Oscar Biblarz, this book provides interdisciplinary coverage including thermodynamics, aerodynamics, flight performance, propellant chemistry and more. This thoroughly revised ninth edition includes discussion and analysis of recent advances in the field, representing an authoritative reference for students and working engineers alike. In any**

**engineering field, theory is only as useful as it is practical; this book emphasizes relevant real-world applications of fundamental concepts to link "thinking" and "doing". This book will help readers: Understand the physics of flight and the chemistry of propulsion Analyze liquid, solid, gas, and hybrid propellants, and the engines they fuel Consider high-temperature combustion, stability, and the principles of electric and chemical propulsion Dissect the workings of systems in**

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**common use around the world today Delve into the latest advances in materials, systems, propellants, and more Broad in scope, rich in detail, and clear in explanation, this seminal work provides an unparalleled foundation in aerospace engineering topics. Learning through the lens of modern applications untangles complex topics and helps students fully grasp the intricacies on a more intuitive level. Rocket Propulsion Elements, Ninth Edition merges information and utility building a solid**

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**foundation for innovation.  
Solid Rocket Propellants  
Investigations of Novel  
Energetic Materials to  
Stabilize Rocket Motors  
Energetic Materials  
Research, Applications, and  
New Technologies  
The Chemistry and  
Technology of Solid Rocket  
Propellants (A Treatise on  
Solid Propellants)**