Preface

With my involvement in combustion and propulsion for over thirty five years in teaching, research and in the development of propulsion systems for space vehicles as well as missiles, I have had to participate in many reviews as a member some times, chairman at other times to discuss the preliminary design of a vehicle or unclarified test results from which one would need to make some sense to suggest a considered future course of action. The meetings have left indelible mark in me and perhaps altered the traditional "academic" in me nearly completely. Real systems behave in ways that appear strange at first sight, but a careful examination, modeling of the system and analysis show a small but influential parameter that sets everything in the right place. Nature's inscrutable ways and the power of analysis to clarify them have been a source of amazement and joy many a time.

The current book titled "Understanding Aerospace Chemical Propulsion" has grown out of my many faceted activities over the last three and half decades.

There are many good books on propulsion. There is a need to see if a new book is needed at all, and if a new one is written, what will be new in it.

Many treat non-air breathing and air breathing engines separately. A few treat them in the same volume, but as separate topics. It is intended here that both be treated in the same book and comparisons drawn where possible. The development of many of the propulsion systems has reached maturity and changes if any, are made to meet specific needs of a class of clients. It is necessary to understand if the systems that have been developed follow the general principles of thermodynamics and if they fall short of expectations of thermodynamics what engineering limitations make them deviate from expectations. This book therefore draws upon the data on many propulsion systems both air breathing and non-air breathing far more extensively than any other book written till now and subjects the data to analysis to see a pattern and draw possible general conclusions. *Data from Indian developments have rarely been documented as a part of a book earlier. This book attempts to make amends for this lacuna.*

This book is limited to chemical propulsion. Many books on propulsion deal with other methods of propulsion, like electric and ion rockets. I have felt that the

subject of chemical propulsion itself is vast and deserves a more comprehensive treatment than is possible otherwise.

There are eleven chapters in the book. Chapter 1 is a detailed introduction to propulsion systems. All the systems discussed subsequently in the book are discussed at a level where a reading should give the reader an overview. Chapter 2 deals with the question of needs and specifications of the propulsion systems. This provides an appreciation of why so many varieties of propulsion systems have been developed and what requirements they fulfill.

Chapter 3 deals with efficiencies of propulsion systems. This is a classical subject that provides a backdrop for detailed system analysis. Chapter 4 lays further background with the necessary thermodynamic and gas dynamic fundamentals needed in any book that discusses propulsion system performance. Chapter 5 is concerned with the detailed cycle analysis of several propulsion systems - most airbreathing engines - in a format that helps capture the relationship between performance parameters (thrust per unit area, dimensionless thrust, normalized flow rate and specific impulse) on geometric, design and flight variables. Chapter 6 is concerned with a detailed discussion of all the components of an airbreathing engine including scramjets - air intake, compressor, combustion chamber, turbine and nozzle. This discussion is around the principles involved in the conceptualization of various design approaches and to understand the variety of systems.

Chapter 7 deals with fuels, propellants and their characterization. While the range of fuels used in airbreathing engines is not wide, the range prevalent in rocket engines is very wide and it is important to understand why so many of them have still are around. The principles involved in characterizing them for adiabatic flame temperature and composition are presented. The performance of rocket propellants - solid and liquid are discussed in some detail.

Chapters 8 is devoted to the principles of rocket combustion process - solid, liquid and hybrid. Emphasis is given to clearly delineating the process fundamentals in all the combustion processes and connecting them to the performance of the systems.

Chapter 9 is devoted to solid propulsion systems - propellant grain geometry, internal ballistics of solid rocket motors, ignition systems, nozzle thermal analysis and protection schemes, thrust vector control (including flex nozzles), and features of large size motors.

Chapter 10 is concerned with liquid rocket engines. Monopropellant rocket engines, zero-g propellant acquisition devices, thruster life management and related aspects occupy the first part. Bipropellant rocket engines with all the elements – injection systems, thrust chamber sizing and cooling aspects, feed systems – turbines and pumps, arrangement of feed system – thrust chambers for optimal performance are discussed in considerable detail.

Chapter 11 is devoted to combustion instability in solid and liquid rockets. The fundamental features of low frequency and high frequency instabilities, the causes for their occurrence and solutions dominate the discussion in this chapter.

Comparisons are sought between gas turbine combustion chambers and rocket engine combustion chambers, fundamental process commonalities between rocket engines and air breathing engines, turbines and compressors in air breathing engines and turbines and pumps in rocket engines.

Who do I think should read this book? Engineers beginning their career in the Aerospace industry who should have a good understanding of the underlying principles of propulsion systems can benefit considerably from reading this book. Engineers who have turned managers wanting to move up and shoulder greater responsibilities, overseeing more than one group should revisit the ideas on the commonalities between propulsion systems from which they would have alienated themselves for decade or more working hard at specific tasks. Their understanding would be considerably enhanced and they might even enjoy reading some sections since they have had practical insight into some systems in great detail.

I have benefitted from many in a critical analysis of propulsion systems that has provided insight into systems. A colleague, Prof. P. J. Paul has been a companion in many of these journeys towards getting insight. The graphics in this book has been the devoted and careful work of Mr. B. K. Ashwini Kumar. Grateful thanks to him for being patient with the demands for a better picture, a more wholesome depiction many a time. Review of the book towards its improvement has been received from several sources including Prof. A. G. Marathe, Prof. T. Sunderarajan, Dr. P. A. Ramakrishna, Dr. C. S. Bhaskar Dixit, Mr. Sudarshan Kumar and Mr. Binoy Phillip. Contribution to cover page design has come from Dr. N. K. S. Rajan and colleagues. Thanks to all of them. The personnel at the Combustion, Gasification and Propulsion Laboratory where I have spent twenty years have been very understanding and supportive. Grateful thanks to all of them. Finally, none of this would have been possible without the support of my family, especially my wife Indira, who has been an incredible source of encouragement.

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