Preface

Turbomachinery performance, aerodynamics, and heat transfer have been subjects of continuous changes for the last seven decades. Stodola was the fist to make a successful effort to integrate the treatment of almost all components of steam and gas turbines in a single volume monumental work. Almost half a century later, Traupel presented the third and last edition of his work to the turbomachinery community. In his two-volume work, Traupel covered almost all relevant aspects of turbomachinery aerodynamics, performance, structure, rotordynamics, blade vibration, and heat transfer with the information available up to the mid-seventies. In the meantime, the introduction of high speed computers and sophisticated computational methods has significantly contributed to an exponential growth of information covering almost all aspects of turbomachinery design. This situation has lead to a growing tendency in technical specialization causing the number of engineers with the state-of-the-art combined knowledge of major turbomachinery aspects such as, aerodynamics, heat transfer, combustion, rotordynamics, and structure, to diminish. Another, not minor, factor in the context of specialization is the use of "black boxes" in engineering in general and in turbomachinery in particular. During my 25 years of turbomachinery R&D experience, I have been encountering engineers who can use commercial codes for calculating the complex turbomachinery flow field without knowing the underlying physics of the code they use. This circumstance constituted one of the factors in defining the framework of this book, which aims at providing the students and practicing turbomachinery design engineers with a sold background in turbomachinery flow physics and performance. As a consequence, it does not cover all aspects of turbomachinery design. It is primarily concerned with the fundamental turbomachinery flow physics and its application to different turbomachinery components and systems. I have tried to provide the turbomachinery community, including students and practicing engineers, with a lasting foundation on which they can build their specialized structures.

I started working on this book when I left Brown Boveri, Gas Turbine Division in Switzerland (1987) and joined Texas A&M University. A part of my lecture notes in graduate level turbomachinery constitutes the basics of this book, which consists of three parts. Part I encompassing Chapters 1 to 6 deals with turbomachinery flow physics. Explaining the physics of a highly three-dimensional flow through a turbine or a compressor stage requires adequate tools. Tensor analysis is a powerful tool to deal with this type of flow. Almost all graduate level fluid mechanics and computational fluid dynamics (CFD) courses at Texas A&M University, and most likely at other universities, make use of tensor analysis. For the reader, who might not be familiar with the tensor analysis, I tailored the quintessential of tensor analysis in Appendixes A and B to the need of the reader who is willing to spend a few hours on this topic.

Chapters 2 and 3 deal with the Kinematics and Differential Balances in turbomachinery in three-dimensional form. In dealing with three-dimensional turbulent flows through a turbomachinery component, I refrained from presenting a multitude of existing turbulence models for three reasons. Firstly, the models are changing continuously; the one which is thought today to be the ultimo ratio may be obsolete tomorrow. Secondly, there is a vast amount of papers and publications devoted to turbulence modeling and numerical methods in turbomachinery. In my view, summarizing these models and methods without getting into details is not appropriate for a text. Thirdly, the emergence of the direct numerical simulation (DNS) as the ultimate solution method, though not very practical at the time being, will in the near future undoubtedly eliminate the problems that are inherently associated with Reynolds averaged Navier Stokes equations (RANS). Considering this situation, I focused my effort on briefly presenting the RANS-equations and introducing the intermittency function. The resulting equations containing the product of the intermittency and the Reynolds stress tensor clearly illustrate how the accuracy of these two models affect the numerical results. As a logical followup, Chapter 4 extensively discusses the integral balances in turbomachinery. Chapters 5 and 6 deal with a unified treatment of energy transfer, stage characteristics, and cascade and stage aerodynamics. Contrary to the traditional approach that treats turbine and compressor stages of axial or radial configuration differently, I have tried to treat these components using the same set of equations.

Part II of this book containing Chapters 7 through 11 starts with the treatment of cascade and stage efficiency and loss determination from a physically plausible point of view. I refrained from presenting recipe-type of empirical formulas that have no physical foundation. Chapters 10 and 11 deal with simple designs of compressors and turbine blades and calculation of incidence and deviation. Radial equilibrium is discussed in Chapter 11 which concludes Part II.

Part III of the book is entirely dedicated to dynamic performance of turbomachinery components and systems. Particular attention is paid to gas turbine components, their individual modeling, and integration into the gas turbine system. It includes Chapter 12 to 18. Chapter 12 introduces the non-linear dynamic simulation of turbomachinery systems and its theoretical background. Starting from a set of general four dimensional partial differential equations in temporal-spatial domain, two-dimensional equation sets are derived that constitute the basis for component modeling. The following Chapter 13 deals with generic modeling of turbomachinery components and systems followed by Chapters 14, 15, 16, and 17 in which individual components ranging from the inlet nozzle to the compressor, combustion chamber, turbine, and exhaust diffuser are modeled. In modeling compressor and turbine components, non-linear adiabatic and diabatic expansion and compression calculation methods are presented. Chapter 18 treats gas turbine engines, design and dynamic performance. Three representative case studies conclude this chapter. In preparing Part III, I tried to be as concrete as possible by providing examples for each individual component.

In typing several thousand equations, errors may occur. I tried hard to eliminate typing, spelling and other errors, but I have no doubt that some remain to be found by readers. In this case, I sincerely appreciate the reader notifying me of any mistakes found; the electronic address is given below. I also welcome any comments or suggestions regarding the improvement of future editions of the book.

My sincere thanks are due to many fine individuals and institutions. First and foremost, I would like to thank the faculty of the Technische Universität Darmstadt, from whom I received my entire engineering education. I finalized major chapters of the manuscript during my sabbatical in Germany, where I received the Alexander von Humboldt Prize. I am indebted to the Alexander von Humboldt Foundation for this Prize and the material support for my research sabbatical in Germany. My thanks are extended to Prof. Bernd Stoffel, Prof. Ditmar Hennecke, and Dipl. Ing. Bernd Matyschok for providing me with a very congenial working environment. I truly enjoyed interacting with these fine individuals. NASA Glenn Research Center sponsored the development of the nonlinear dynamic code GETRAN, which I used to simulate cases in Part III. I wish to extend my thanks to Mr. Carl Lorenzo, Chief of Control Division, Dr. D. Paxson, and the administration of NASA Glenn Research center. I also thank Dr. Richard Hearsey for providing me with a three-dimensional compressor blade design example that he obtained from his streamline curvature program. I also would like to extend my thanks to Dr. Arthur Wennerstom for providing me with the updated theory on the streamline curvature method.

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