AXIAL-FLOW COMPRESSORS

A STRATEGY FOR AERODYNAMIC DESIGN AND ANALYSIS

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To Anne

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PREFACE

Books on compressor aerodynamics approach the subject in various ways depending on the intended audience. Introductions to the fundamentals are available to students and newcomers to the field. The experienced aerodynamicist can find more comprehensive overviews of the core technologies that review alternate approaches and summarize important contributions that have significantly advanced the state of the art. Users of compressors can find books that address the alternatives and critical issues of particular interest to the application, selection, procurement and operation of compressors. But in recent years, the aerodynamicist seeking detailed information and practical guidance on the effective application of basic technology to compressor aerodynamic design and analysis has been less fortunate.

When I started working in this field, books of that type were available, although they were somewhat dated. *The Centrifugal Compressor Stage* (Ferguson, 1963), *Axial Flow Compressors* (Horlock, 1958) and *Aero-Thermodynamics and Flow in Turbomachines* (Vavra, 1960) were my particular favorites, and they provided valuable guidance during my early efforts to formulate compressor aerodynamic design and analysis systems. Unfortunately, their modern equivalents have simply not appeared. With his usual insight, Cumpsty (1989) recognizes and discusses this change in emphasis in recent books in his preface to *Compressor Aerodynamics*. He attributes it to the expanded roles of the computer and of proprietary industrial research and development, which have combined to make it rather impractical for authors to provide a general and detailed description of modern compressor aerodynamic design and analysis methods. Several years ago, similar reasoning led me to consider a different type of book to meet this need. If a general description of aerodynamic design and analysis methods is no longer practical, a detailed description of a specific aerodynamic design and analysis system might be a viable alternative. Although unsure of how it might be received, I decided to write a book on centrifugal compressor aerodynamics and managed to find a publisher willing to try something different (Aungier, 2000). The feedback received since my book was published confirms that there is interest in this type of book as well as a significant audience.

Aerodynamic design and analysis systems evolve through a trial-and-error process while we painfully learn what capabilities should be included, how to use them effectively and how they can interact efficiently to support the overall process. The conversion of basic technology into a working design and analysis system is a very complex process involving many decisions and false starts. Along the way, all developers expend a lot of time and effort formulating virtually identical models for phenomena fundamental to the process. These critical details are quite important to aerodynamicists who must develop, maintain or improve an aerodynamic design and analysis system. The present book approaches axial-flow compressor aerodynamics in a manner similar to that of my previous book on centrifugal compressors. The approach used is a description of a comprehensive aerodynamic design and analysis system in sufficient detail so that readers can readily implement the complete system or any of its components.

This proved to be more difficult for axial-flow compressors than was the case for centrifugal compressors. Centrifugal compressor stage designs tend to be fairly unique and specific to the design objectives. Most current design and analysis systems share many common features and are used in a wide range of applications. The basis for axial-flow compressor design is far more varied and application-dependent, often based on proprietary information that is not available in the open literature. Indeed, it is now quite common to find designs based on proprietary and customized airfoil families, such as the popular controlled diffusion airfoil. The geometry and performance characteristics of these proprietary airfoils are well known only to the organizations that developed them. There are also inherent differences in the technology used on industrial axial-flow and centrifugal compressors. The development of a completely original industrial axial-flow compressor design is relatively rare. These compressors are almost always unique, one-of-a-kind designs that must rely on variations of standard components to minimize risks while maintaining acceptable development and manufacturing costs. Hence, the variety of application experience is far more limited for the axial-flow compressor design and analysis system than was the case for the centrifugal compressor system.

I decided that the desired objectives could still be achieved by adopting the classical design approach based on the systematic application of standard airfoil families to develop the blade geometry used in the compressors. The basic principles of the design process described here remain applicable when proprietary airfoil families are in use. But it is likely to be necessary to adapt them to reflect the specific geometry and performance characteristics of those airfoils. Aerodynamic performance prediction accuracy is established by comparing predictions with experimental data for several axial-flow compressors. That established performance prediction accuracy is then used to demonstrate the effectiveness of the overall design and analysis system. A substantial number of design examples are included to illustrate the use of this design and analysis system, as well as to provide some evaluation of alternate design approaches suggested in the literature, or which I have found to be effective.

Considerable care is taken to provide complete and detailed descriptions of this comprehensive aerodynamic design and analysis system for axial-flow compressors. The basic principles of thermodynamics and fluid mechanics required are presented in a form particularly well-suited to the axial-flow compressor application. Well-defined empirical models are used to augment these basic principles to address the essential problem areas of performance analysis, stage design, compressor design and internal flow analysis. Descriptions of numerical methods used are included as well as other critical considerations important to readers who may wish to apply these methods. In a few cases where components are common to both my centrifugal and axial-flow compressor design and analysis systems, I refer to Aungier (2000) rather than repeat some rather lengthy and detailed descriptions that will be of interest only to readers who choose to implement those specific methods.

Some important topics have received inadequate treatment or have been completely omitted. Surge and stall are discussed only in the context of estimating the expected limits of stable operation, while noise and blade vibration are not discussed at all. I prefer to limit myself to topics on which I can offer at least some original ideas. I always feel uncomfortable when presenting ideas obtained almost entirely from others, even when I have considerable confidence in the sources. I much prefer that readers obtain such information from qualified authors, even if it does display my own limitations.