"John is the only person I know that can fill the gap between technology and philosophy; and he really did in this book. I recommend this text for students and professional engineers, as well as for non-experienced people who are interested in getting a frank and sometimes humorous assessment of gas turbine technology."

—Alberto Traverso, University of Genoa

"This book is clearly written by an expert with a lot of industry experience in OEMs (original equipment manufacturers) and operation, resulting in a book that shows a very practical approach to design and analysis of turbomachinery that matters in the real world without lacking the theoretical depths that are necessary to understand the topic thoroughly. This very well-written book covers the theoretical basics of thermodynamics as well as components such as the compressor, the combustor, the turbine, the whole engine, and additional topics needed to understand the analysis and design of electrical power generation equipment. It provides a comprehensive overview for everyone interested in this fascinating topic, be it a practitioner with OEMs and utilities, or academics, such as a researcher or a new student of the field.

This long-awaited book closes a gap in the literature between the practitioner's view and a purely theoretical approach."

—Hans-Juergen Kiesow, ABB, Siemens (retired)

"It is rare that one comes across a book that can be considered seminal in the area of gas turbine engineering and that provides an excellent blend of theory and practice of the state of the art of heavy- duty advanced gas turbines. The book provides a detailed, lucid, and insightful treatment of a wide range of gas turbine topics, including history, cycles, components and their interactions, and technology trends. It provides a quantitative and qualitative treatment of the subject matter with usable equations, insights, and rules of thumb that enable quick design checks and calculations. It will be of immense value to designers and users of gas turbines. John's technical leadership over the past two and a half decades has contributed immeasurably to the current understanding of large advanced gas turbines. Much of this expertise has been successfully encapsulated in this book. This book is of archival quality and will endure and enrich gas turbine engineers for decades to come."

—Cyrus B. Meher-Homji, PE, Bechtel Fellow and Turbomachinery Technology Manager, Bechtel Corporation

Gas Turbines for Electric Power Generation

In this essential reference, both students and practitioners in the field will find an accessible discussion of electric power generation with gas turbine power plants using quantitative and qualitative tools. Beginning with a basic discussion of thermodynamics of gas turbine cycles from a second law perspective, the material goes on to provide an in-depth analysis of the translation of the cycle to a final product, facilitating quick estimates.

In order to provide readers with the knowledge they need to design turbines effectively, there are explanations of simple- and combined-cycle design considerations and state-of-the-art performance prediction and optimization techniques, as well as rules of thumb for design and off-design performance and operational flexibility and simplified calculations for myriad design and off-design performance. The text also features an introduction to proper material selection, manufacturing techniques, and the construction, maintenance, and operation of gas turbine power plants.

S. Can Gülen (PhD) PE, Bechtel Fellow, ASME Fellow, has a combined 25 years of mechanical engineering experience covering a wide spectrum of technology, system, and software design, development, assessment, and analysis in the field of steam and gas turbine combined-cycle process and power plant turbomachinery and thermodynamics at Thermoflow, Inc., General Electric, and Bechtel.

He has written numerous technical papers and journal articles on design practices and technical assessment reports. He holds more than 20 US patents on gas turbine performance, cost, optimization, data reconciliation, analysis, and modeling.

Gas Turbines for Electric Power Generation

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Contents

Preface

He who defends everything, defends nothing.

Frederick II of Prussia

To paraphrase the great Prussian emperor, to cover everything is to cover nothing. This book is a monograph on a specific class of heat engines, namely the heavy-duty industrial gas turbine for electric power generation. It does not cover gas turbines used for aircraft, marine, or land-based vehicle propulsion (i.e., there is no discussion of turbofan, turbojet, or turboprop engines, except in a historical context). Its focus is fully on land-based (i.e., stationary shaft) power generation and conversion thereof into electric power via alternating current synchronous machines; especially so-called frame machines with outputs of 100 MWe or more, which are also known as heavy-duty industrial gas turbines. In other words, a discussion of "microturbines" is not to be found herein.

This is not a textbook, although it can be used by a student of mechanical engineering with sufficient background in thermodynamics, fluid mechanics, and heat transfer as a useful reference to help complete certain class assignments.

This is not a handbook of generalized information either. In our times, the necessity of handbooks is debatable. A wide range of detailed information on any given subject is only one mouse click away. This book is a compendium of expert knowledge, which is either impossible to find online or, even if found, is either too sketchy or too diluted or too obscure to be of immediate, practical use.

The intended audience is primarily professionals (i.e., engineers and researchers) who are working in the industry or in research organizations on various aspects of electric power generation with gas turbines. Graduate and undergraduate students who are working on projects toward their degree with an ultimate goal of joining the industry can be added to this group as well.

It is an advanced text with little material of an introductory nature (mostly a few paragraphs to start the main narrative). In other words, one will not find the derivation of Navier–Stokes equations from the analysis of an infinitesimally small control volume of fluid in this book. The goal of the author is to provide the reader with specialized knowledge, calculation methods, and tools that can be readily applied to the solution of the day-to-day problems encountered in the design, development, optimization, operation, and maintenance of gas turbine power plants. Said methods and tools comprise

specific data (some hard to find – even on the Internet, at least not in a compact and readily usable form), practical formulae, Visual Basic code, charts, and rules of thumbs. Most of the specific methods and tools have been developed and used by the author over the course of more than two decades spent in the industry.

What is the use of such a monograph? After all, at the time of writing (i.e., near the end of the second decade of the twenty-first century), almost all aspects of gas turbine power plant design are dominated by highly sophisticated, extremely expensive (i.e., not available to individuals) computer software with steep learning curves. These "black box" tools incorporate the latest techniques in computational fluid dynamics and finite element analysis fortified with flashy graphical user interfaces and other "digital" accoutrements on the most advanced computing platforms to enable engineers (some fresh out of school) to design, say, advanced airfoils in order to squeeze the last 0.01 percent efficiency from the compressor or the turbine. Most complicated gas turbine combined cycle calculations for tens or hundreds of cases can be done in a matter of seconds by user-friendly heat balance simulation software.

The goal of this monograph, as envisioned by the author, is to provide the junior engineer or researcher using those tools, as well as his or her supervisor with decades of experience under his or her belt, with a single source of reference to put every little detail in its rightful place in the proverbial big picture, which will be expounded upon in the next few pages.

Before moving on, however, there is a simple fact that needs to be stated unequivocally. This book is dedicated to the memory of Mustafa Kemal Atatürk (1881–193∞) and his elite cadre of reformers. Without their vision, sacrifices and groundbreaking work, there would not have been a fertile ground where my parents, teachers, mentors, family and friends could shape me into the author of this book.