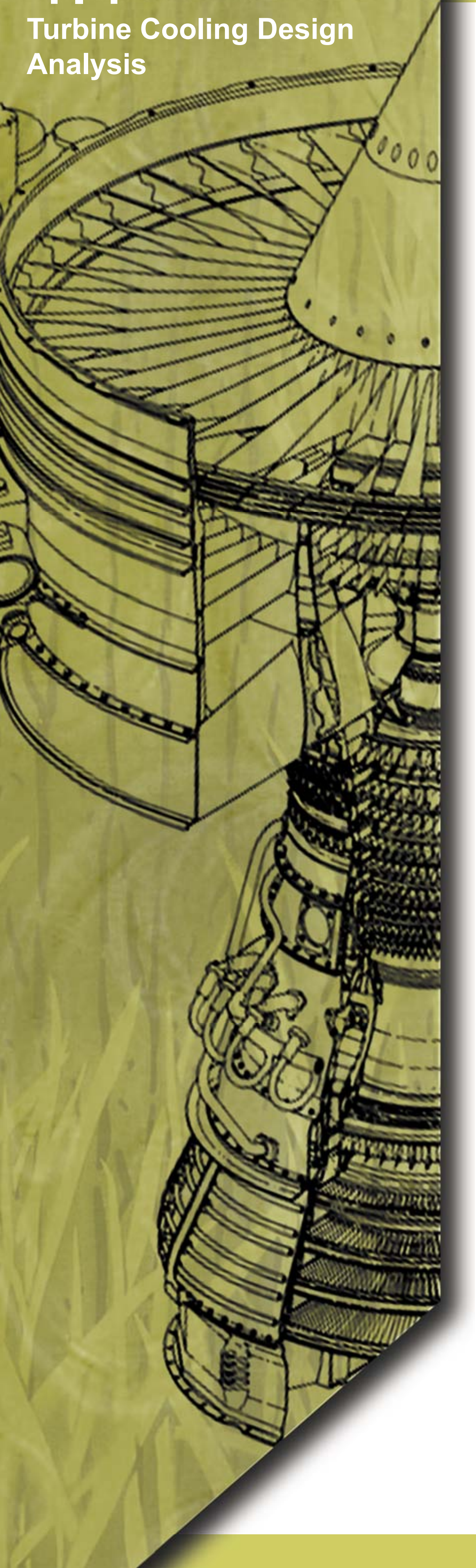
4.1 Turbine Cooling Design Analysis



4.1-1 Introduction

Turbine cooling methods have provided the ability to increase turbine inlet temperatures above melting temperatures of turbine airfoil components with not only airfoil survivability, but also extending airfoil life. These cooling methods can be broadly classified into internal and external methods. Internal cooling methods include the use of geometric features placed in the flow path of internal channels within the turbine airfoils to promote turbulence, thereby enhancing convective heat transfer coefficients. These geometric features generally include ribs, pin fins, and impingement holes. External cooling methods include the use of film-cooling holes that are placed in the surface of the airfoils with the hole shapes and hole placement being the design issue.

Because the flow fields across turbine vanes and blades vary relative to the position on the airfoil, one would expect that the cooling design would vary. Consider that the flow at the airfoil mid span is primarily two-dimensional while the flow at the airfoil edges is clearly influenced by the inner hub and outer casings of the turbine. The flows influencing the inner hub and outer cases often contain vortices that give rise to velocity components that are orthogonal to the primary flow direction. Not only do the cooling schemes vary in these regions, but the methods that are used to analyze these various sections also vary. Because these cooling schemes are relatively complex, the analysis methods employed are not straightforward.

Section 4.1 is aimed at providing the reader with methods that are currently used to analyze complex turbine cooling schemes as well as a background for understanding relevant effects on the different cooling methods. Turbine airfoil geometries have also evolved over the years to reduce pressure losses across each stage resulting in three-dimensional airfoil designs. Section 4.2 provides the reader with an understanding of three dimensional airfoil geometries.

- **Karen Thole**

BIOGRAPHY

4.1 Introduction
4.2.3 Airfoil Endwall Heat Transfer

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Dr. Karen Thole is the Department Head of Mechanical Engineering at Penn State University. Her B.S. and M.S. degrees are in Mechanical Engineering from the University of Illinois, and her Ph.D. in Mechanical Engineering is from the University of Texas at Austin. After receiving her Ph.D. in 1992, she spent two years as a post-doctoral researcher at the University of Karslruhe in Karslruhe Germany. After her post-doctoral position, she accepted an assistant professor position at the University of Wisconsin-Madison where she taught and performed research in the Mechanical Engineering Department. In 1999 she accepted a position in the Mechanical Engineering Department at Virginia Tech where she was promoted to full professor in 2003. Dr. Thole's areas of expertise are heat transfer and fluid mechanics specializing in understanding high freestream turbulance effects. Over the past few years she has developed a number of unique testing facilities directed towards gas turbine heat transfer issues including a combustor simulator that simulates the flow field effects relevant to those entering the turbine section of an engine. Dr. Thole has been responsible for attracting research funding amounting to over $4 million from such agencies at the Department of Energy, US Air Force, Pratt & Whitney, Modine Manufacturing, Siemens-Westinghouse and the National Science Foundation. She has published over 100 peer reviewed papers with a number of these presentations given to international audiences.