Preface

This monograph was conceived as an overview of the potential and achievements of the analytical and numerical modelling of convective heat and mass transfer in different types of rotating flows. Flow rotation can be a consequence of (i) *system rotation*, (ii) *flow swirl* imposed by so-called swirl generators and (iii) *curvature of surfaces* or larger segments of the geometry such as turns, bends, curved connections, etc. Rotation, swirl or curvature-induced volume forces often referred to as centrifugal and Coriolis forces can significantly affect the flow pattern, as well as the heat and mass transfer rate.

Rotating flows arise in numerous scientific and engineering applications. As practical examples one can mention turbomachinery, energy systems, automotive engineering, aerospace engineering, medical equipment, processing engineering and many others. One of the important scientific applications is a rotating disk electrode involved in experimental determination of the diffusion coefficient in electrolytes. A cone-plate or a cone-disk device, which includes a fixed disk and a rotating cone that touches the disk by its apex, is widely known in measurements of the viscosity coefficient of liquids.

One can mention several books, which elucidate many aspects of the physics and provide quantification for many parameters of rotating flows. These are classical books of L.A. Dorfman “Hydrodynamic Resistance and the Heat Loss of Rotating Solids” (Oliver and Boyd, Edinburgh, UK, 1963) and V.G. Levich “Physicochemical Hydrodynamics” (Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962), which for many decades were desktop books for specialists in the fields of convective heat and mass transfer in rotating disk systems. The fundamental review monograph of J.M. Owen & R.H. Rogers “Flow and Heat Transfer in Rotating-Disc Systems” (Research Studies Press Ltd., UK, 1989 & 1995) summarized results of experimental investigations and theoretical modelling in the area of secondary air cooling systems of gas turbines, including rotor−stator systems and rotating cavities formed by parallel co-rotating disks. The book “Heat Transfer and Fluid Flow in Rotating Coolant Channels” (Research Studies Press, J. Wiley and Sons, 1981) by W.D. Morris is devoted mostly to experimental investigations of the hydraulic resistance and average heat transfer in channels rotating about a parallel axis. In the recent book "Rotating flow" (Elsevier Inc., Amsterdam etc., 2011), P.R.N. Childs shed light on the basic theory of rotating flows and contributed to the development of the integral methods for rotating-disk systems, including rotor-stator configurations and rotating cavities.

During the past decades, methods of experimental and theoretical investigations of scientific and practical problems of convective heat and mass transfer, which the aforementioned books deal with, have made considerable progress. This resulted in obtaining new accurate experimental and numerical results for a series of rotating geometries studied before and emerging during the past years. As a result, the analysis and generalizations of the experimental and numerical data provided in the aforementioned books are often insufficient. Integral methods have been rather successfully applied to several rotating-disk geometries. However, theoretical model assumptions underlying the known integral methods demonstrated their restricted capabilities in light of the newly obtained experimental and numerical data. A powerful modelling technique based on the exact self-similar solutions of the Navier–Stokes and energy equations appeared to be insufficiently developed for a few rotating disk geometries, where appropriate self-similar forms of the solutions have not been derived. In addition, a few important scientific and practical problems were not touched in the above-mentioned books: (a) transient conjugate heat transfer; (b) uniform orthogonal flow impingement onto a disk; (c) fluid flow, heat and mass transfer in a small gap between a rotating disk and/or a cone that touches the disk by its apex; (d) convective heat and mass transfer at Prandtl and Schmidt numbers, both moderately larger than unity with the application to the experimental technique based on naphthalene sublimation in air, and much larger than unity with the application in electrochemistry.

All said, the above became an incentive for me to undertake investigations that were summarized in the form of a book by Shevchuk I.V. "Convective Heat and Mass Transfer in Rotating Disk Systems (Springer Verlag, Berlin, Heidelberg, 2009). Since then, I have conducted new studies on the subject of rotating flows published as a series of research papers. In the same time, the international scientific community has also contributed much to this research area, which provided valuable material for validation and corroboration of the models and numerical results presented in my book.

In comparison with the previous book, my new monograph outlines the further progress in the integral methods, self-similar and analytical solutions for the problems of convective heat and mass transfer in rotating-disk systems validated through extensive comparisons with the experimental data including those that have been published during the past six years. Most part of the new monograph is devoted to system rotation-induced fluid flows and deals with several rotating-disk geometries. Swirl flows were also modelled in some of these geometries. In addition, the scope of the new monograph was extended to cover other types of rotating flows such as those in (a) the channels rotating around a parallel axis, and (b) the two-pass ribbed channels with 180° bends. These studies provide examples of design optimization of air cooling systems of the rotors of electrical motors and gas turbine blades, respectively.

The present book consists of nine chapters. The book is mainly focused on convective heat transfer in air flow, with the exception of Chap. 6, which deals with heat and mass transfer at Prandtl or Schmidt numbers larger than unity.

Chapter 1 depicts geometries studied in this book, outlines forces influencing the flow and presents a general mathematical description in the form of momentum, continuity, energy and convective diffusion equations written in a vector form, Cartesian and cylindrical polar coordinate systems.

In Chap. 2, the general mathematical description is adapted to rotating disk systems. The chapter contains also an overview of the existing methods of solution, the integral method developed by the author, and a general analytical solution for the turbulent boundary layer flow and heat transfer in rotating-disk systems obtained using this method.

Chapter 3 is devoted to steady-state and unsteady heat transfer of a single rotating disk. As demonstrated here, the present integral method is significantly more accurate and incorporates a wider variety of thermal boundary conditions than other integral methods. Chapter 3 critically overviews the most reliable experimental data for transitional flow, provides recommendations for the calculation of average heat transfer of an *entire* disk and briefly outlines some important aspects of laminar transient heat transfer.

In Chap. 4, results of the analytical and numerical modelling of external flow over a rotating disk and outward flow between parallel co-rotating disks are described and compared with experimental data. In particular, Chap. 4 presents solutions for the cases of (a) disk rotation in a fluid subject to solid-body rotation, (b) accelerating non-rotating radial flow and (c) centrifugal swirling radial flow in a gap between parallel co-rotating disks.

Chapter 5 focuses on laminar flow, heat and mass transfer between a disk and a cone that touches the disk with its apex. It comprises such geometries as "rotating cone—stationary disk", "rotating disk—stationary cone", "co-rotating or contra-rotating disk and cone" and "non-rotating conical diffuser". Novel is the section describing effects of the Prandtl and Schmidt numbers, as well as a review of the relevant recently published works.

In Chap. 6, results of different authors for the problems of convective heat and mass transfer for the Prandtl and Schmidt numbers larger than unity are critically analysed and generalized. Chapter 6 presents original theoretical models of the author developed for naphthalene sublimation in air and electrochemical problems. In the integral method of the author, effects of large Prandtl and Schmidt numbers are taken into account.

Chapter 7 describes results of the CDF modelling of convective heat transfer in pipes rotating around a parallel axis including effects of the flow angle of attack at the inlet to the pipe, as well as influence of the cross-section geometry (circular or elliptic pipes).

In Chap. 8, original results of the simulation and optimization of convective heat transfer in the varying aspect ratio two-pass internal ribbed cooling channels with 180° bends are outlined and analysed from a single viewpoint.

Chapter 9 presents overall conclusions to the material presented in the book.

The present book is an official publication of my habilitation thesis (Habilitationsschrift) prepared during my work as a university lecturer at the Institute of Aerospace Thermodynamics (ITLR), University of Stuttgart, Germany and successfully presented at the Faculty of Aerospace Engineering and Geodesy, University of Stuttgart on 24 April 2015. I would like to deeply thank the main referee of my habilitation thesis, Director of the ITLR Prof. Dr.-Ing. habil. Bernhard Weigand for his strong support of my aspiration to successfully accomplish this work, as well as for his numerous valuable advices and fruitful discussions. I would also like to warmly thank the co-referees, Professor D.Phil. Peter R.N. Childs (Imperial College London, UK), Professor Dr. Andrey V. Kuznetsov (North Carolina State University, U.S.A.) and Professor Dr.-Ing. habil. Yuri B. Zudin (National Research Center "Kurchatov Institute", Moscow, Russia) for reviewing my habilitation thesis and for participation in the habilitation process.

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