Preface to the Second Edition

Roughly 10 years ago the first edition of this book was published. Since then a lot of the material of this book has been used for lectures at the University of Stuttgart, for Bachelor- and Master-Thesis work and for research.

I am happy about all the positive responses to this book during the past years from my students and researchers all over the world. For this edition, the chapters have been updated and extended, where necessary. In addition, Appendix E has been added. Here the reader can find short solutions to the problems given at the end of each chapter.

In the web page www.uni-stuttgart.de/itlr/Analytical-Methods the reader can find additional material for the book. Here, also a solution manual for the problems given in the book is provided. The Login and Password for this web page is

Login: Analytical-Methods
Password: methods1000

I would like to thank Kathrin Eisenschmidt and Dr. Hassan Gomaa for the helpful discussions of the second edition of this book. In addition, I would like to thank Christian Biegger for helping me with some of the figures.

Finally, I would like to express my thanks to Springer Press for the very good cooperation during the preparation of this manuscript.

Filderstadt, January 2015 Bernhard Weigand

Preface to the First Edition

Partial differential equations are the basis for nearly all technical processes in heat transfer and fluid mechanics. In my lectures over the past 7 years I became aware of the fact that a lot of the students studying mechanical or aerospace engineering and also a lot of the engineers in industry today focus more and more on numerical methods for solving these partial differential equations. Analytical methods, taught in undergraduate mathematics, in thermodynamics and fluid mechanics, are quickly discarded, because most people believe that almost all problems, appearing in *real* applications, can easily be solved by numerical methods. In addition, most of the examples shown in basic lectures are *so simple* that the students develop the impression that analytical methods are inappropriate for more complicated *realistic technical* problems.

It was exactly the above described mindset that inspired me several years ago to give lectures on analytical methods for heat and mass transfer problems. The basic idea of these lectures is to show some selected analytical methods and to explain their application to more complicated problems, which are technically relevant. Of course, this means that some of the standard analytical methods might not be discussed in these lectures and are also not present in this book (for example, integral transforms). On the other hand, it can be shown that the analytical methods discussed here are applicable to interesting problems and the student or engineer learns how to solve useful technical problems analytically.

This means that the main intent of this book is to show the usefulness of analytical methods, in a world, which focuses more and more on numerical methods. Of course, there is no doubt that the knowledge of numerical solution methods is very important and there is a big chance in using numerical tools to gain inside into flow physics and heat transfer characteristics. However, numerical methods are always dependent on grid quality and grid size and also on a lot of implementation features. Analytical methods can be used to validate and improve numerical methods. So the engineer might simplify a problem up to the extent that he can obtain an analytical solution. This analytical solution might be used later to check and to improve the numerical solution for the full problem without any simplifications.

This book has been written for graduate students and engineers. The mathematics needed to understand the solution approach is developed mostly during the actual solution of the problem under consideration. This means that the book includes only few proofs. The reader is referred in these situations to other books for these more basic mathematical considerations. This approach has been taken in order to keep the focus of the book on the solution method itself and not to disrupt the analysis of the technical problem.

The book is structured into six chapters. Chapter 1 provides a short introduction to the topic.

Chapter 2 provides an introduction to the solution of linear partial differential equations. After discussing the classification and the character of the solutions of second-order partial differential equations, the method of separation of variables is discussed in detail.

Chapter 3 is concerned with the solution of thermal entrance problems for pipe and channel flows. This means that solutions of the energy equation are considered for a hydrodynamically fully developed velocity profile. These problems lead to the solution of Sturm-Liouville eigenvalue problems, which are discussed for laminar and turbulent flows and for different wall boundary conditions. For the problems considered in Chap. 3, axial heat conduction within the flow can be ignored, because the Peclet number in the flow is sufficiently large. This means that the problems under consideration are parabolic in nature. Because such eigenvalue problems normally cannot be solved analytically, a numerical procedure is discussed on how to solve them. In Appendix C, this numerical solution method is explained in detail and the reader is provided links to an Internet page containing several source codes and executables.

Chapter 4 explains analytical solution methods for Sturm-Liouville eigenvalue problems for large eigenvalues. Here the focus is to explain an asymptotic analysis for a complicated problem, which is technically relevant. This chapter also provides comparisons between numerically and analytically predicted eigenvalues and constants. These comparisons show the usefulness of the analytical solution. Furthermore, it is explained how the method can be used for related problems.

In Chapter 5 the heat transfer in pipe and channel flows for small Peclet numbers is considered. In contrast to the problems discussed in Chaps. 3 and 4, the axial heat conduction in the fluid cannot be ignored. This leads to elliptic problems. A method is presented, which gives rise to solutions that are as simple as the ones presented in Chap. 3. The extension of this method to more complicated problems, for example, for the heat transfer in hydrodynamically fully developed duct flows with a heated zone of finite length, is also explained.

Chapter 6 is devoted finally to the solution of nonlinear partial differential equations. The idea behind this chapter was to provide a short overview of different solution methods for nonlinear partial differential equations. However, the main focus is on the derivation of similarity solutions. Here, different solution methods are explained. These are the method of dimensional analysis, group-theory methods, and the method of the free parameter. The methods are demonstrated for a simple heat conduction problem as well as for complicated boundary layer problems.

Many people helped me in all phases of the preparation of this book. I am very grateful for many helpful discussions with my colleague Prof. Jens von Wolfersdorf concerning all aspects of the analytical solution methods. I also thank very much Martin Stricker and Marco Schüler who helped me with the figures. Many thanks also go to Dr. Grazia Lamanna for the helpful discussions and her support in finishing this book. Also, I would like to thank Karl Straub very much for reading the manuscript.

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Finally, I am very grateful for the very good cooperation with Springer Press during the preparation of this manuscript.

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