Preface

The aerodynamic research of rotors has contributed significantly to the successful development of the modern wind turbine. Probably, the most important contribution to wind turbine aerodynamics is due to Glauert (1935), who collected all available work on aerodynamics in a single textbook. In this book, the main ingredients of the Blade Element Momentum (BEM) theory was formulated, which include the general momentum theory, the blade element approach, and the tip correction. Today, the aerodynamic research on wind turbines is highly specialized and forms one of the knowledge frontiers of modern engineering science, including scientific disciplines such as turbulence theory, control theory and sophisticated numerical techniques. In spite of this, most practical designs of wind turbines still rely on the 'classical' BEM theory and the various extensions that have been introduced in order to extend the applicability of the basic technique. There is therefore still a need for validating and challenging the basic approach forming the BEM technique.

The aim of this book is to reconsider the basic approaches behind the BEM method and in particular to assess and validate the equations forming the general momentum theory. Although this theory is relatively simple, there are numerous examples in the literature on misinterpretations and even wrong statements derived from the theory. The main reason for the problems associated with the interpretation of the theory is that it contains more unknowns than equations, and it therefore is required to introduce various simplifications to establish a closed set of equations. In the original work of Glauert (1935), these simplifications were postulated without any further justification, simply because it was not possible to assess their validity. However, with the use of numerical fluid mechanics (CFD) it is today possible to validate the influence of the various terms and, in particular, to assess the impact on the loading and performance when neglecting some of them. Part of the present book concerns the validation, using CFD, of the different terms in the equations forming the momentum theory. Other parts concern new ideas for extending the theory and for enhancing the accuracy of the BEM approach. The book contains new as well as already published material, but in all cases the author has strived to put the material into a new and more consistent context than what is usually found in textbooks.

The book is primarily intended for researchers and experienced students with a basic knowledge of fluid mechanics wishing to understand and expand their knowledge of wind turbine aerodynamics. The author has strived to make the book self-consistent, hence all necessary derivations are shown, and it should not be necessary to seek help in other literature to understand the content in this book.

Chapter 1 contains a brief review of the history of wind energy and of the aerodynamics of wind turbines. In Chap. 2 the main basic definitions, to be used later in the thesis, are introduced. In Chap. 3 the one-dimensional axial momentum theory is revisited and the errors committed when using locally a one-dimensional approach on a differential element is assessed. Furthermore, it is demonstrated how one-dimensional axial momentum theory may be applied to analyse the additional performance achieved for rotors located in diffusers and to derive corrections for rotors tested in wind tunnels. Finally, the chapter contains a description of how one-dimensional momentum theory can be applied to the somewhat exotic case of a wind turbine driven vehicle. In Chap. 4 the equations forming the general momentum theory is derived. Usually in textbooks, these equations are derived with some a priori unverified assumptions, which in many cases have caused misinterpretations with respect to the importance of the various terms. In the present work, the axial momentum equation is first derived without any simplifying assumptions, after which different approaches are derived from the full equation, and the terms that usually are omitted in the general momentum theory are assessed by comparative CFD computations. Chapter 5 continues with a description and comparison of different proposals for optimum aerodynamic rotor models based on the general momentum theory. In Chap. 6 one of the aerodynamics models, the Joukowsky model, is analysed in detail for small tip speed ratios. The analysis is carried both analytically and by comparison to additional CFD computations. Chapter 7 introduces the blade-element/momentum (BEM) theory. The chapter gives both a survey of the main ingredients in the 'standard' method and the various 'engineering adds-on'. Furthermore, techniques for extending the 'standard' approach by inclusion of correction terms are introduced and compared. In Chap. 8 the tip correction is discussed in detail, and it is shown that the 'traditional' Prandtl/Glauert tip correction contains an inherent inconsistency in the vicinity of the tip when using tabulated airfoil data. A remedy to solve this problem is proposed and a new additional tip correction, based on the so-called decambering technique, is introduced. In Chap. 9 an analytical solution to the finite-bladed optimum Betz rotor is given, and the results are compared to other optimum rotor models, both with respect to performance and resulting rotor geometry. Finally, in the Appendix, the CFD technique used for assessing the various terms in the analysed rotor models is described.

Reference

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