Preface

The standard approach in the study of wind turbine aerodynamics consists in using momentum analyses. The momentum theory of an actuator disk is an example of momentum analysis. Blade element momentum (BEM) and the conventional computation fluid dynamics (CFD) are two numerical methods also based on momentum analyses. Velocity and pressure are the main variables used in momentum analysis. The equations can also be formulated using vorticity as main variable. This leads to an alternative approach referred to as vorticity-based methods. The great potential of vorticity-based methods comes from the multitude of formulations they offer, ranging from simple analytical models to advanced numerical methods. The analytical model will be referred to as vortex theories and the numerical methods as vortex methods.

The term vorticity often intimidates the newcomer, but this fear vanishes when one realizes that velocity and vorticity offer two different, but often equivalent, points of view. For instance, the momentum theory of an actuator disk with constant loading can be equivalently studied by considering the tubular vorticity sheet that is present at the surface of the streamtube. Vorticity plays an important role in wind turbine aerodynamics since strong vortices are present in the wakes in particular. Vorticity and vorticity-based methods cannot be omitted in a book on the topic. Most of the analytical models used in BEM methods are derived from analytical vortex models. Further, numerical vortex methods are now competing with conventional CFD methods in terms of accuracy and computational time, and they are becoming a common tool for the study of wind turbine aerodynamics.

The aim of this book is to show the relevance of vorticity-based methods for the study of wind turbine aerodynamics and to present historical and recent developments in the field with a sufficient level of details for the book to be self-contained.

This book is intended for students and researchers curious about rotor aerodynamics and/or about vorticity-based methods. The book introduces the fundamentals of fluid mechanics, momentum theories, vortex theories, and vortex methods necessary for the study of rotors and wind turbines in particular. Rotor theories are presented in a great level of details at the beginning of the book. These theories include the blade element theory, the Kutta–Joukowski theory, the momentum theory, and the BEM method. Different momentum theories are derived from first principles using a critical approach. The remaining of the book focuses on vortex theory and vortex methods with application to wind turbine aerodynamics. Examples of vortex theory applications that are discussed in this book are optimal rotor design, tip-loss corrections, yaw models, and dynamic inflow models. Historical derivations and recent extensions of the models are presented. The cylindrical vortex model is another example of a simple analytical vortex model used in this book. In this model, a wind turbine and its wake are simplified using a vortex system of cylindrical shape. Formulations equivalent to the ones used in a BEM algorithm are obtained. The model provides a wake-rotation correction which greatly improves the accuracy of BEM algorithms. The cylindrical model is also used to provide the analytical velocity field upstream of a turbine or a wind farm (i.e., the induction zone) under aligned or yawed conditions. Such results are obtained in a couple of seconds with an impressive accuracy compared to numerical results from CFD methods which would require days of computation. Different applications of numerical vortex methods are presented in this book. Numerical methods are used for instance to investigate the influence of a wind turbine on the incoming turbulence. Sheared inflows are also investigated. It is shown in particular that most vortex methods omit a term resulting in excessive upward displacement of the wind turbine wake. Many analytical flows are derived in detail in this book: vortex rings, Hill's vortex, vortex blobs, etc. They are used throughout the book to devise simple rotor models or to validate the implementation of numerical methods. Several MATLAB programs are provided to ease some of the most complex implementations: BEM codes, vortex cylinder velocity functions, Goldstein's circulation, lifting-line codes, Karman–Trefftz conformal map, projection functions for vortex particle methods, etc.

Part I introduces the fluid mechanics foundations relevant to this book. Part II introduces rotor aerodynamics, including momentum analyses, vortex models, and the BEM method. Part III focuses on classical vortex theory results which originated from the study of rotors with optimal circulation. Part IV presents the recent developments in rotor aerodynamics based on analytical vortex flows. Part V presents recent applications of vortex methods. Part VI provides detailed analytical solutions that are relevant for rotor aerodynamics, either for the derivation of vortex models or for the implementation and validation of vortex methods. Part VII is dedicated to vortex methods. Part VIII provides mathematical complements to some chapters of the book.

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