

Contents

1	Introduction	1
1.1	Introduction	1
1.1.1	A Brief Historical Review of Wind Energy	1
1.1.2	The Aerodynamics of Wind Turbines	3
	References	6
2	Basic Definitions	7
3	One-Dimensional Axial Momentum Theory	9
3.1	Basics of Axial Momentum Theory	10
3.2	Assessment of Basic Assumptions of 1D Momentum Theory	11
3.3	Assessment of Axial Momentum Theory on Differential Form	14
3.4	One-Dimensional Momentum Theory Applied to a Diffuser-Augmented Wind Turbine	17
3.5	Wind Tunnel Corrections Using Axial Momentum Theory	23
3.5.1	Wind Tunnel Correction for Closed Test Section	24
3.5.2	Wind Tunnel Correction for Open Test Section	28
3.6	Axial Momentum Theory Applied to Wind Turbine-Driven Vehicle	33
3.6.1	Mechanical System Without Losses	33
3.6.2	Mechanical System With Losses	38
	References	41
4	The General Momentum Theory	43
4.1	General Equations	43
4.2	The Glauert Model	49
4.3	The Model of Burton et al.	50
4.4	The Model of Joukowsky	51
4.5	Discussion and Assessment of the Validity of the General Momentum Theory	53
	References	58

5	Optimum Rotor Performance Based on Momentum Theory	59
5.1	The Optimum Power Coefficient	59
5.2	The Optimum Rotor Model of Glauert	60
5.3	The Optimum Rotor Model of Burton, Sharpe et al.	62
5.4	The Optimum Rotor Model of Joukowski	63
5.5	A Modified Optimum Glauert Rotor Model	64
5.6	A Modified Optimum Joukowski Model Without Wake Expansion	65
5.7	Comparison of the Performance of Optimum Rotor Models	66
5.8	Design and Comparison of Blade Geometries for Optimum Rotors	68
5.8.1	Expressions for Design of Plan Forms	68
5.8.2	Comparison of Different Optimum Design.	70
	References	73
6	Detailed Analysis of the Joukowski Model	75
6.1	Background	75
6.2	Basic Equations	76
6.3	Results and Discussion	77
6.4	Inherent Upper Limits from the Momentum Equations	81
6.5	A Likely Explanation of the High Power Coefficient at Small Tip Speed Ratios	83
6.6	Rotor-Induced Vortex Breakdown.	86
6.7	Navier–Stokes Simulations of the Joukowski Rotor at Small Tip Speed Ratios	88
6.8	Design and Test of Joukowski Rotor at Small Tip Speed Ratios	93
	References	96
7	Blade-Element/Momentum Theory	99
7.1	Basics of the ‘Standard’ Blade-Element/Momentum Theory	100
7.2	Engineering Modifications	103
7.2.1	Tip Correction	103
7.2.2	Correction for Heavily Loaded Rotors.	104
7.2.3	Yaw Correction	105
7.2.4	Dynamic Wake	105
7.2.5	Airfoil Data	106
7.3	Alternative Formulations of the BEM Theory.	107
7.3.1	The Approach by Glauert	109
7.3.2	Alternative Model 1	109
7.3.3	Alternative Model 2	110
7.3.4	Alternative Model 3	111
7.3.5	Overview of the Models	112

7.4	Comparative Study of the Different BEM Alternatives	113
7.4.1	Comparison at a Design Tip Speed Ratio $\lambda = 6$	113
7.4.2	Comparison at a Design Tip Speed Ratio $\lambda = 3$	117
	References	120
8	The Tip Correction	123
8.1	Background	123
8.2	The Finite Number of Blades Approximation by Prandtl	124
8.3	The Tip Correction of Glauert	131
8.4	Alternative Formulations of the Glauert Tip Correction	133
8.5	Analysis of the Prandtl/Glauert Tip Correction	134
8.6	Generalized Tip Correction Formula	138
8.7	Application of the Tip Correction in Generalized Numerical Actuator Disc/Line Models.	139
8.8	The Decamber Correction	140
8.8.1	Description of the Decamber Technique	142
8.8.2	Results and Discussion	146
	References	149
9	The Finite-Bladed Betz Rotor	151
9.1	Background	151
9.2	Basics of Simple Vortex Theory.	152
9.3	Optimum Rotor Conditions	154
9.4	Solution of the Betz Problem.	157
9.5	Assessment of Different Solutions to the Betz Problem.	166
9.6	Analysis of the Infinite-Bladed Betz Rotor.	169
9.7	Analysis of the Finite-Bladed Betz Rotor.	175
	References	179
	Appendix A: Generalized Axisymmetric Navier–Stokes Actuator Disc Modelling	181

General Momentum Theory for Horizontal Axis Wind
Turbines

Sørensen, J.N.

2016, XI, 194 p., Hardcover

ISBN: 978-3-319-22113-7