Delft University of Technology

Faculty of Aerospace Engineering
Rotor / wake Aerodynamics - AE4135

Rotor / wake Aerodynamics
Assignment 1: Blade Element Theory

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Contents

Nomenlacture 1

α	angle of attack at blade element $(-)$
β	blade twist angle at blade element $(-)$
λ	tip speed ratio $(-)$
ρ	fluid density $(\mathrm{kg \cdot m^{-3}})$
Γ	circulation at blade element $(\mathrm{m^2 \cdot s^{-1}})$
Φ	perceived-wind inflow-angle at blade element $(-)$
Ω	rotor rotational velocity $(\mathrm{rad \cdot s^{-1}})$
a	axial induction factor $(-)$
a'	azimuthal induction factor $(-)$
c	blade element chord (m)
C_d	drag coefficient $(-)$
C_l	lift coefficient $(-)$
C_T	thrust coefficient $(-)$
Drag	drag force per unit span $(\mathrm{N \cdot m^{-1}})$
Lift	lift force per unit span $(\mathrm{N \cdot m^{-1}})$
F_{azim}	azimuthal/tangential force per unit span $(\mathrm{N \cdot m^{-1}})$
F_{axial}	axial force per unit span $(\mathrm{N \cdot m^{-1}})$
N_{blades}	number of blades $(-)$
$V_{\mathrm{axial}} = U_{\mathrm{rotor}}$	axial velocity perceived by blade element, axial velocity at rotor $(\mathrm{m \cdot s^{-1}})$
V_P	velocity perceived by blade element $(\mathrm{m \cdot s^{-1}})$
V_{tan}	azimuthal/tangential velocity perceived by blade element $(\mathrm{m \cdot s^{-1}})$

Introduction 2

Table 2.1: Wind turbine geometrical specifications

Variable	Value
Radius (R)	50 [m]
Number of Blades	3
Blade starts at	0.2 r/R
Twist	14*(1-r/R) [degrees]
Blade Pitch	-2 [degrees]
Chord Distribution	3*(1-r/R)+1 [m]
Airfoil	DU 95-W-180
Rotor yaw angle	0, 15 and 30 [degrees]

Table 2.2: Wind turbine operational specifications

Variable	Value
Wind speed (U0)	10 [m/s]
Tip speed ratio (λ)	6, 8, 10
Rotor yaw angle	0, 15, 30 [degrees]

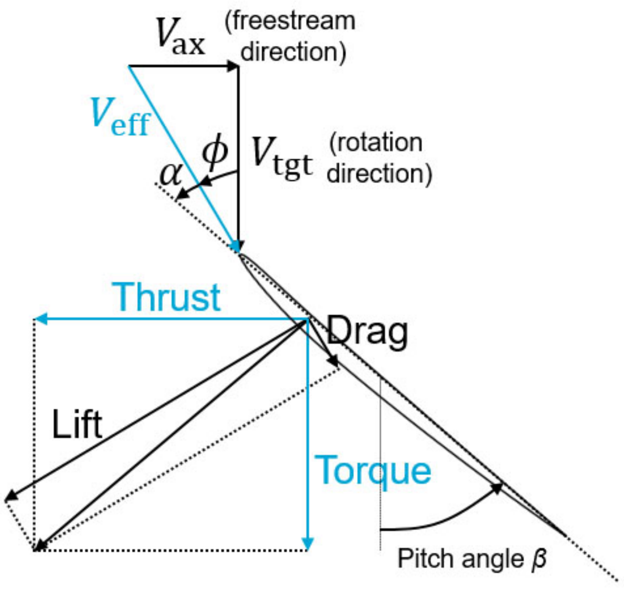


Figure 2.1: Caption

Flow diagram of the code 3

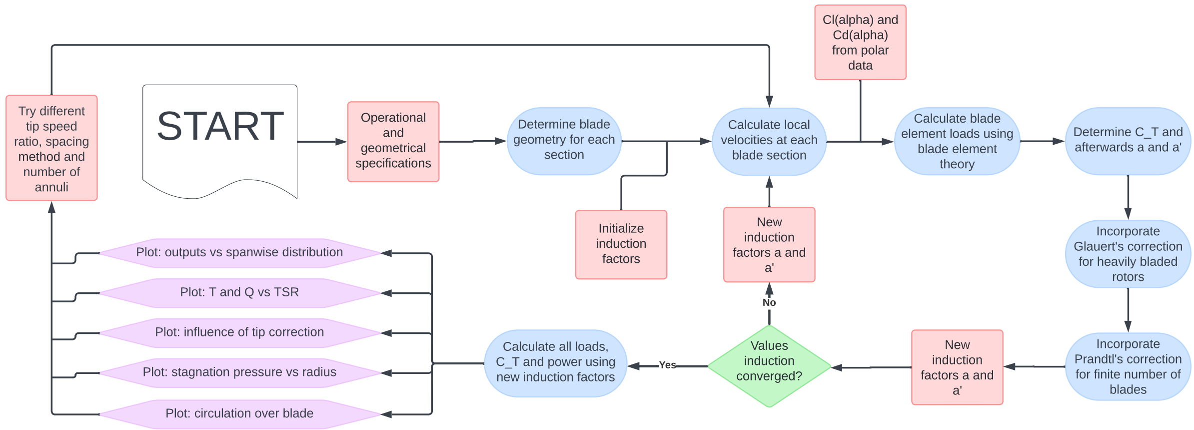


Figure 3.1: Flow diagram of the code

3.1 Assumptions

- **Steady Flow:** the flow characteristics are assumed to be independent of time.
- **Inviscid Flow:** the flow is assumed to be inviscid. This means no viscous effects are taken into account.
- **Incompressible Flow:** the flow is assumed to be incompressible. This means the density throughout the streamtube is constant. This enables the use of Bernoulli's equation in locations of a continuous pressure distribution. This also results in the product of area and flow velocity being constant over the flow.
- **2D Flow:** it is assumed that the flow characteristics can accurately be modeled using 2 dimensional flow characteristics.
- **Constant Internal Energy:** it is assumed that the internal energy within the streamtube is constant so there no radiation, convection or conduction occurring.
- **Independent annulus:** the annuli are considered independently of one another. In reality, flow characteristics on one annulus will influence the characteristics on another (cross flow), this effect is ignored.
- **Circular Discs:** the actuator disc in the model is assumed to be of circular shape. In reality slight changes in the shape could occur, these are neglected.
- **Root-section:** it is assumed that the root section till $r/R = 0.2$ has no influence on the performance of the turbine and can be neglected.

Results (axial flow) 4

4.1 Reference Data (for cl(alpha) and cd(alpha))

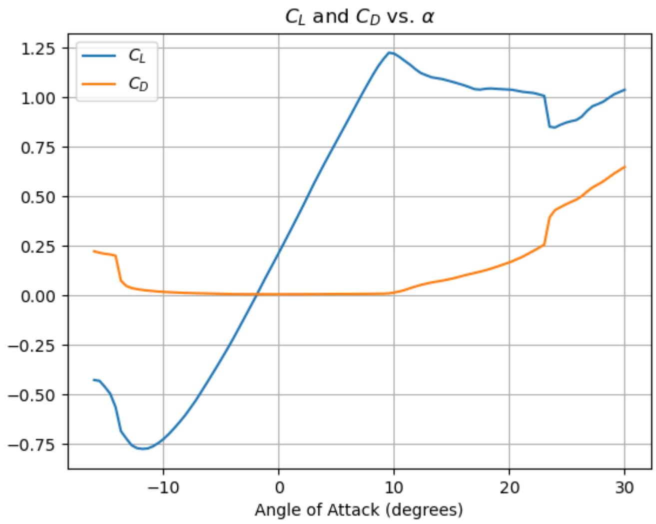


Figure 4.1: Lift Curve and Drag

4.2 Corrections

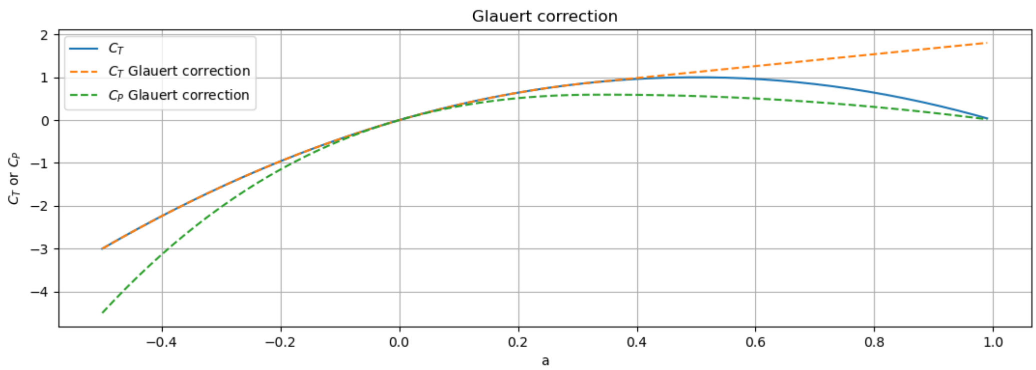


Figure 4.2: Glauert correction

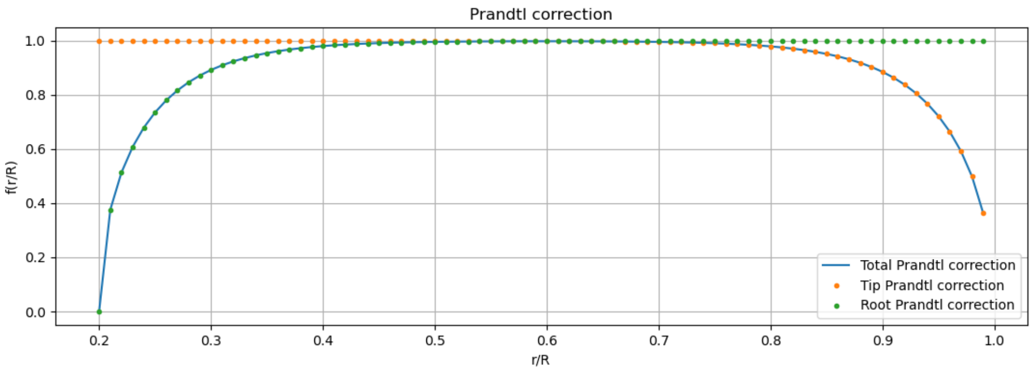


Figure 4.3: Prandtl correction

4.3 Angles

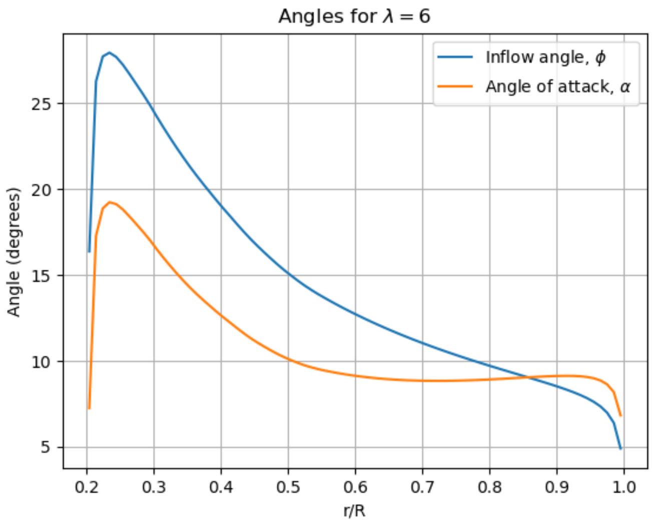


Figure 4.4: Spanwise distribution of Angle of Attack and Inflow Angle for Tip Speed Ratio of 6

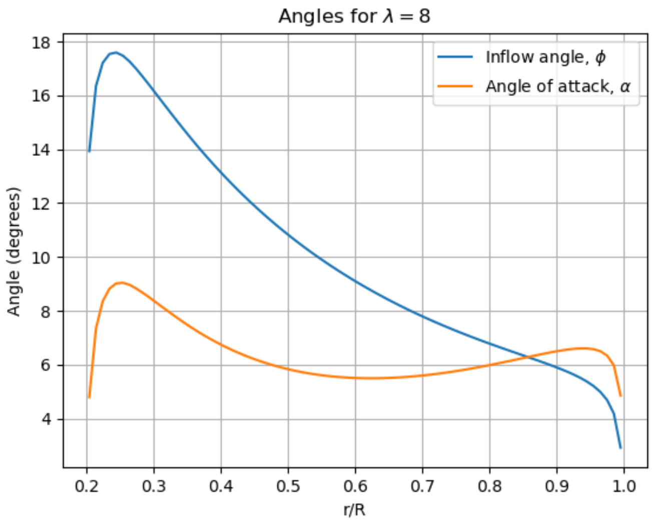


Figure 4.5: Spanwise distribution of Angle of Attack and Inflow Angle for Tip Speed Ratio of 8

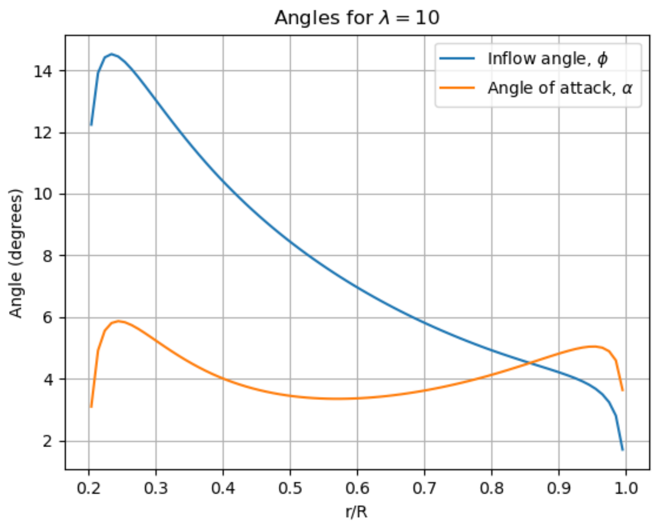


Figure 4.6: Spanwise distribution of Angle of Attack and Inflow Angle for Tip Speed Ratio of 10

4.4 Induction factors

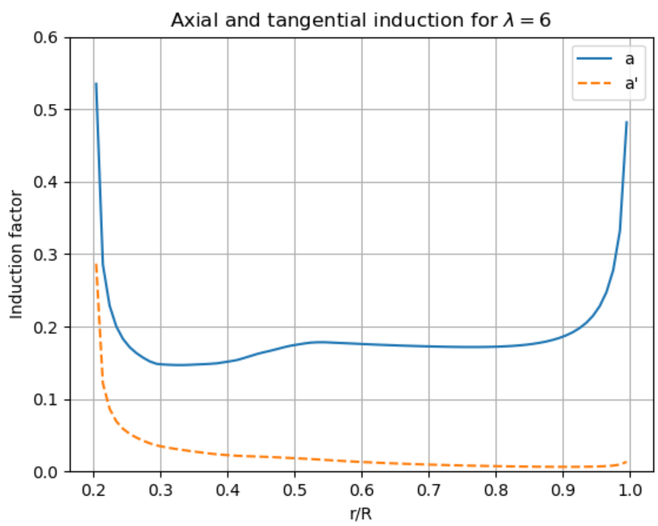


Figure 4.7: Caption

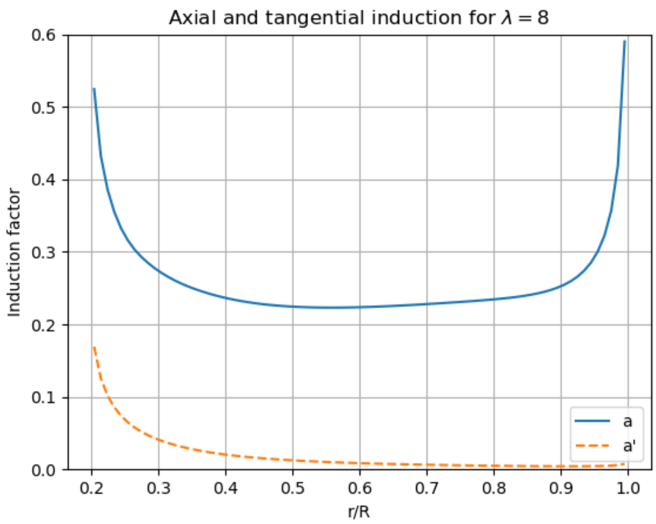


Figure 4.8: Caption

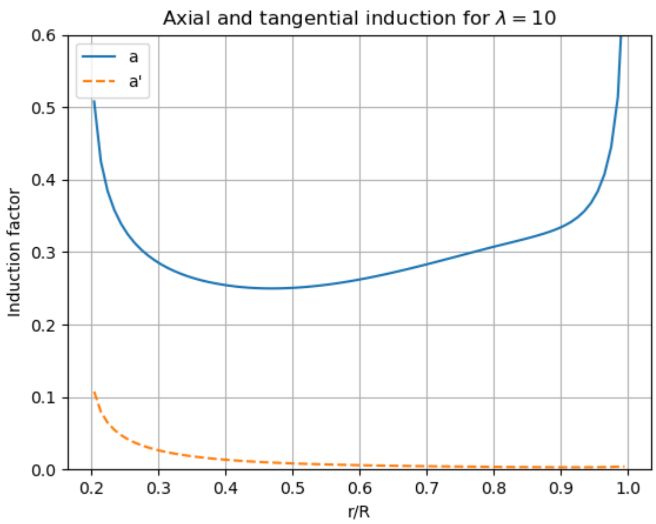


Figure 4.9: Caption

4.5 Forces

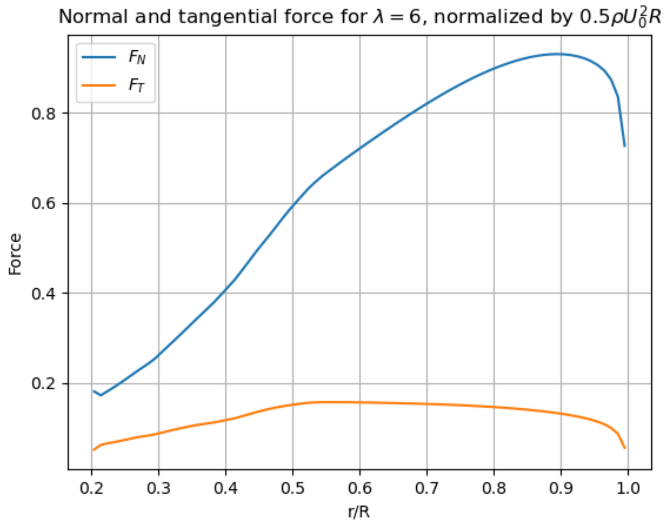


Figure 4.10: Caption

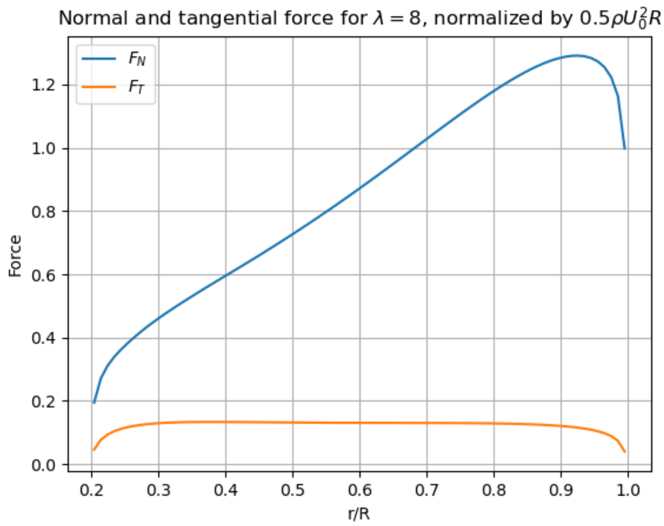


Figure 4.11: Caption

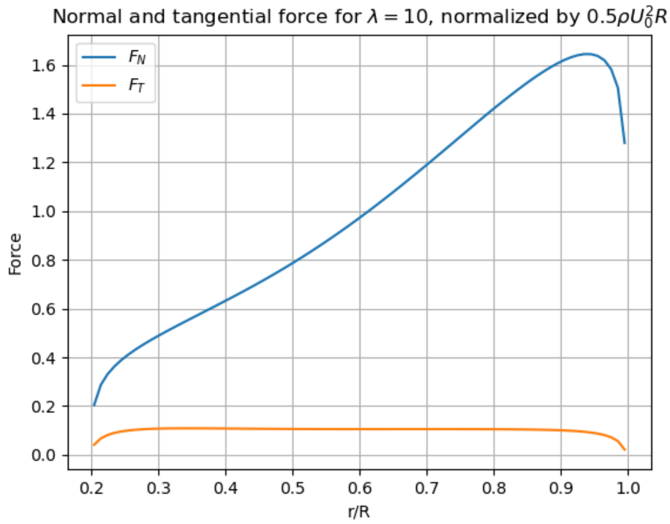
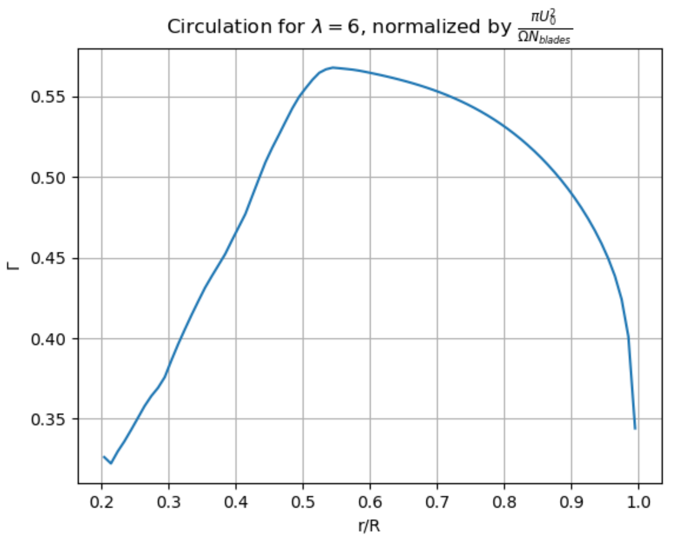


Figure 4.12: Caption

4.6 Circulation



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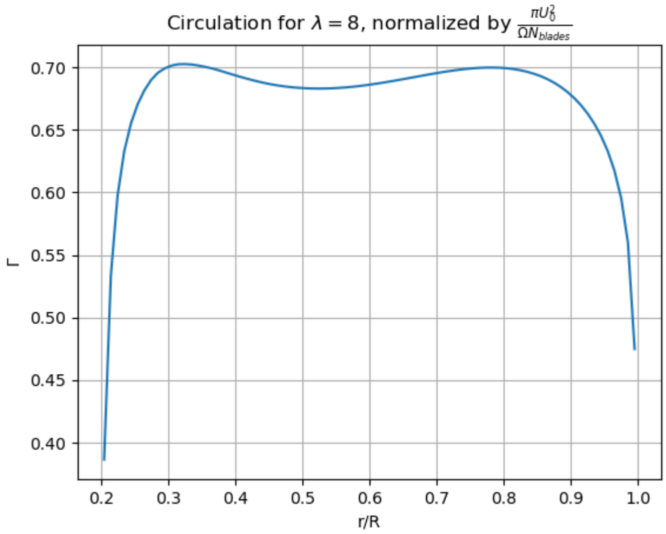


Figure 4.14: Caption

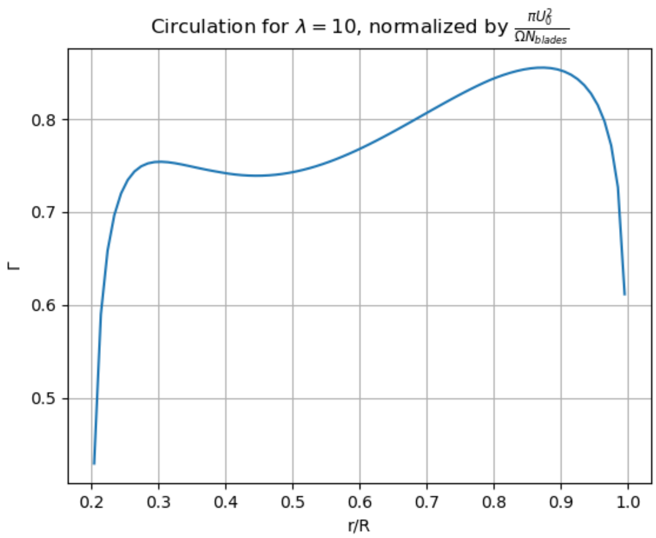
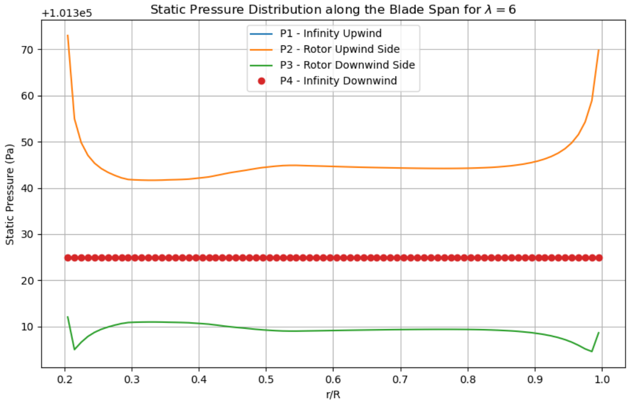


Figure 4.15: Caption

4.7 static pressure



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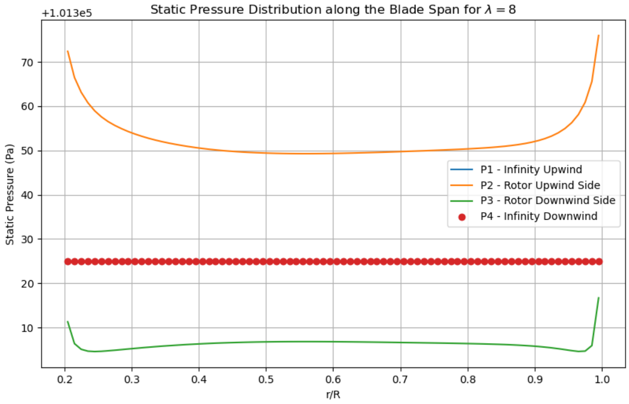


Figure 4.17: Caption

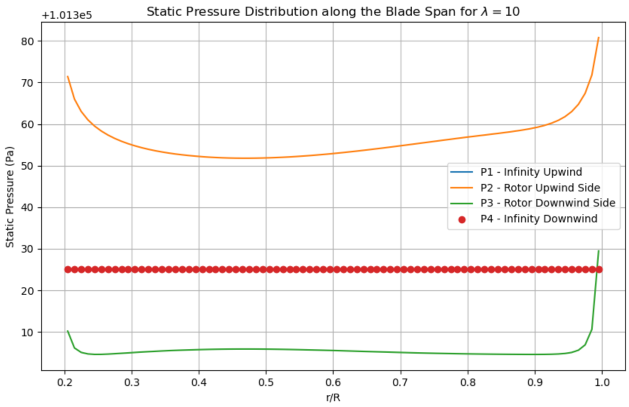
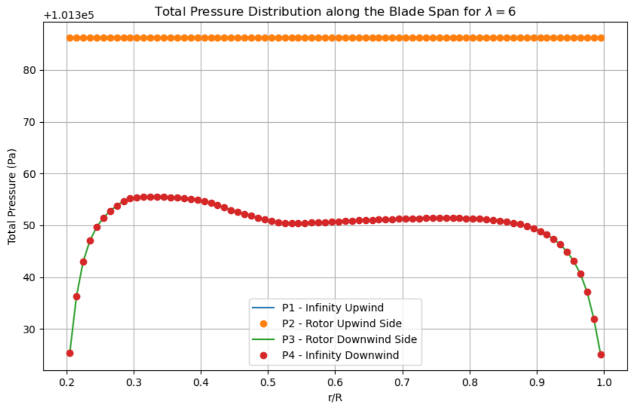


Figure 4.18: Caption

4.8 Total pressure



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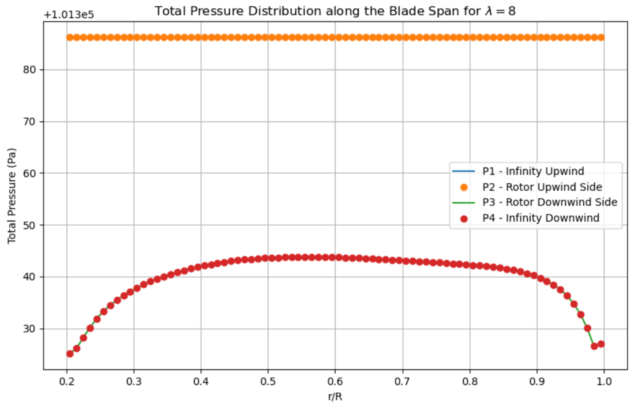

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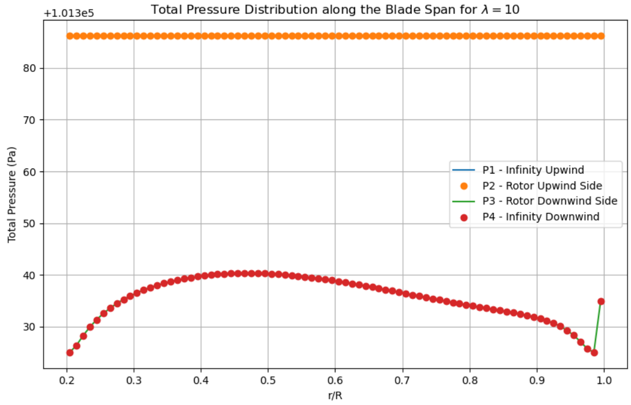


Figure 4.21: Caption

4.9 Thrust and torque vs TSR

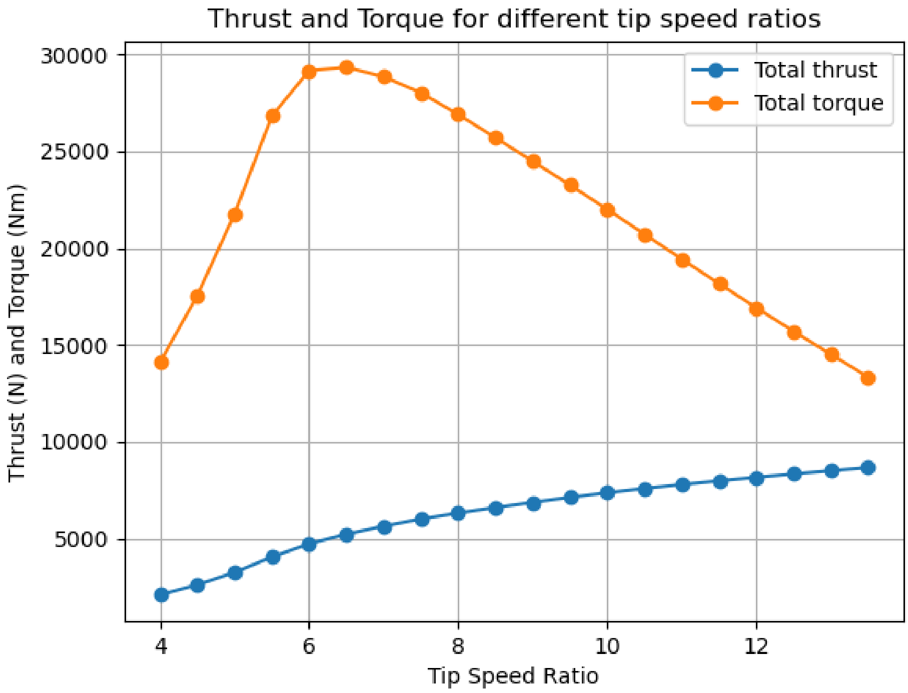
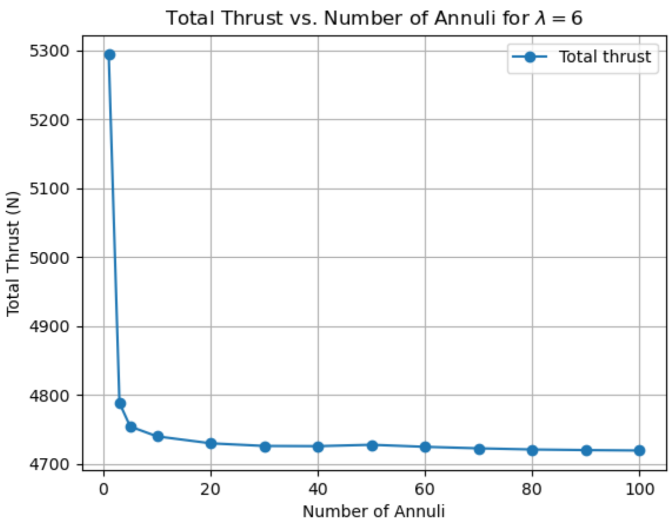


Figure 4.22: Caption

4.10 Thrust vs number of annuli



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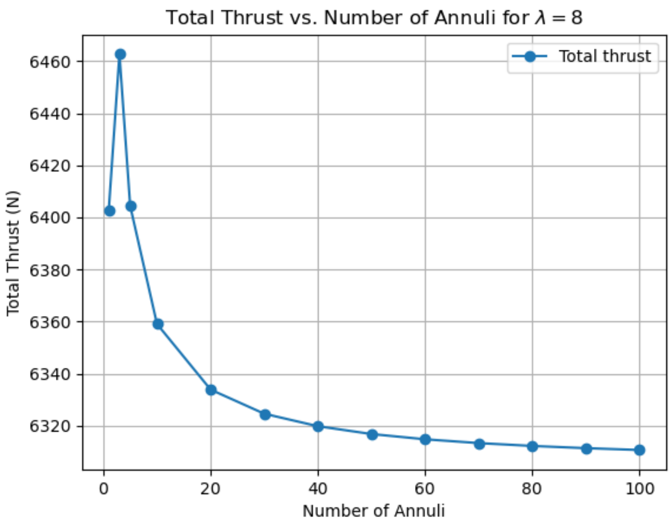

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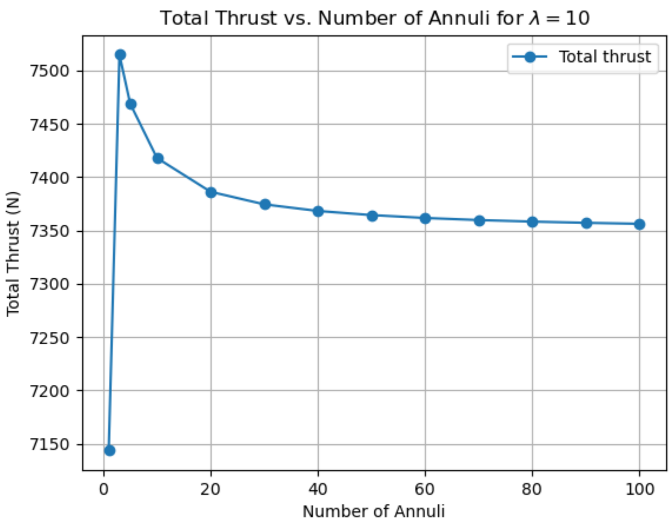
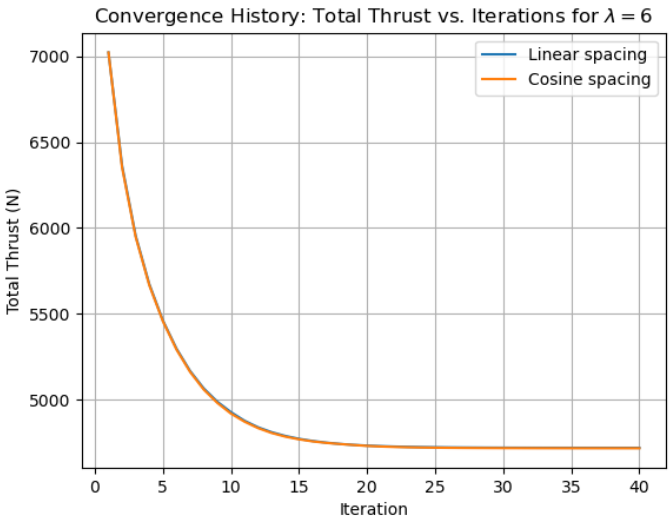


Figure 4.25: Caption

4.11 Effect of spacing method on convergence



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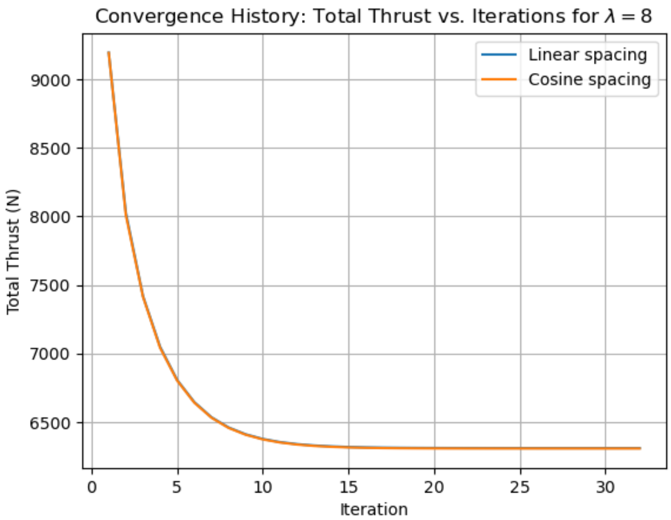

Figure 4.27: Caption

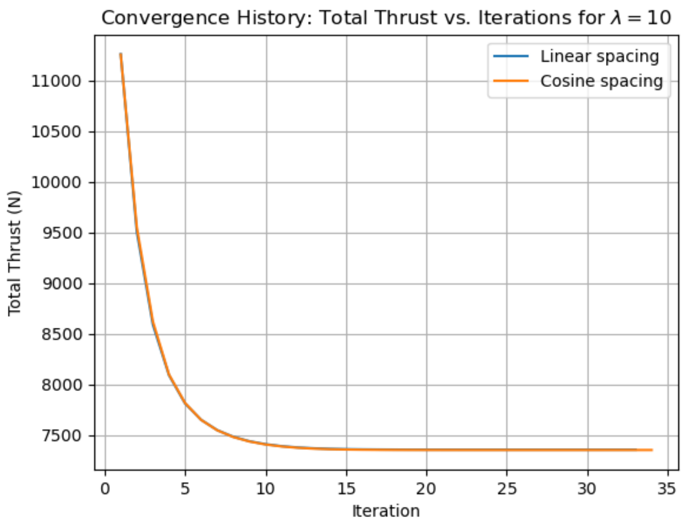

Figure 4.28: Caption

5 Conclusion

6 Python Script