Measurement of the rotor wake using PIV on a scaled turbine rotor in a water flume

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Motivation to this study is the incomprehensible wake!

An alternative presentation of the wake: near wake – far wake – turbulent wake
The next motivation is to study of the wake behind Glauert rotor.

Wake behind Joukowsky rotor - I

Wake behind Betz rotor - II

What is a wake behind Glauert rotor?
Flume

- $V_0 = 0.38$ and $0.5$
The current study is turbine by Glauert opt. for $\lambda=5$

- $D=0.35\text{m}$
- SD7003 aerofoil
- $Re = 20\,000$
- $V_0 = 0.38$ and 0.5
Measurement of the power and trust
Measurement of the blade circulation

Flow direction

Mirror
Rotor
Laser sheet

0,13 m
0.7m

Camera
Blade circulation

\[ \lambda = 3 \]

Circulation

\[ \Gamma = \oint \vec{u} \cdot d\vec{l} \]

\[ \frac{\Gamma}{2\pi U_\infty R} \]
Blade circulation \( \lambda = 5 \)

\[
\Gamma = \oint \vec{u} \cdot d\vec{l}
\]

\[
\frac{\Gamma}{2\pi U_\infty R}
\]
Blade circulation $\lambda = 7$

Circulation

$\Gamma = \int \vec{u} \cdot d\vec{l}$

$\frac{\Gamma}{2\pi U_\infty R}$

Danmarks Tekniske Universitet
Sketch of the setup with stereoscopic PIV
New motivation is to extend a domain of the PIV investigation

Sketch of 12 testing windows of the current experiment

Sketch of the windows in the “MEXICO” PIV-experiment

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Visualizations of WT’s wake TSR=6
Visualizations of WT's wake for different TSR

\( \lambda = 4 \)

\( \lambda = 5 \)

\( \lambda = 6 \)

\( \lambda = 7 \)

\( \lambda = 8 \)
Tip vortex structure, unfolded, 0, 15, 30, 45, 60, 75, 90, 105 deg

λ = 4

λ = 5

λ = 6

λ = 7
Axial velocity, TSR=6, 100 images

Vorticity

U ax.
Instantaneous location of vortex center
0, 15, 30, 45, 60, 75, 90, 105 deg

\[ \lambda = 6 \]

\[ \lambda = 5 \]

\[ \lambda = 4 \]

\[ \lambda = 7 \]
Tip vortex and vectors, TSR=6
Tip vortex – vorticity, phase averaged, TSR=3-7

\(\lambda = 3\)

\(\lambda = 4\)

\(\lambda = 5\)

\(\lambda = 6\)

\(\lambda = 7\)
Axial velocity, phase averaged, TSR = 3-5
Mean Axial Velocity U, TSR 4-7

4

5

6

7
Axial velocity, $U_{rms}$

$\lambda = 3$

$\lambda = 4$

$\lambda = 5$

$\lambda = 6$

$\lambda = 7$
Tangentiel Vel, W-mean TSR 4-7
LDA prediction of wake frequencies
LDA prediction of wake frequencies
Summary

Experimental investigation of the rotor by Glauert Opt. of TSR = 5 was made at TSR 3-8:

- Power and trust coefficients
- Circulation along blade
- Visualization captures dynamics of helical structures
- PIV-mapping of the flow in the wake
- LDA measurements - frequencies

Conclusions

- The wake pitch keeps a constant in axial direction
- The wake expansion coincide with the prediction of the actuator disk theory
- The far wake with double of the axial factor may be indicated before the wake breakdown
- Characteristic frequencies in the wake: blade, rotor and Strouhal
- The wake breakdown with a reduction of the axial factor displays under small Re = 20000 too