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 $\lambda=5$

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

Flow direction

Mirror
Rotor

Laser sheet

Camera

0.7m

0.13 m

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Blade circulation \( \lambda = 3 \)

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

\[ \frac{\Gamma}{2\pi U_\infty R} \]

Circulation

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Blade circulation \( \lambda = 5 \)

Circulation

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

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

Circulation

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

\[ \frac{\Gamma}{2\pi U_\infty R} \]
Sketch of the setup with stereoscopic PIV

(a) Sketch of the setup with stereoscopic PIV

(b) Camera 1

Camera 2

Rotor

Laser sheet

Mirror

45°

1.5 m

1.5 m

Z

Y

X

45°

Laser

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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
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

$\lambda = 4$

$\lambda = 5$

$\lambda = 6$

$\lambda = 7$
Axial velocity, TSR=6, 100 images

\[ \lambda = 5 \]

\[ U_{\text{ax}} \]

Vorticity

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

\( \lambda = 4 \)
\( \lambda = 5 \)
\( \lambda = 6 \)
\( \lambda = 7 \)
Tip vortex and vectors, TSR=6
Axial velocity, phase averaged, TSR = 3-5

\[ \lambda = 3 \]

\[ \lambda = 4 \]

\[ \lambda = 5 \]

\[ \lambda = 6 \]

\[ \lambda = 7 \]
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