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

Mikkelsen, Robert Flemming; Okulov, Valery; Meyer, Knud Erik; Naumov, Igor; Karbardin, I.; Sørensen, Jens Nørkær

Publication date:
2013

Citation (APA):
Measurement of the rotor wake using PIV on a scaled turbine rotor in a water flume

R. Mikkelsen, V.L Okulov, K.E. Meyer I. Naumov, I. Kabardin, J.N. Sørensen

Department Wind Energy, Technical University of Denmark, 2800 Lyngby, Denmark

Institute of Thermophysics, SB RAS, Lavrentyev Ave. 1, Novosibirsk 630090, Russia
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?

![Diagram of Glauert rotor](image)

![Graphs comparison of Glauert, Joukowsky, and Betz rotors](image)
Flume

- $V_0 = 0.38$ and $0.5$
ROTOR

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
Blade circulation $\lambda = 3$

Circulation

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

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

$r/R$
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
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

λ=4

λ=5

λ=6

λ=7

λ=8
Tip vortex structure, unfolded, 0,15,30,45,60,75,90,105 deg

\( \lambda = 6 \)  

\( \lambda = 4 \)  

\( \lambda = 5 \)  

\( \lambda = 6 \)  

\( \lambda = 7 \)  

Danmarks Tekniske Universitet
Axial velocity, TSR=6, 100 images

\[ \lambda = 5 \]

U ax.

Vorticity
Instantaneous location of vortex center
0, 15, 30, 45, 60, 75, 90, 105 deg

$\lambda = 6$

$\lambda = 5$

$\lambda = 4$

$\lambda = 7$

Danmarks Tekniske Universitet
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

\[ \lambda = 3 \]
\[ \lambda = 4 \]
\[ \lambda = 5 \]
\[ \lambda = 6 \]
\[ \lambda = 7 \]
Mean Axial Velocity $U$, TSR 4-7

Graphs showing the variation of $U/R_0$ with $r/R$ for different values of $x/R$. The graphs depict the axial velocity normalized by the radius $R_0$ as a function of the radial position $r/R$ for various axial positions $x/R$. Different lines represent different axial positions $x/R$: $0.05$, $0.5$, $1.0$, and $2.0$. The graphs illustrate the behavior of the axial velocity profile across the radial distance.
Axial velocity, $U_{\text{rms}}$
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