

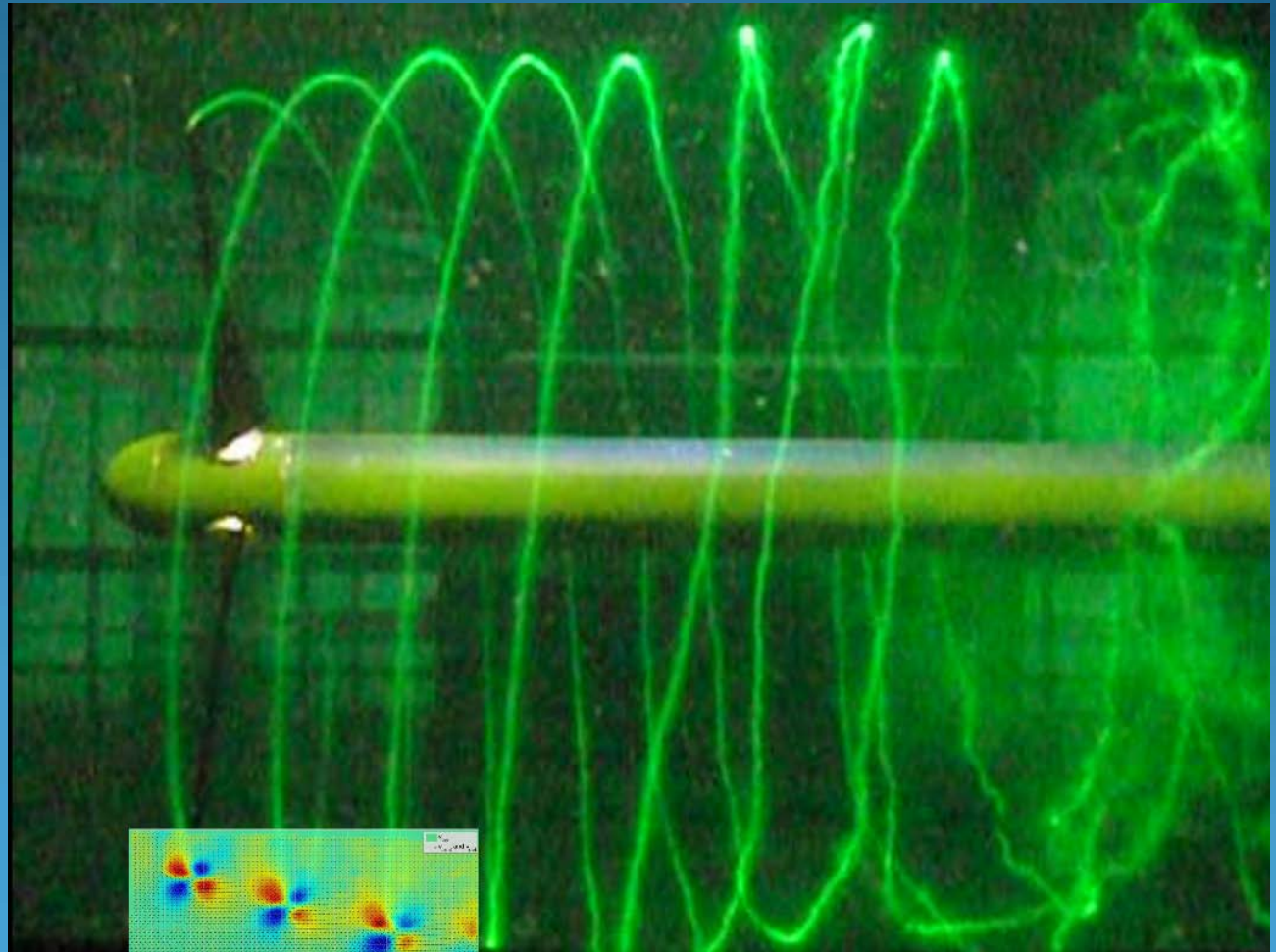
PIV measurements on a wind turbine in a water flume

by

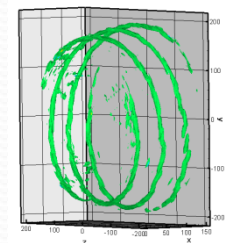
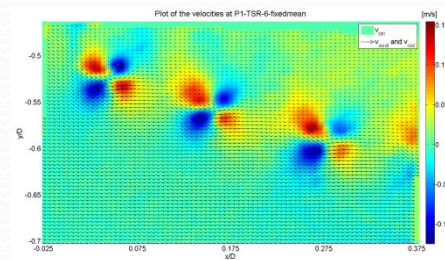
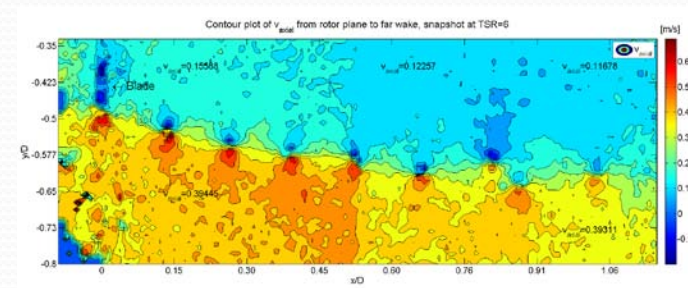
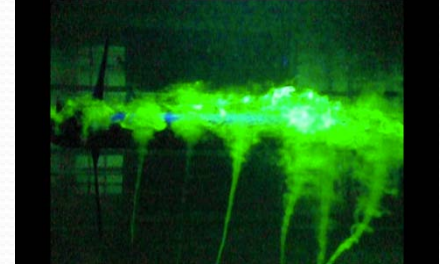
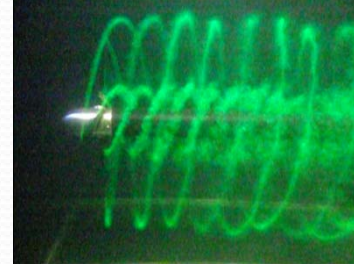
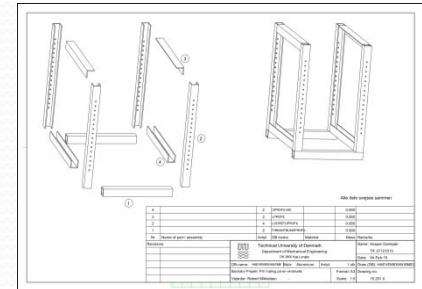
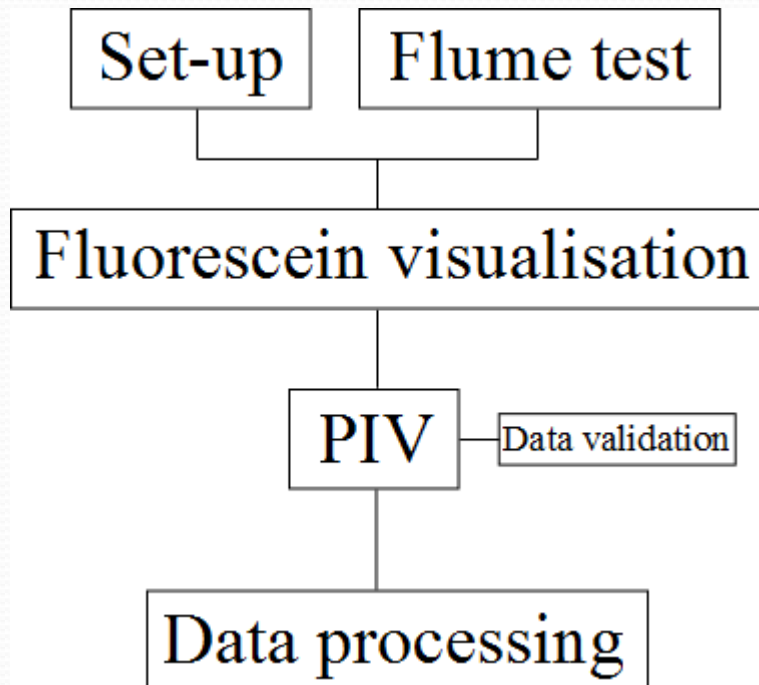
Robert Mikkelsen, Svend Petersen, Kasper Damkjær

Content

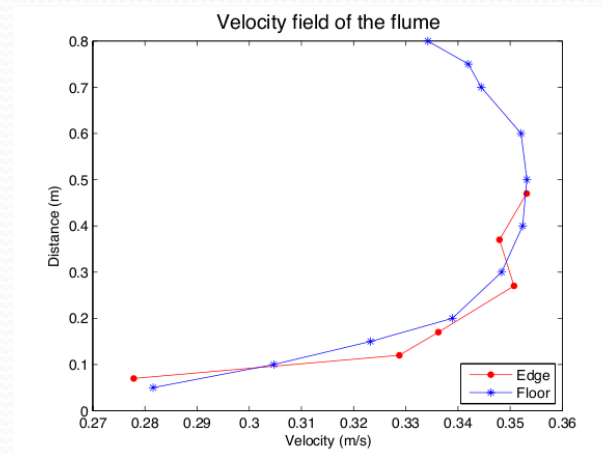
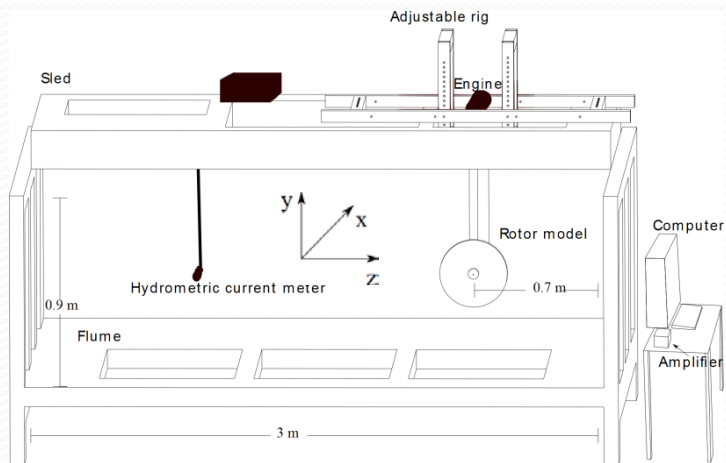
- The project
- Setup in flume
- Some results
- Summary



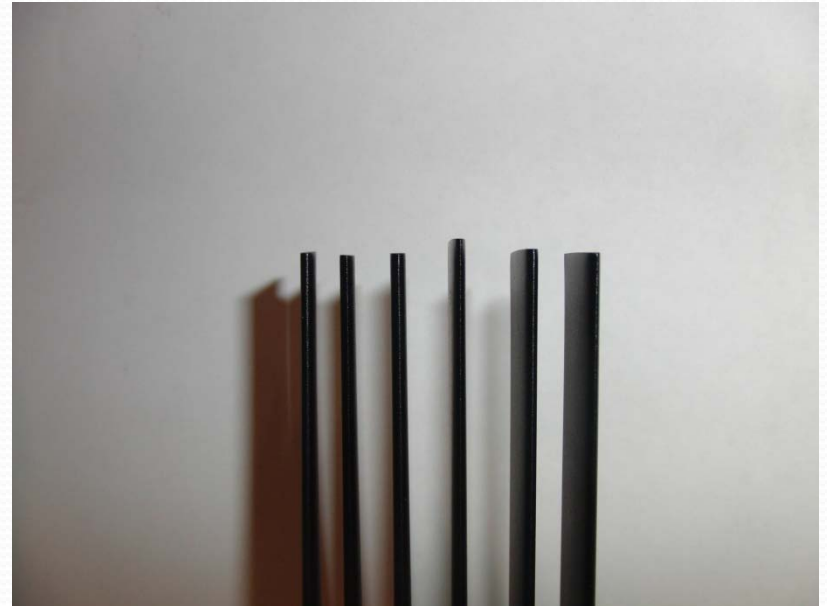
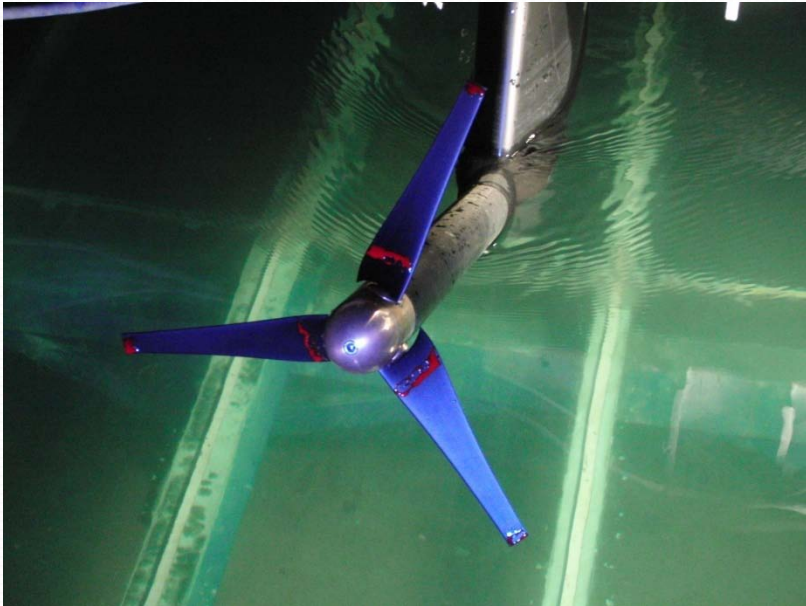
Outline of project



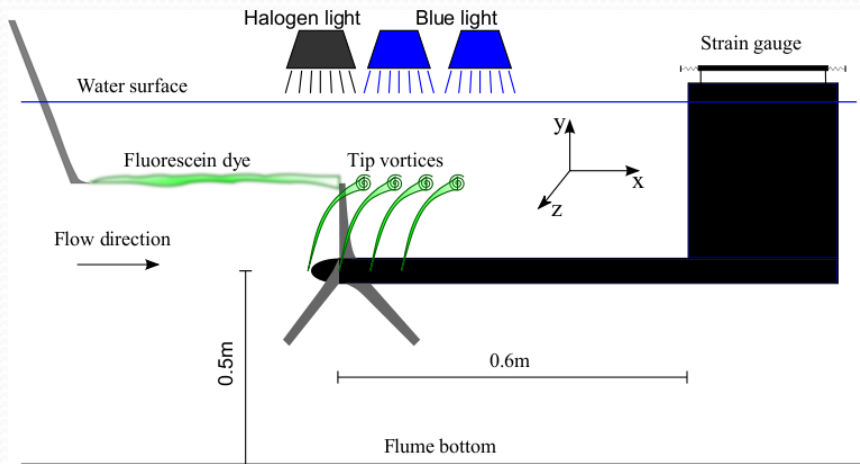
Flume



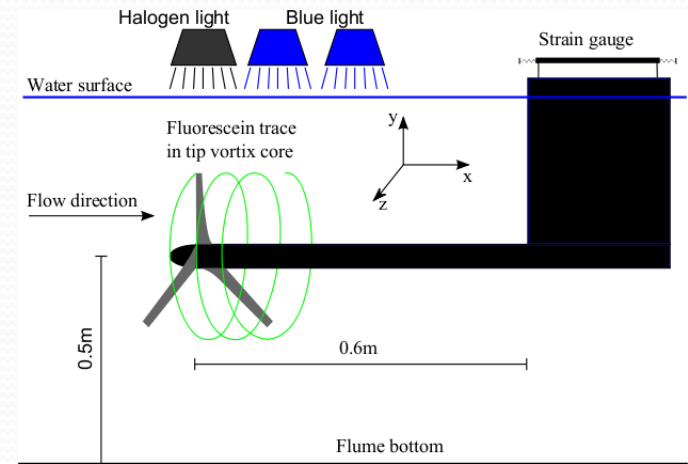
The turbine – Glauert opt. $\lambda=5$



Fluorescein set-up

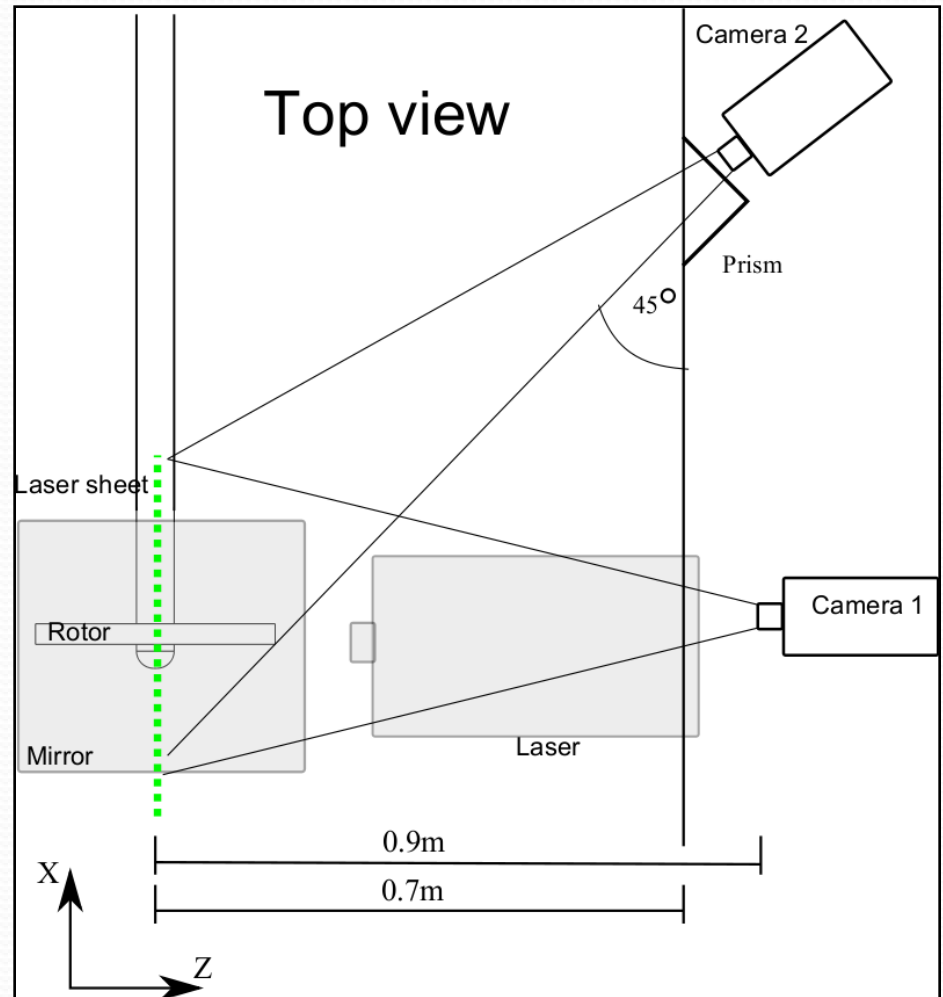
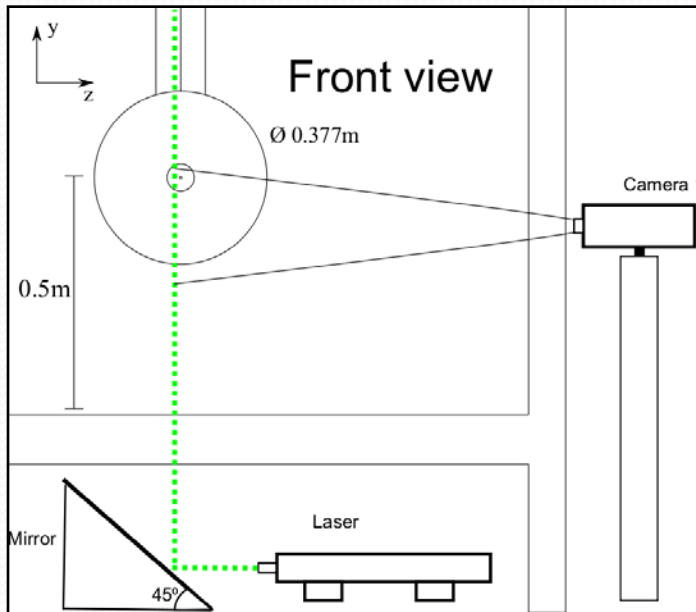


Upstream injection

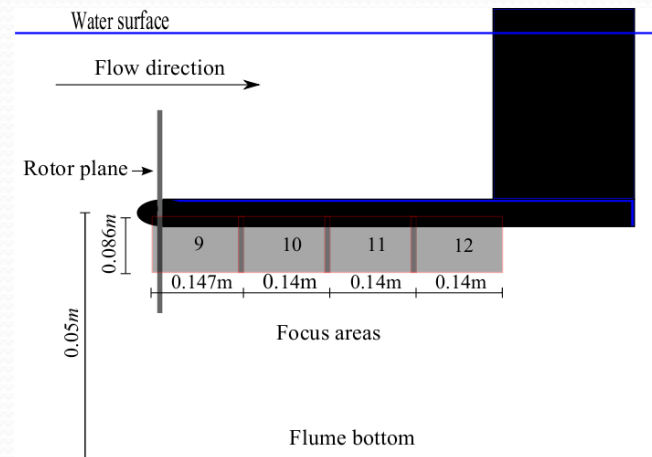
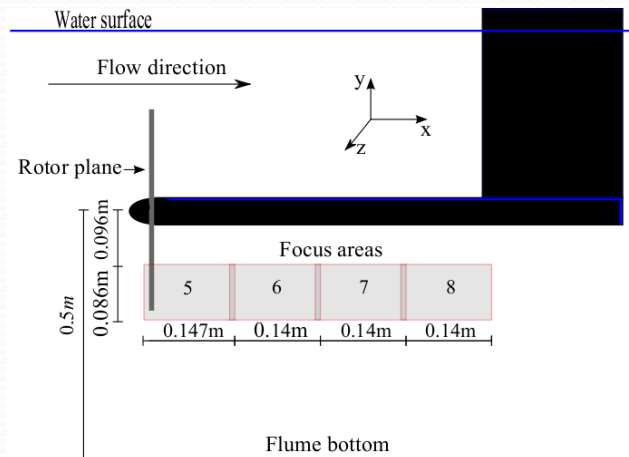
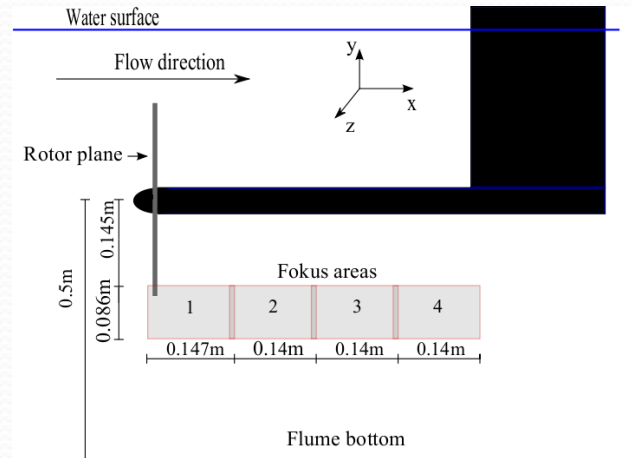
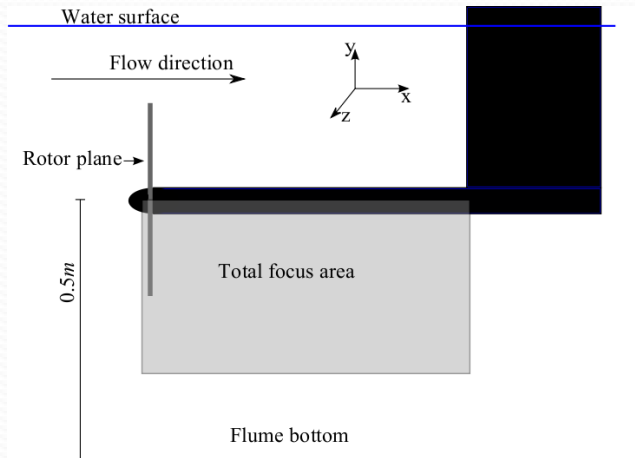


Applied on tip

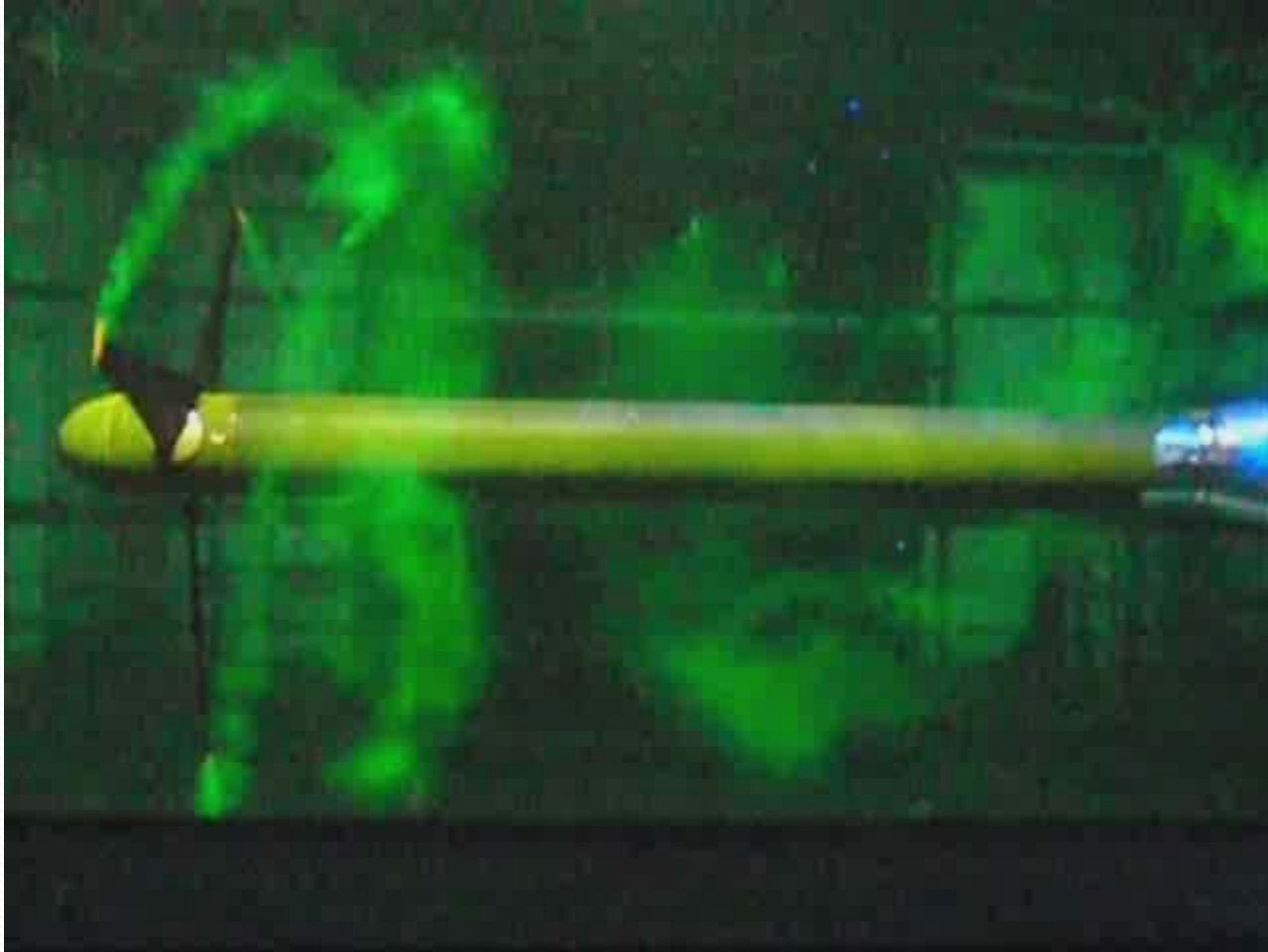
PIV set-up



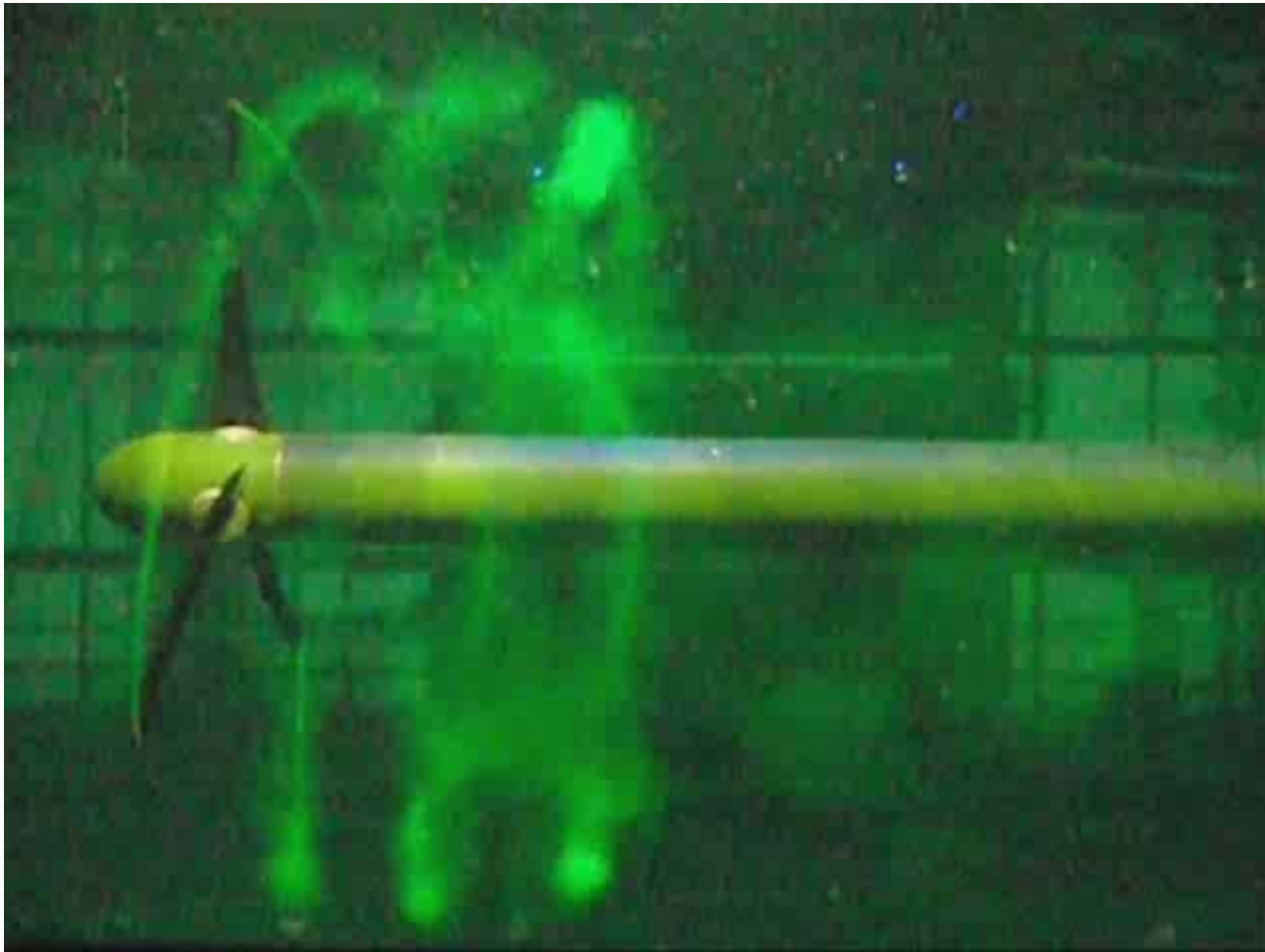
Focus areas



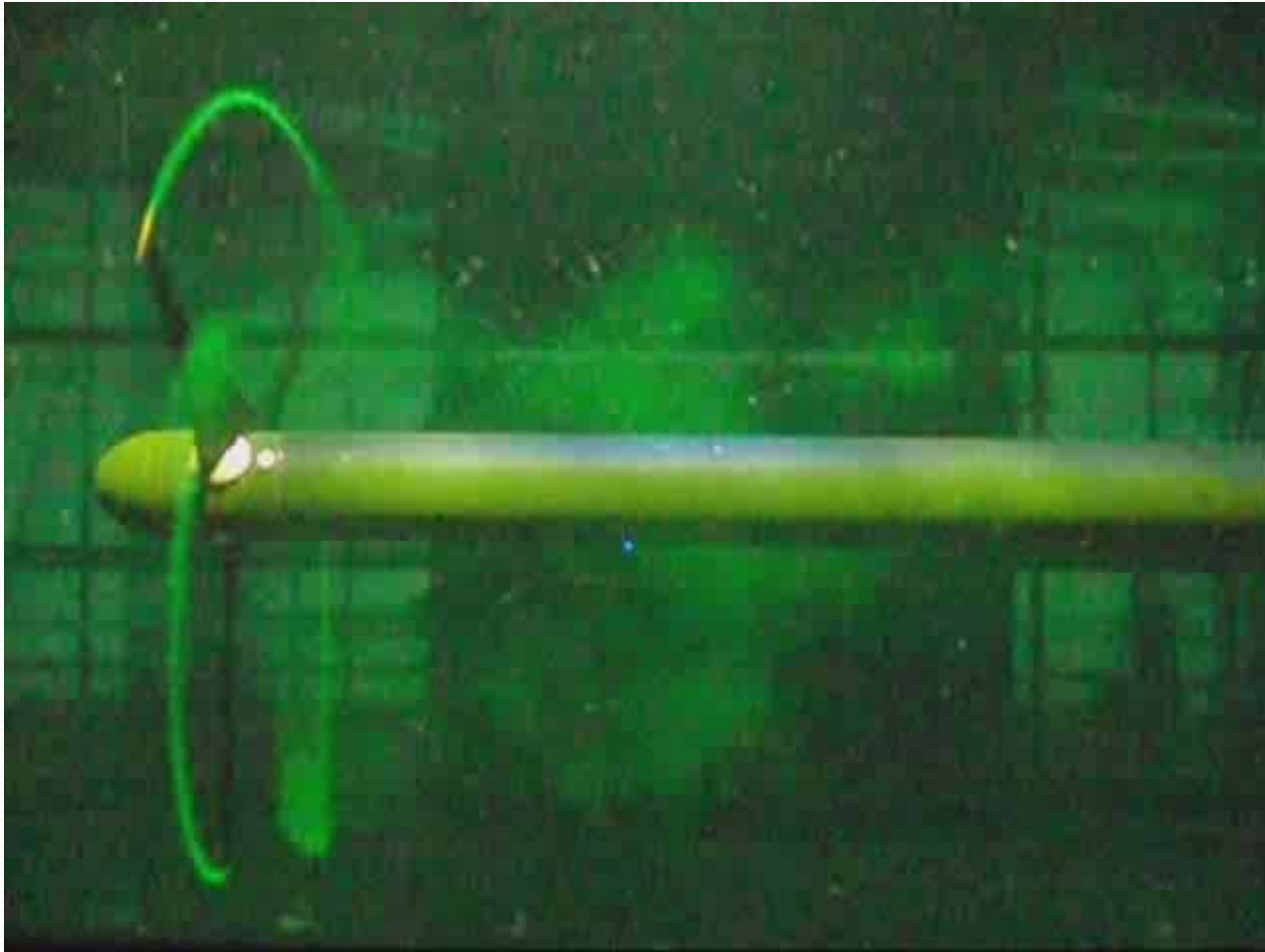
Fluorescein tip injection-TSR 4



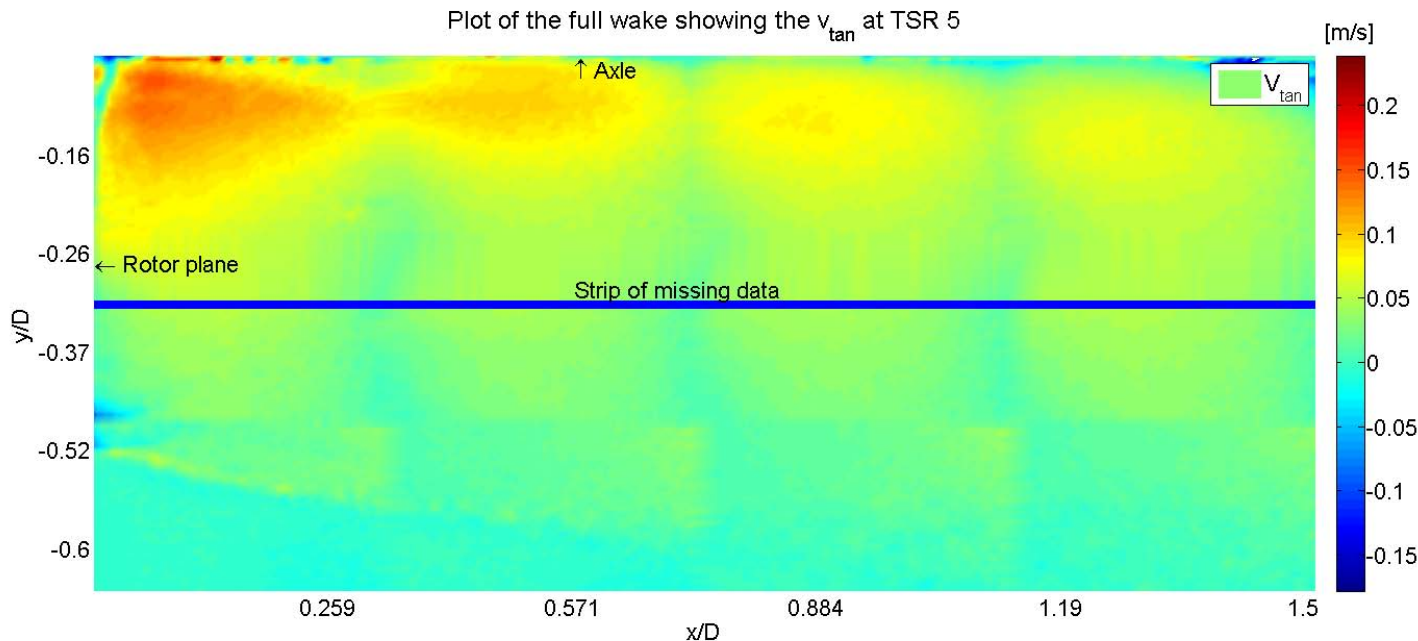
Fluorescein tip injection-TSR 5



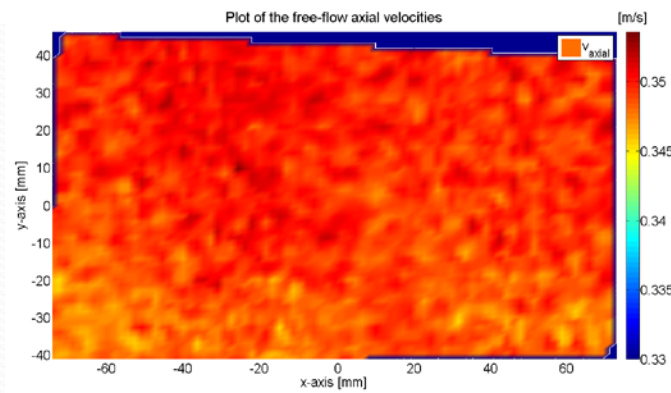
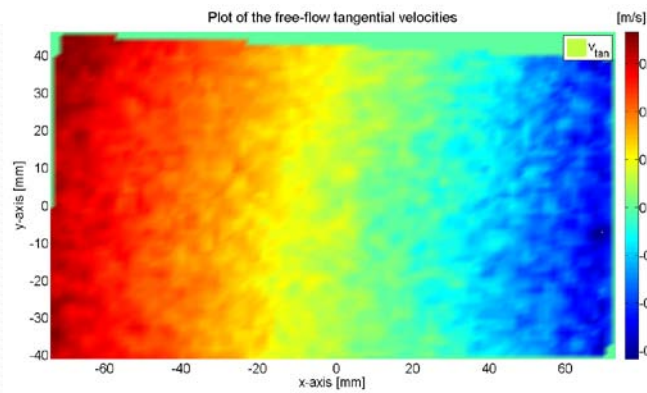
Fluorescein tip injection-TSR 7



Full wake-tangential velocity

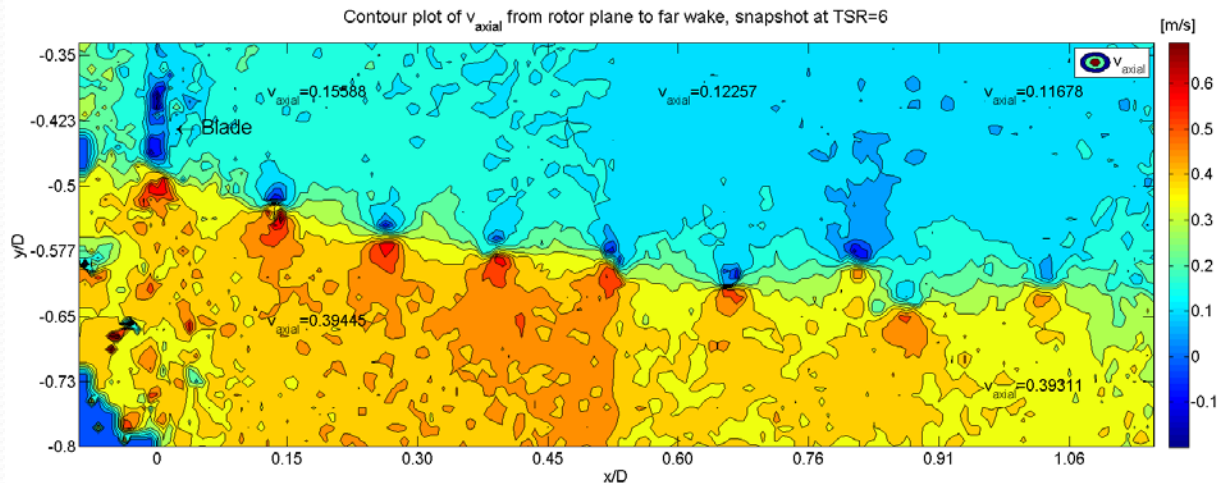
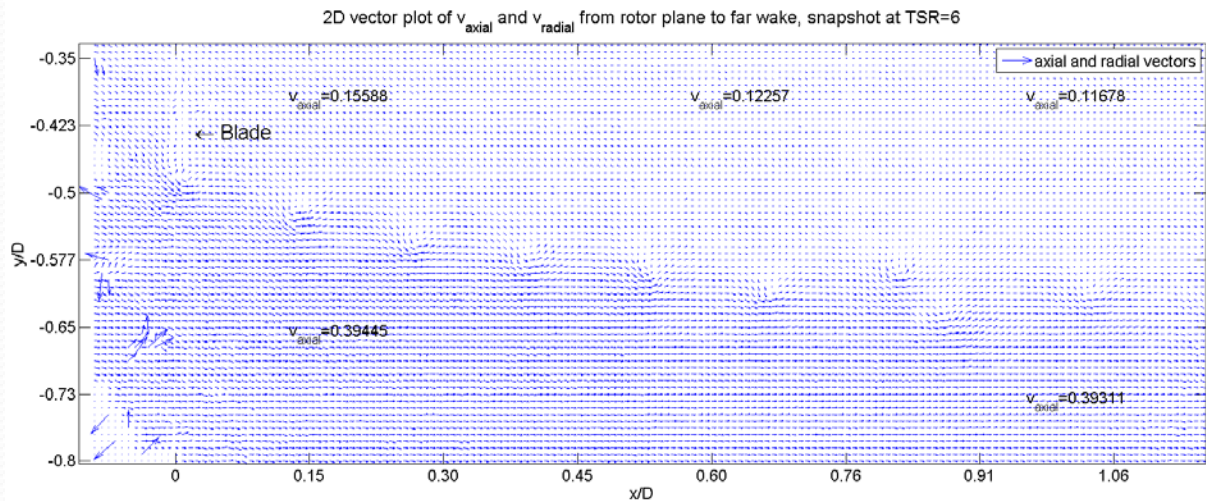


- Distortion
- Missing data
- Mean from 500 pic.



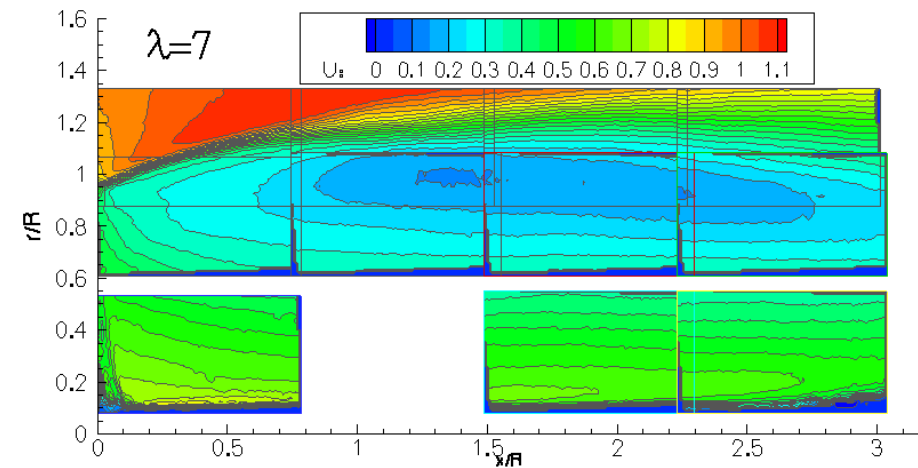
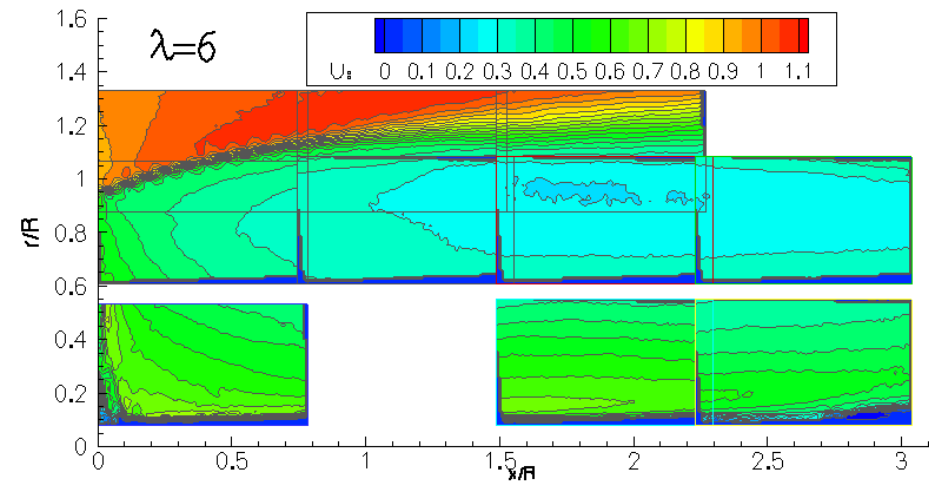
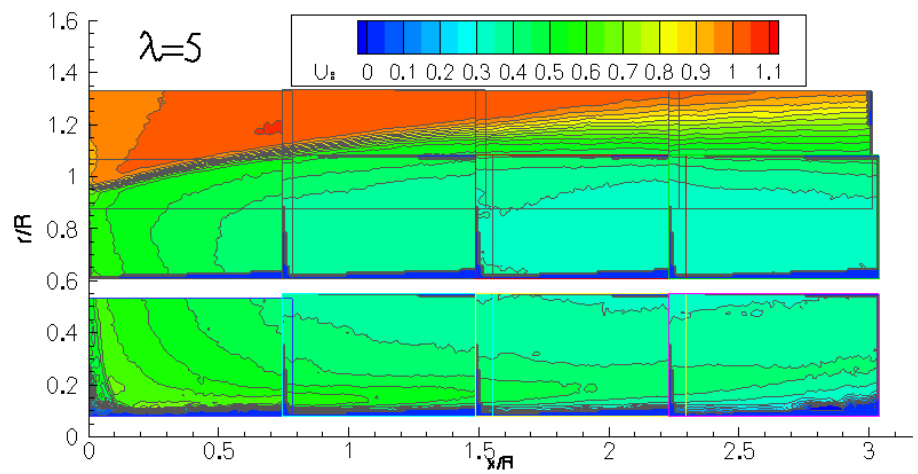
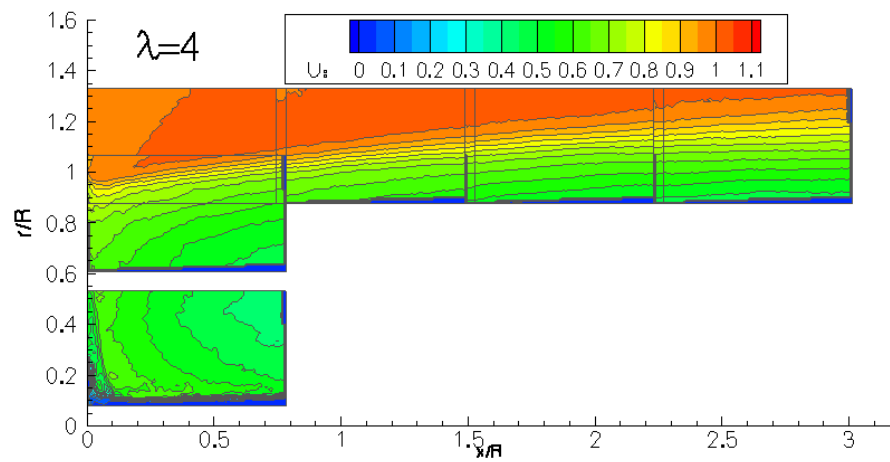
- Distortion in tangential direction
- No distortion in axial direction

2D PIV

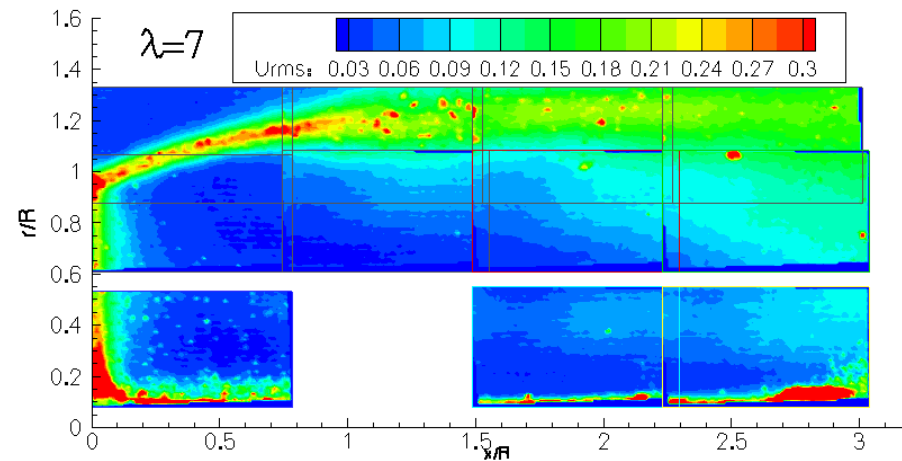
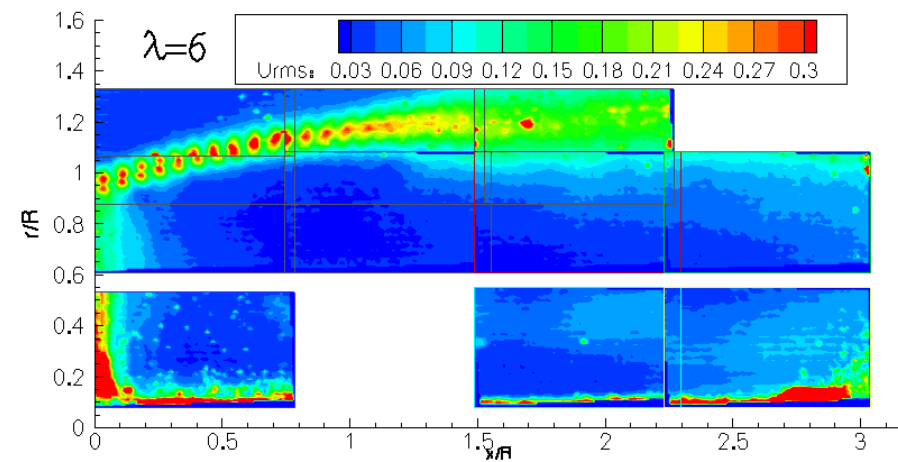
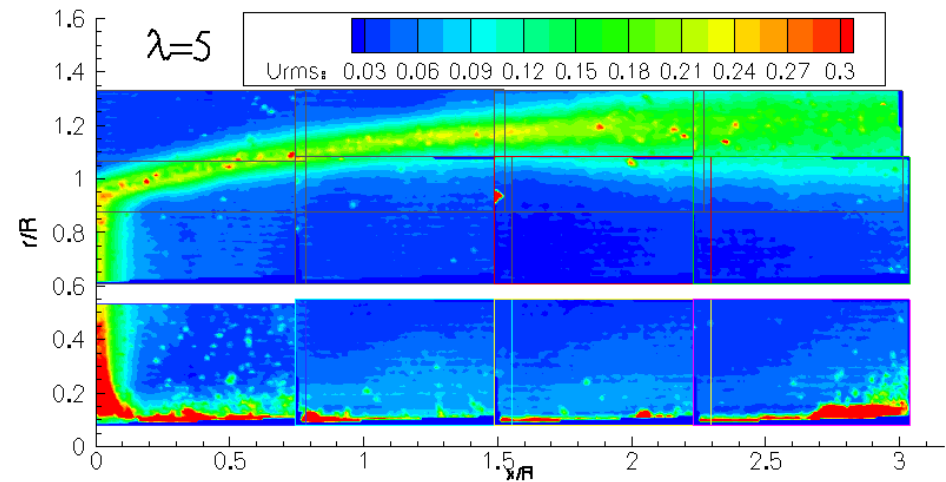
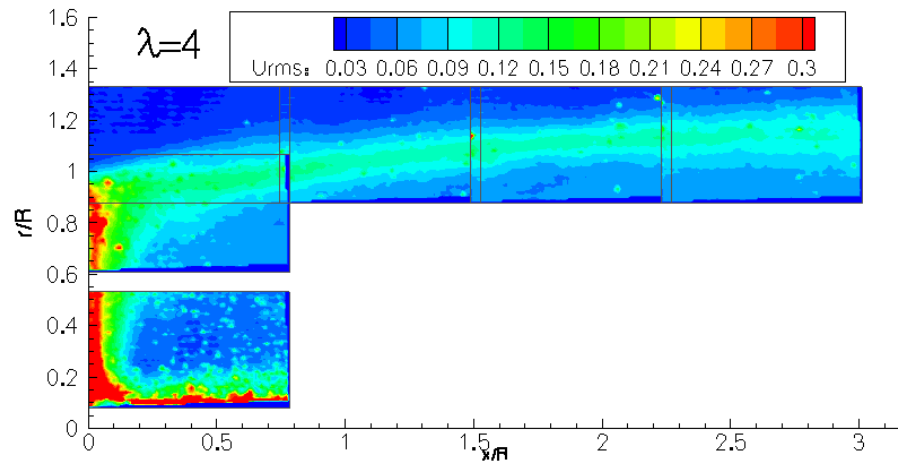


- Clear tip vortices
- Vortex pairing
- Expansion
- Wake and free flow velocity differences
- Decreasing wake velocity

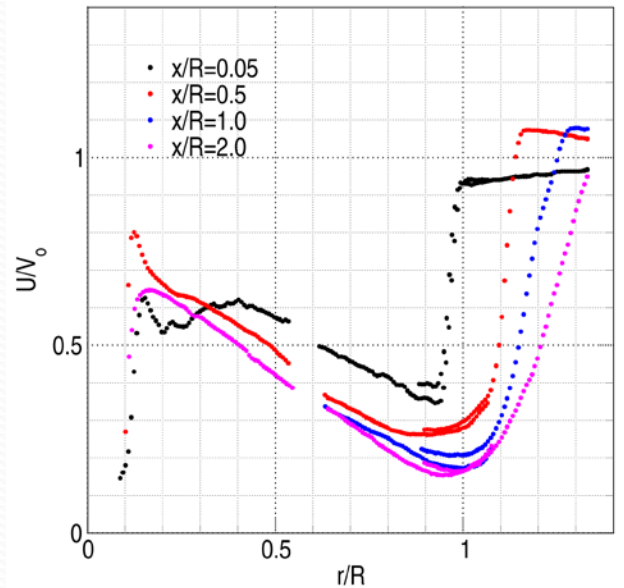
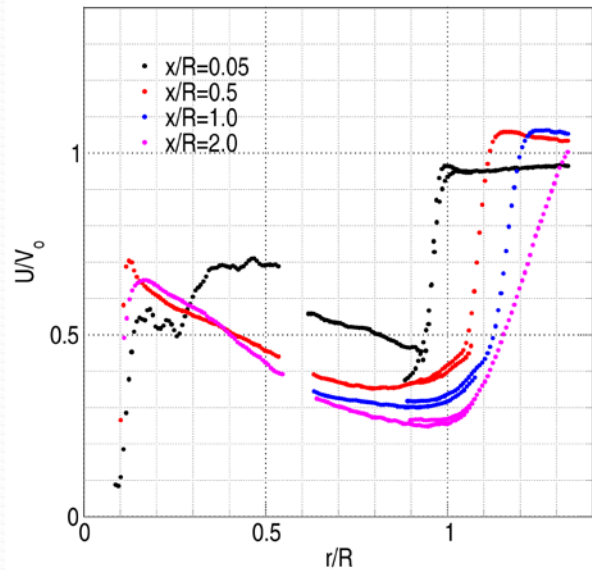
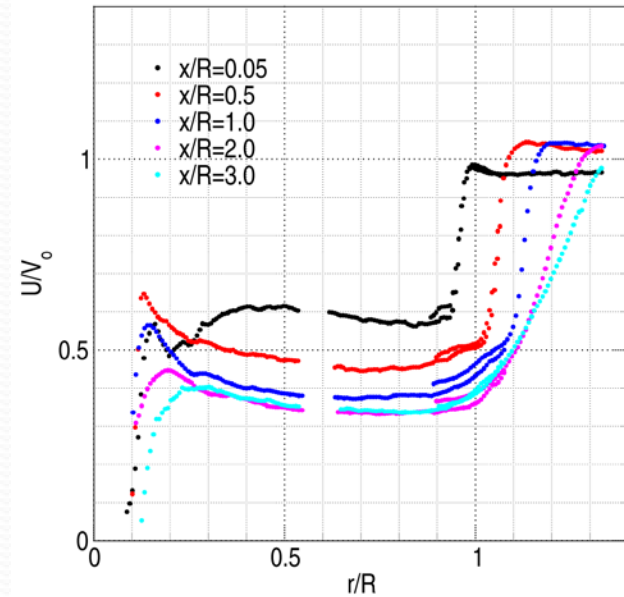
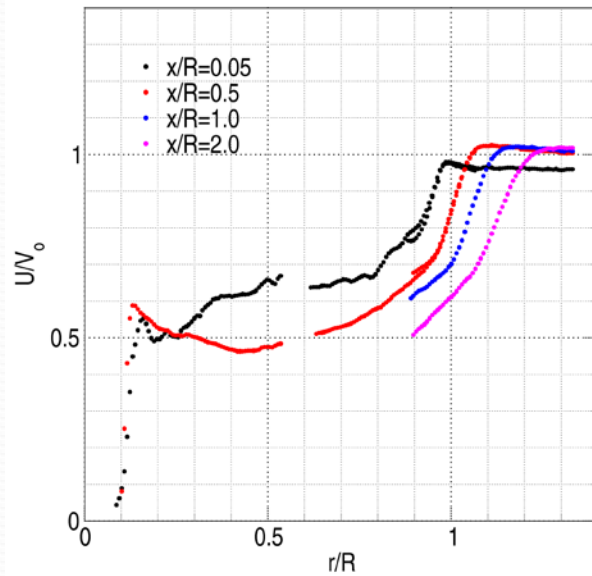
PIV, Axial Velocity U TSR 4-7



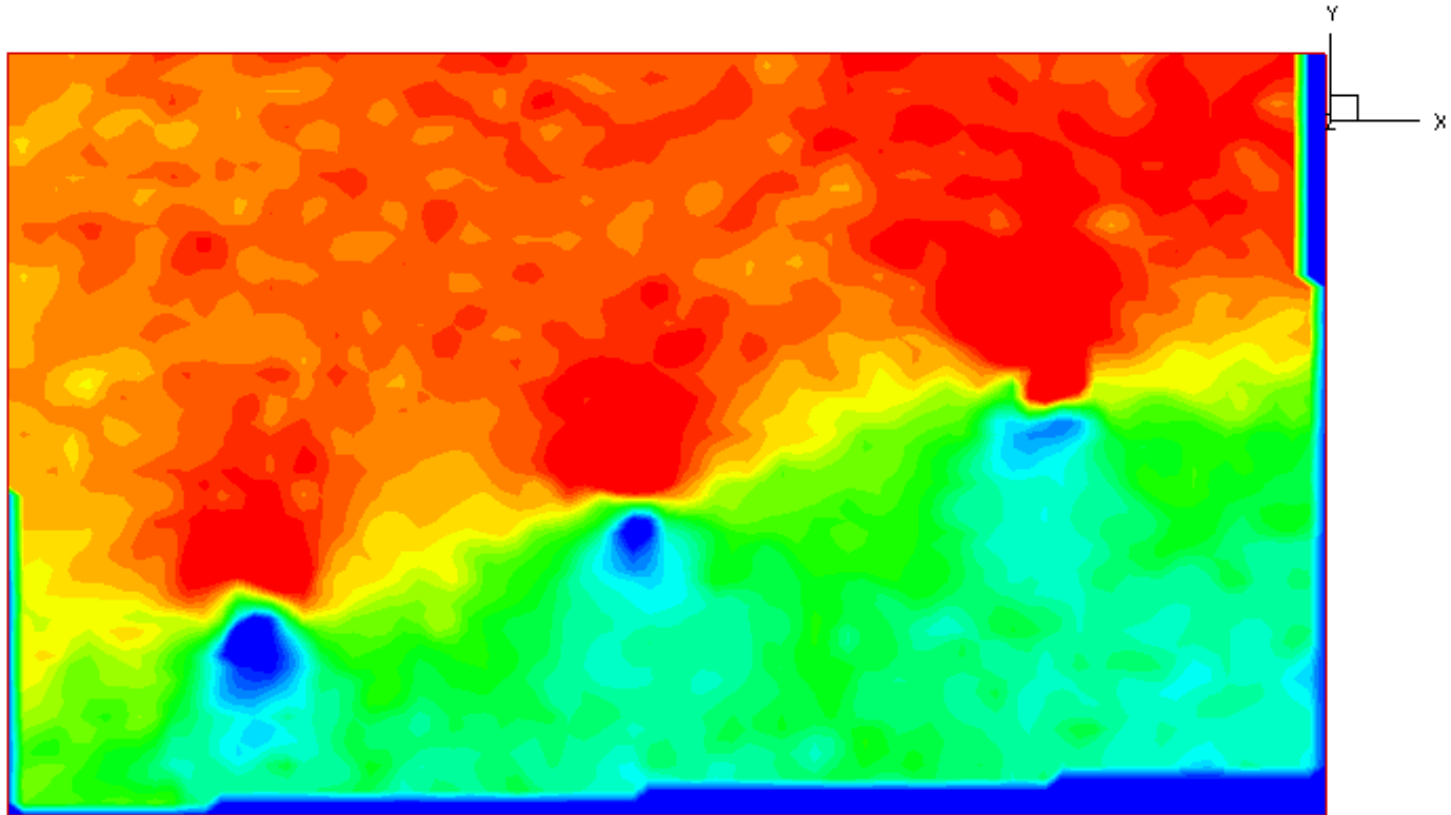
PIV, Axial Velocity Urms TSR 4-7



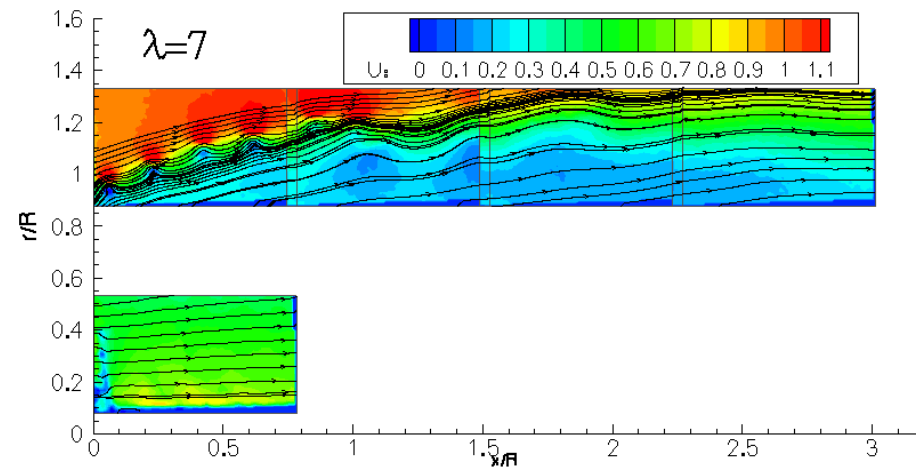
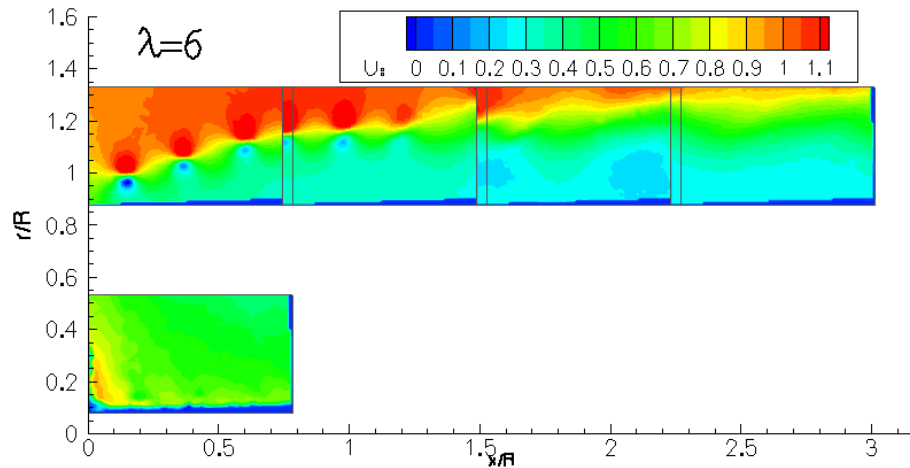
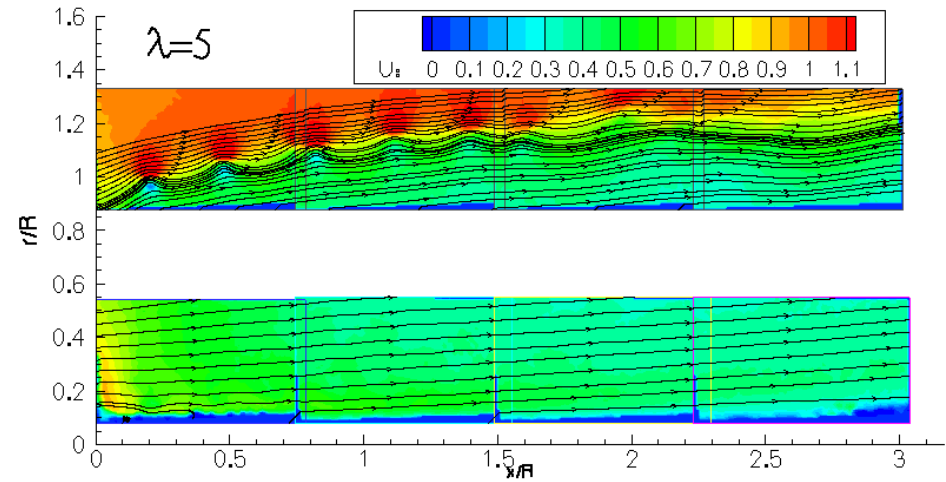
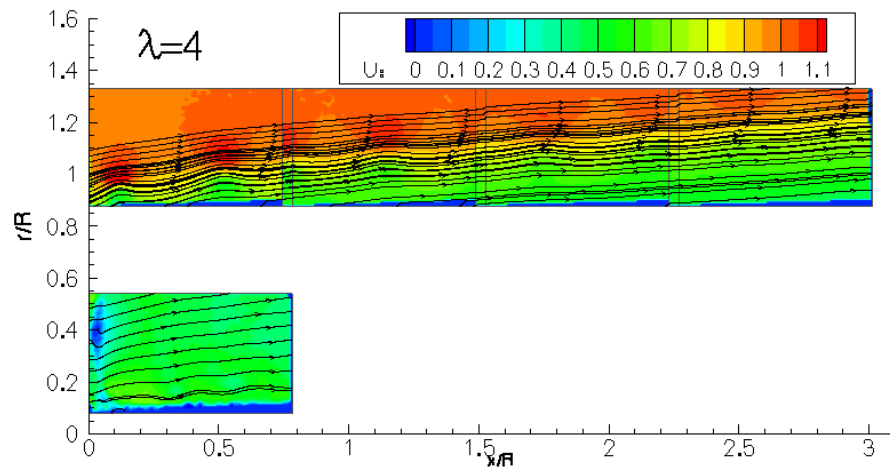
PIV, Axial Velocity U-mean TSR 4-7



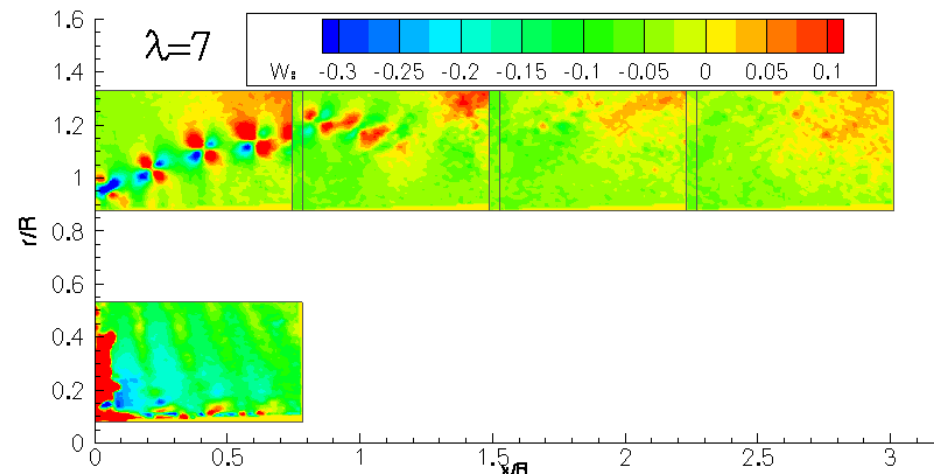
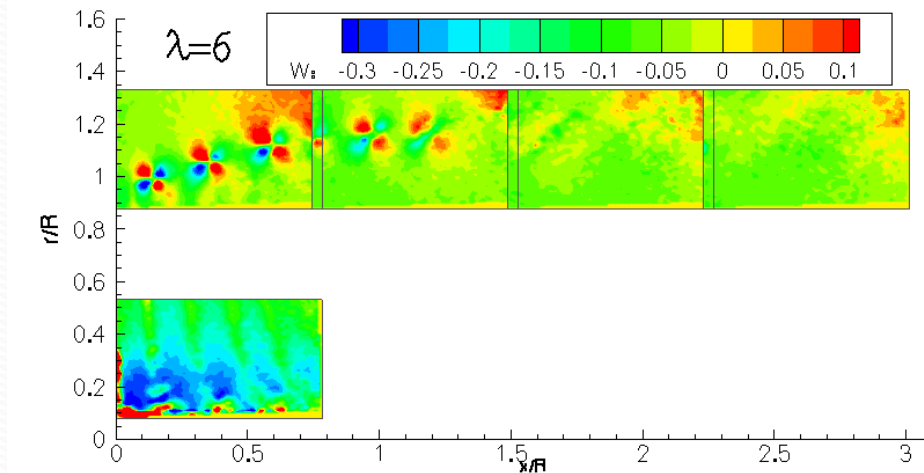
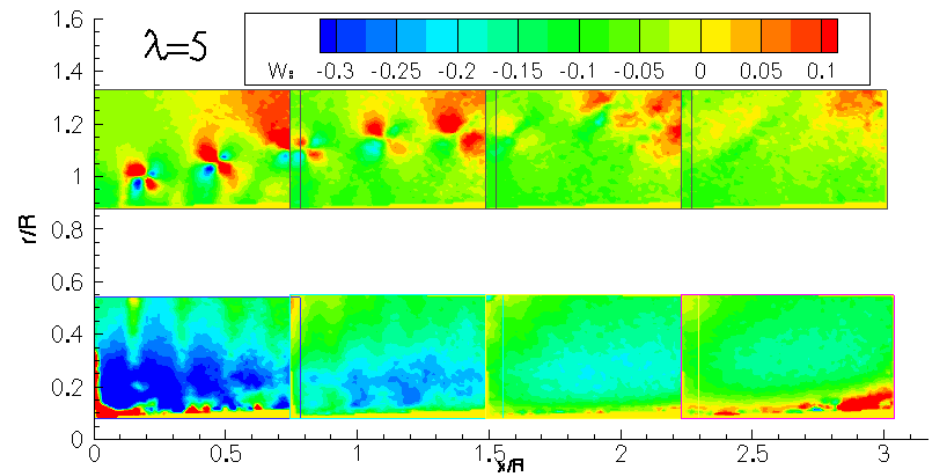
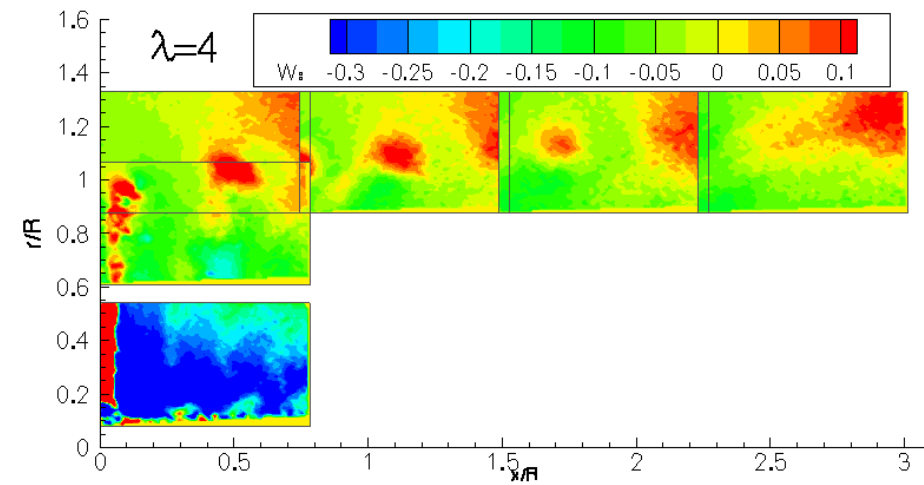
PIV, fixed mean, U-vel, TSR 6



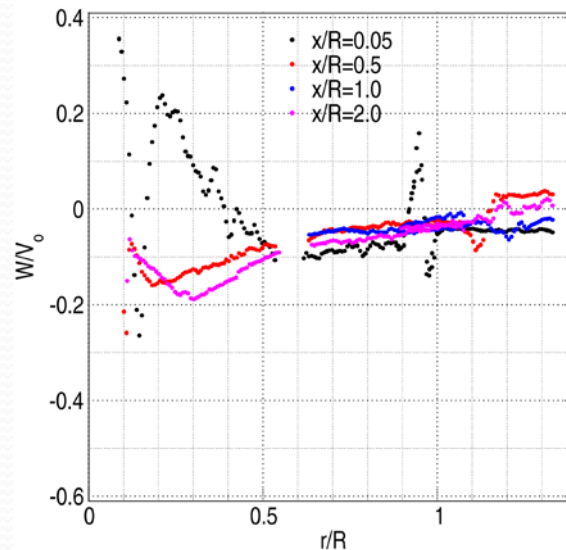
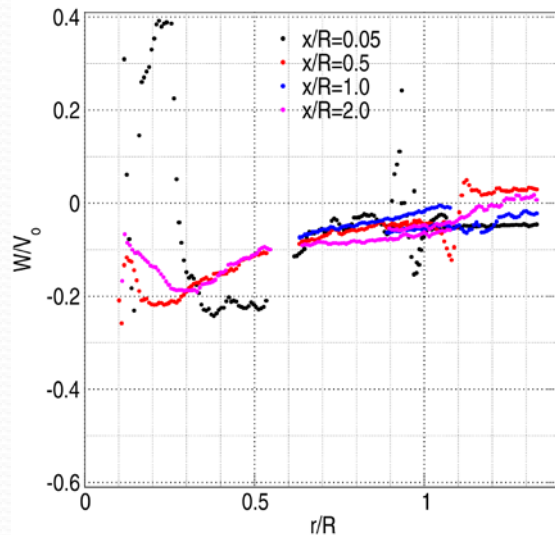
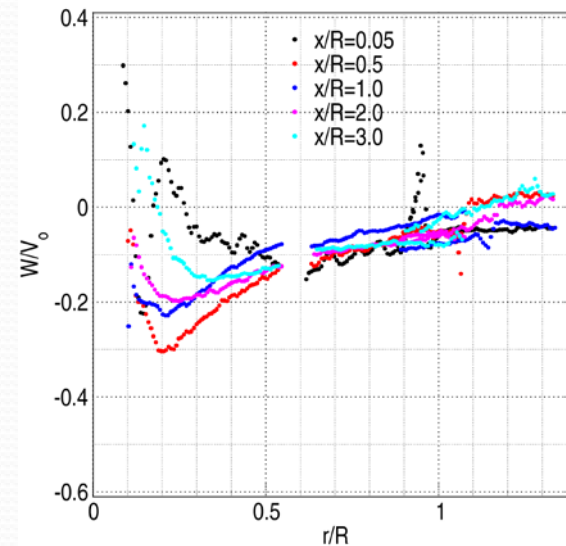
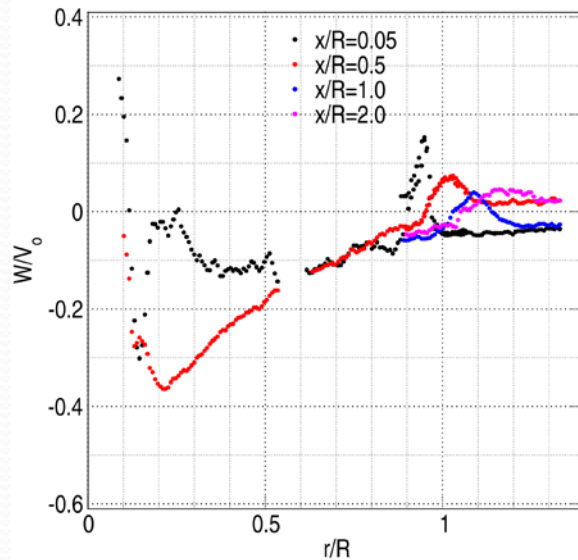
PIV, fixed mean, U-vel, TSR 4-7



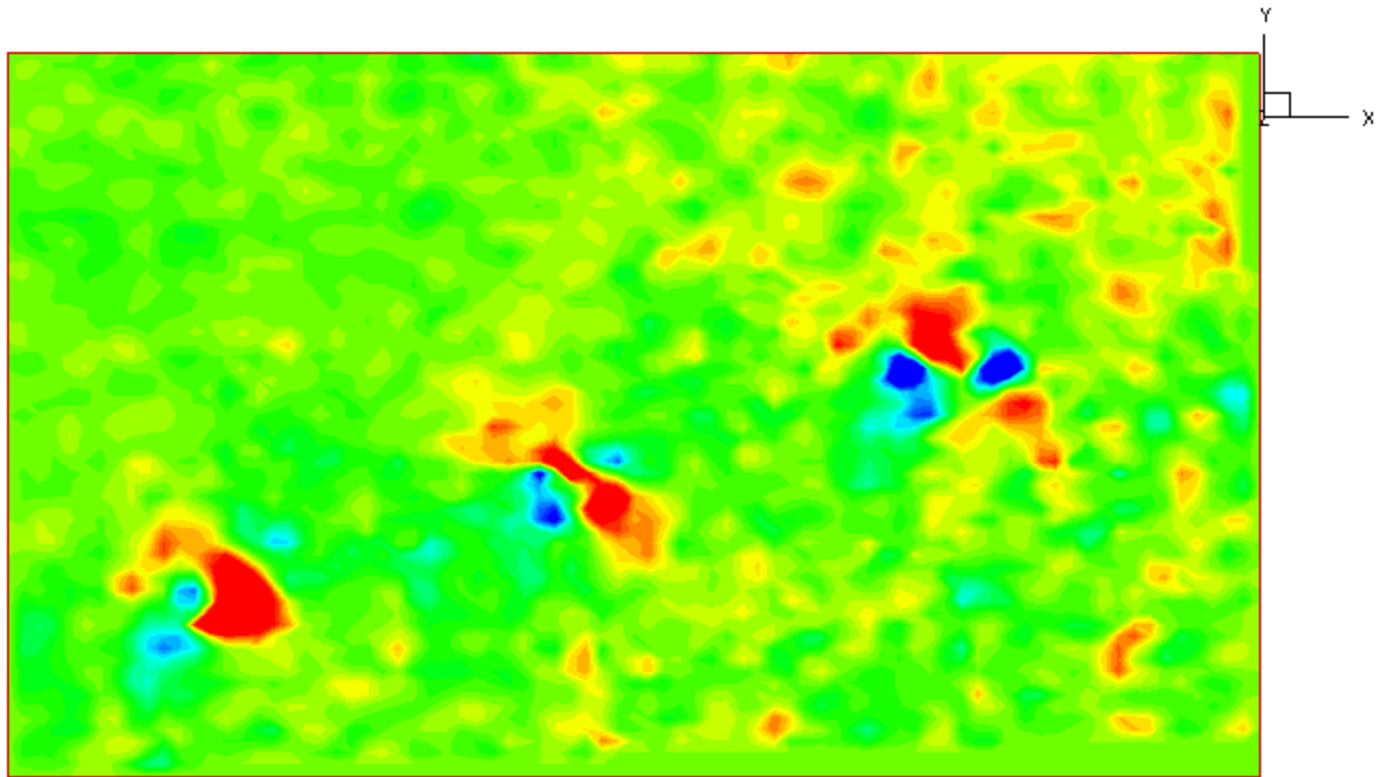
Stereo PIV, fixed mean, W-vel TSR 4-7



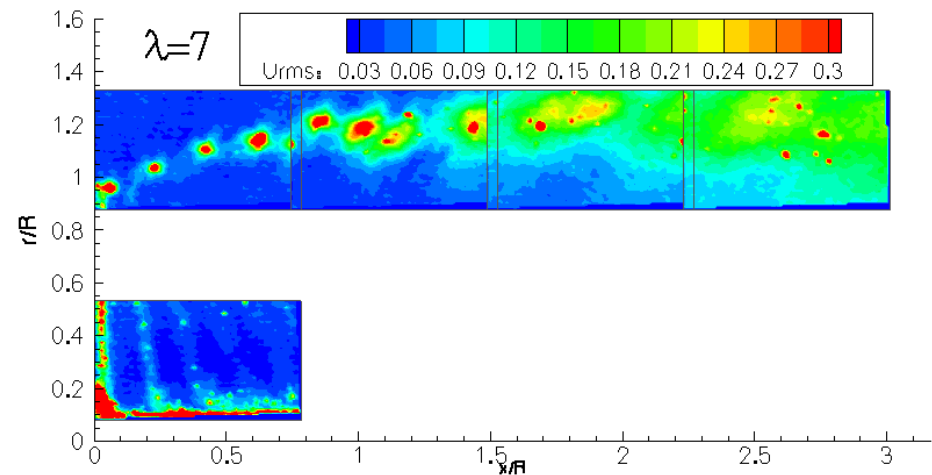
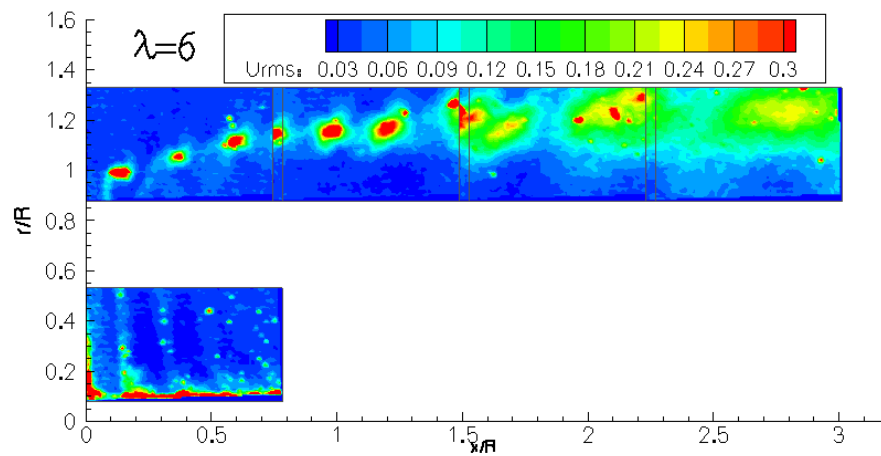
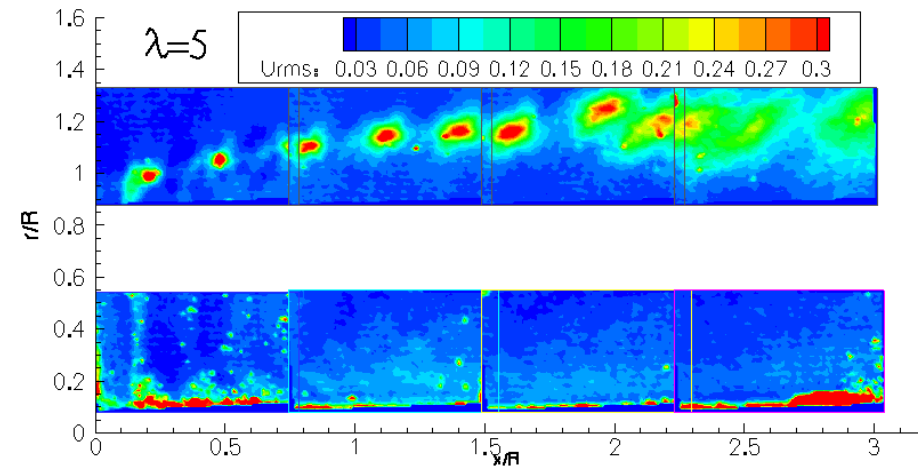
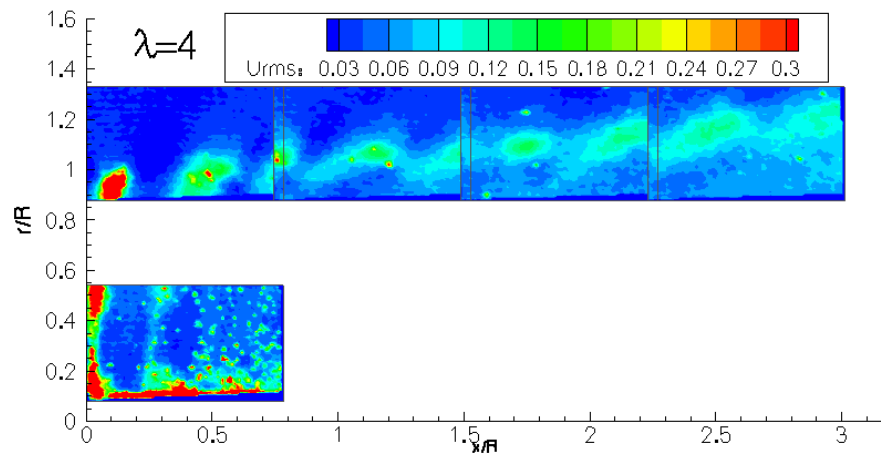
PIV, Tangential Vel, W-mean TSR 4-7



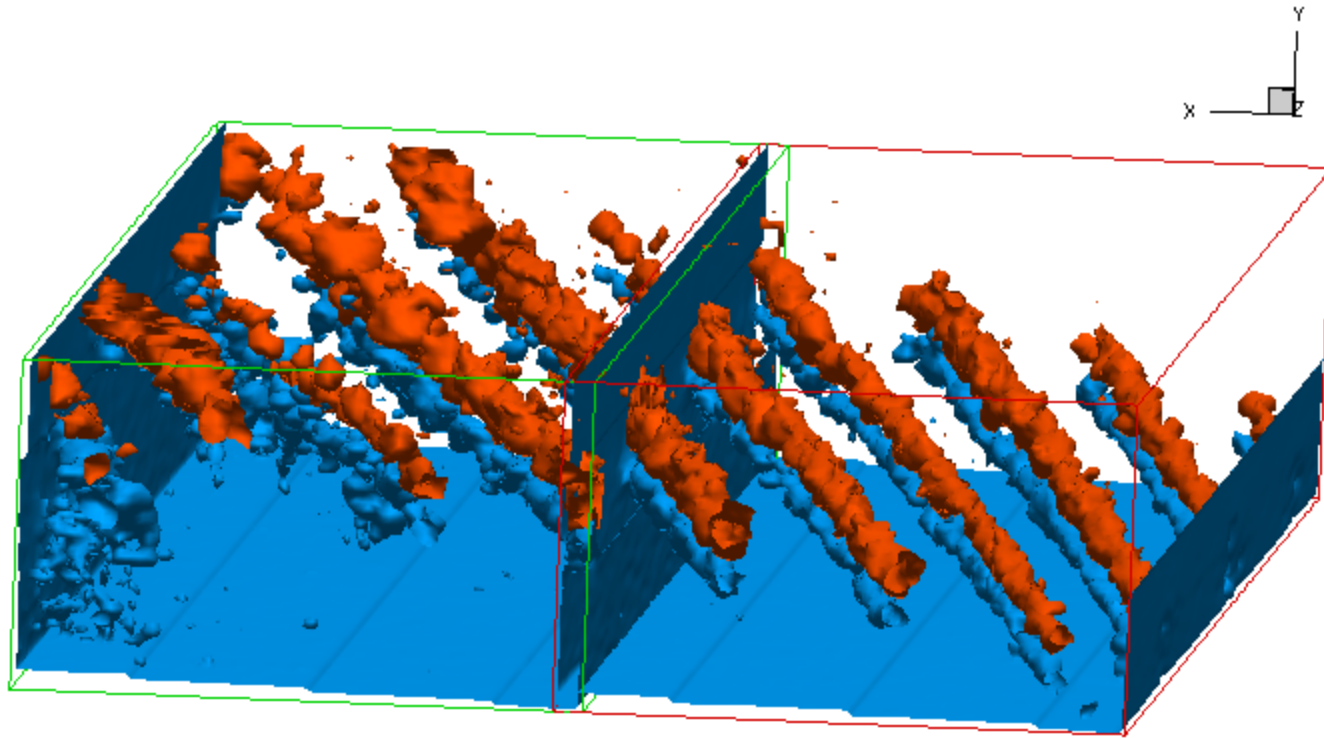
PIV, Fixed mean, W-vel, TSR 6



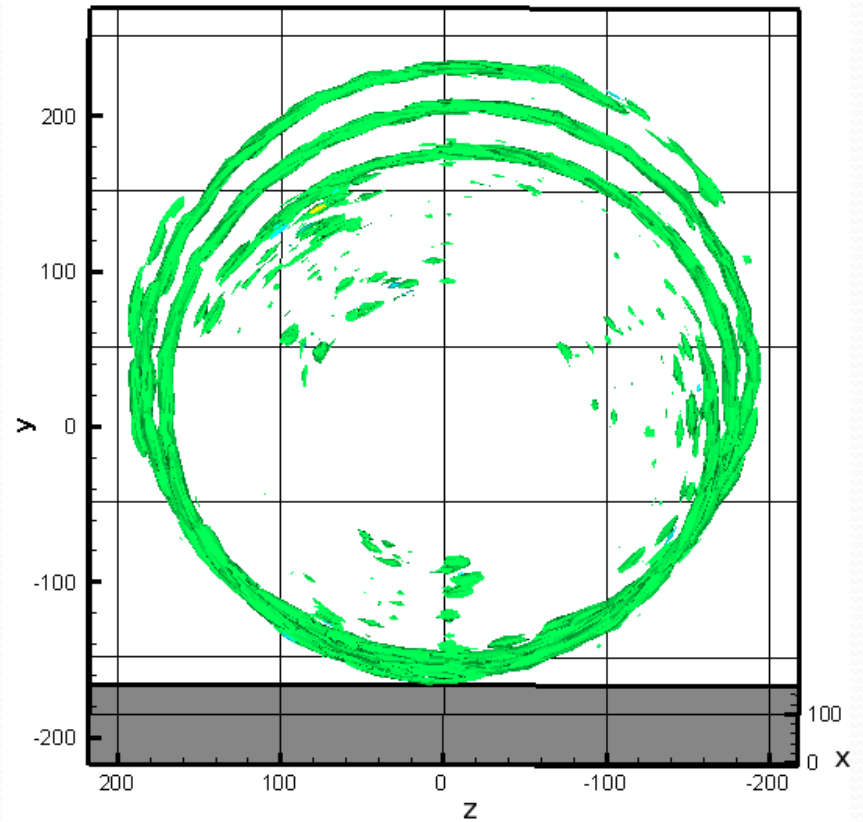
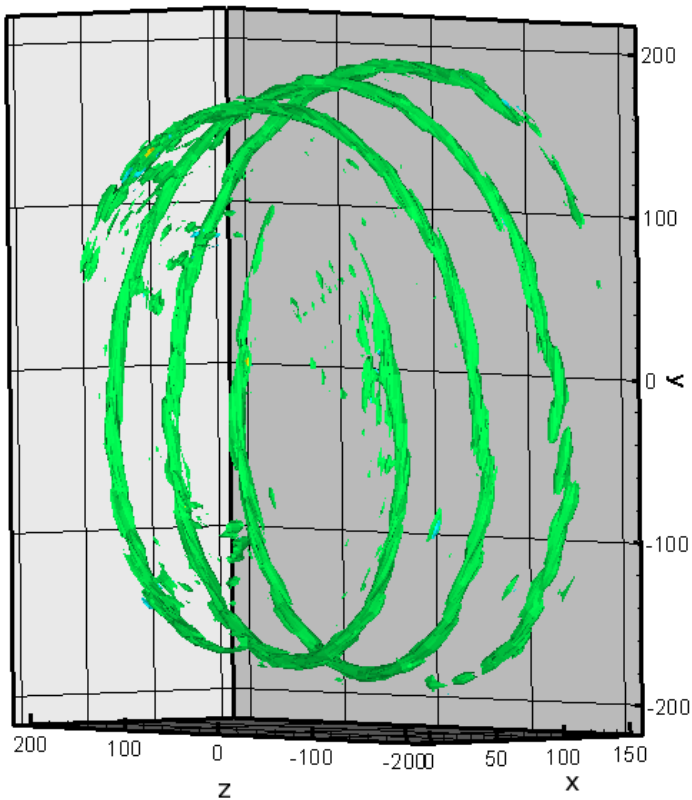
PIV, fixed mean, U-rms, TSR 4-7



PIV, U-vel, TSR 6 unfolded, 5deg/s

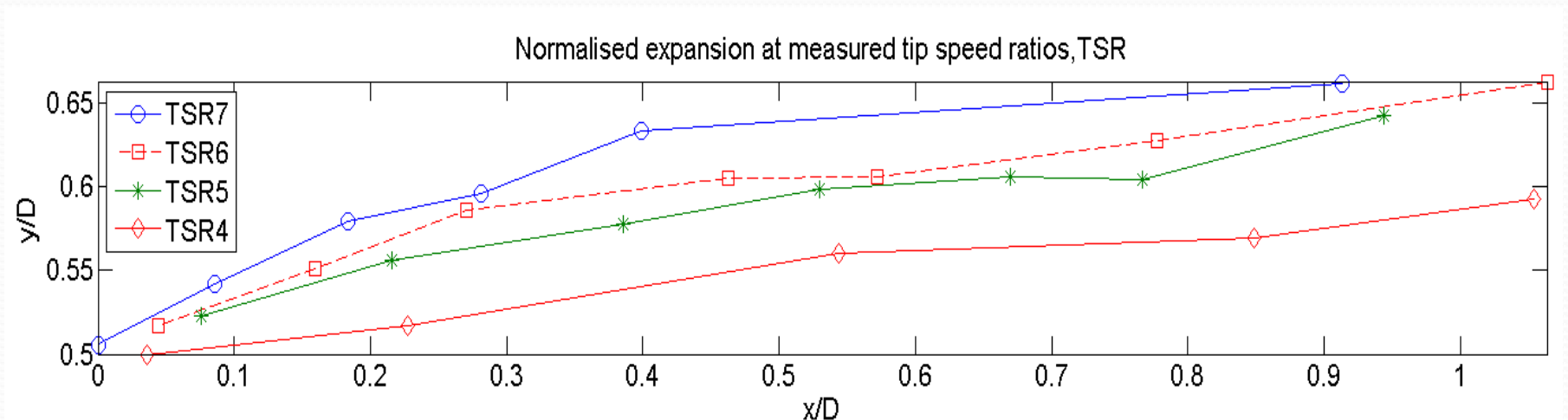


3D iso vorticity

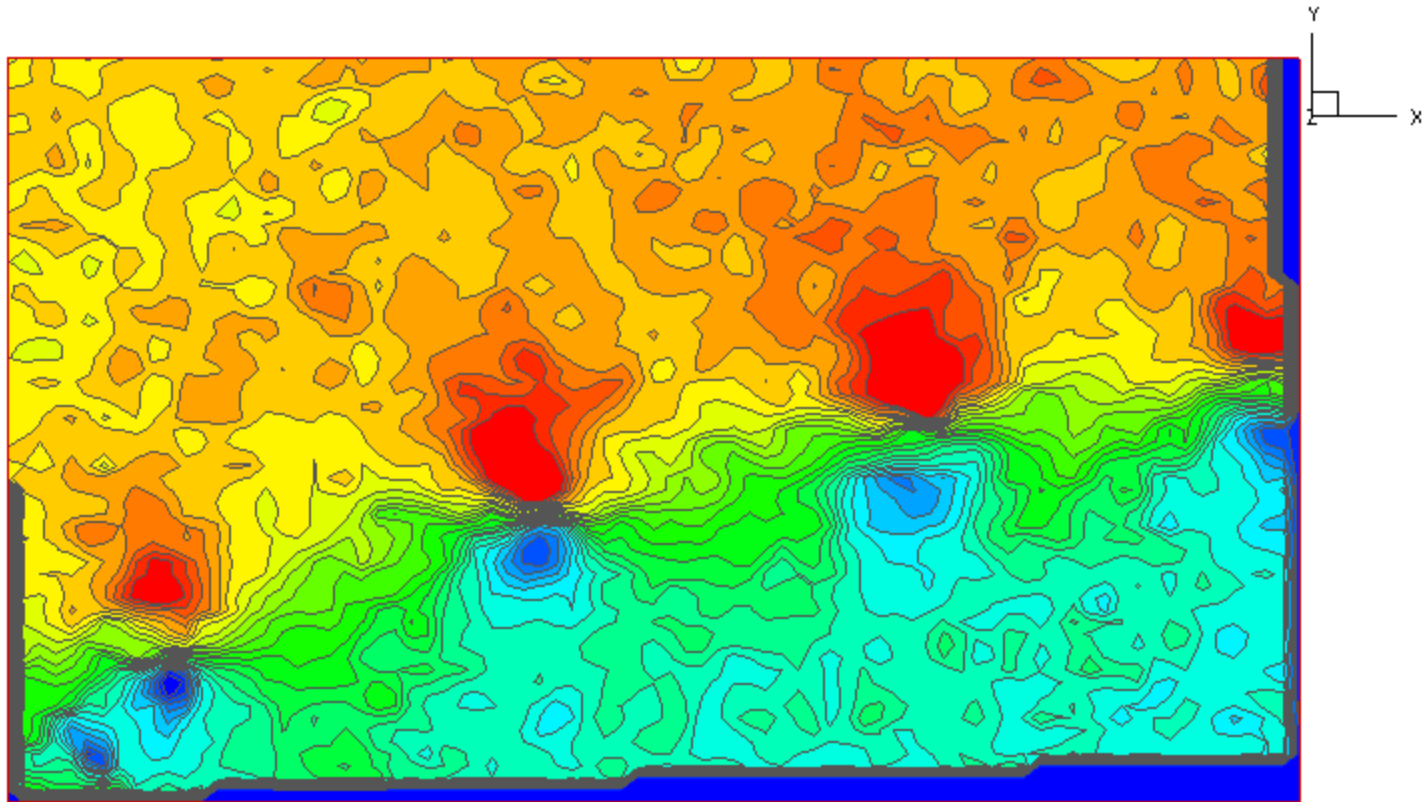


3D map of tip vortex

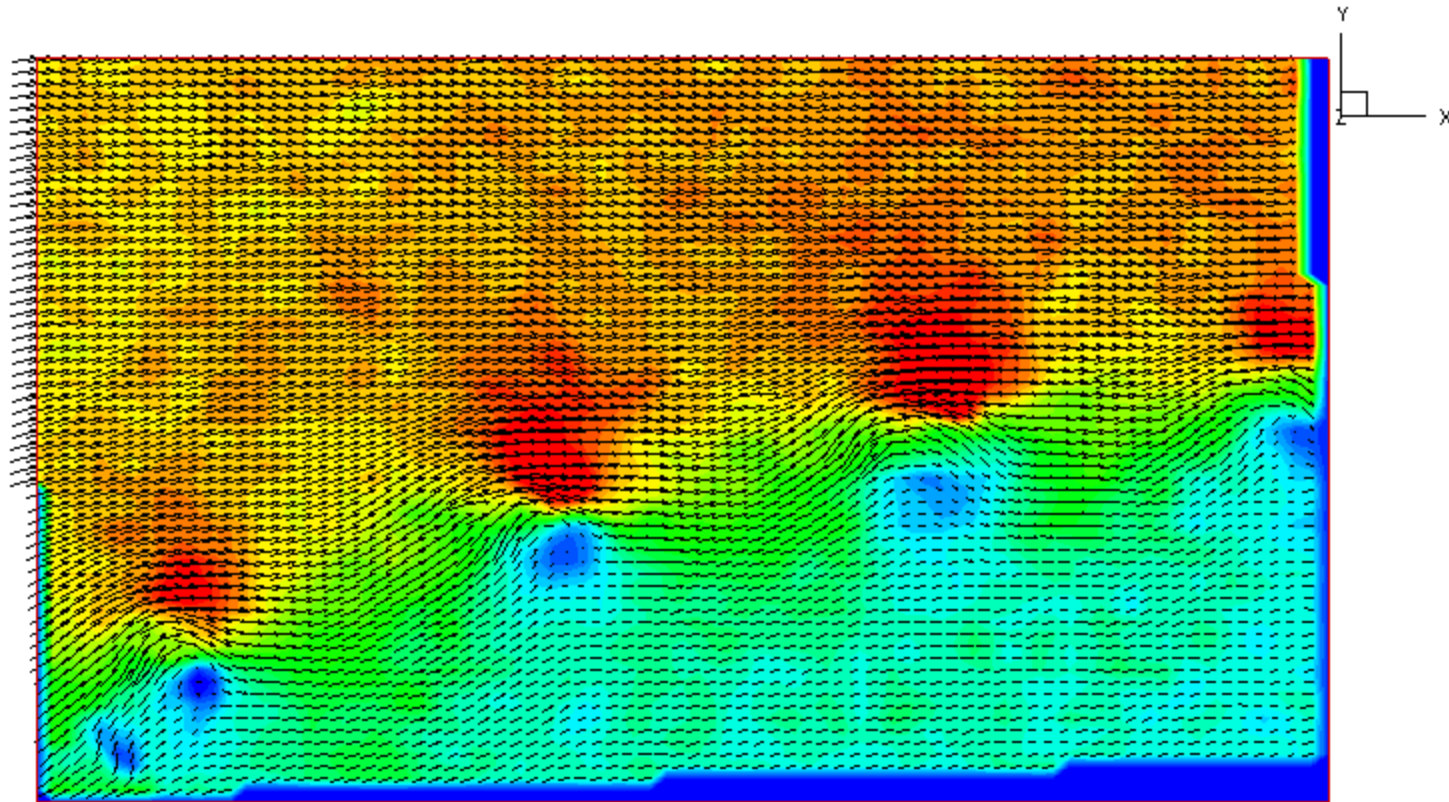
Expansion of the wake



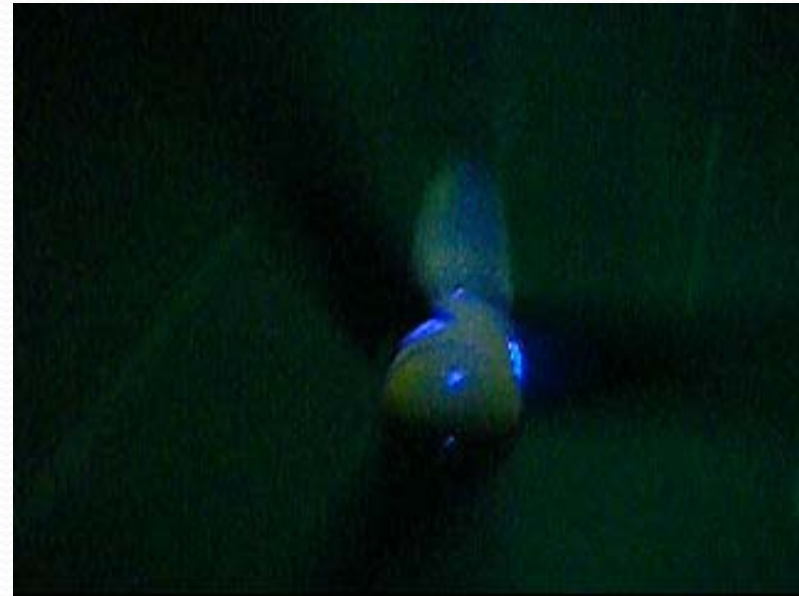
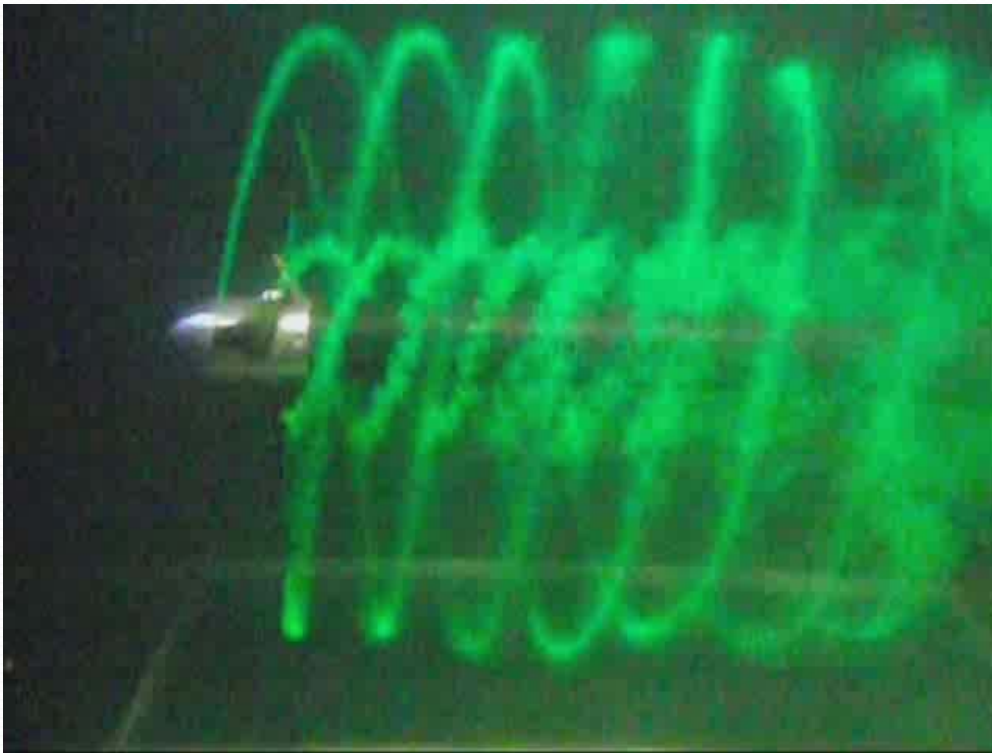
PIV, U-vel, TSR 6 unfolded, 5deg/s



PIV, U-vel, TSR 6 unfolded, 5deg/s

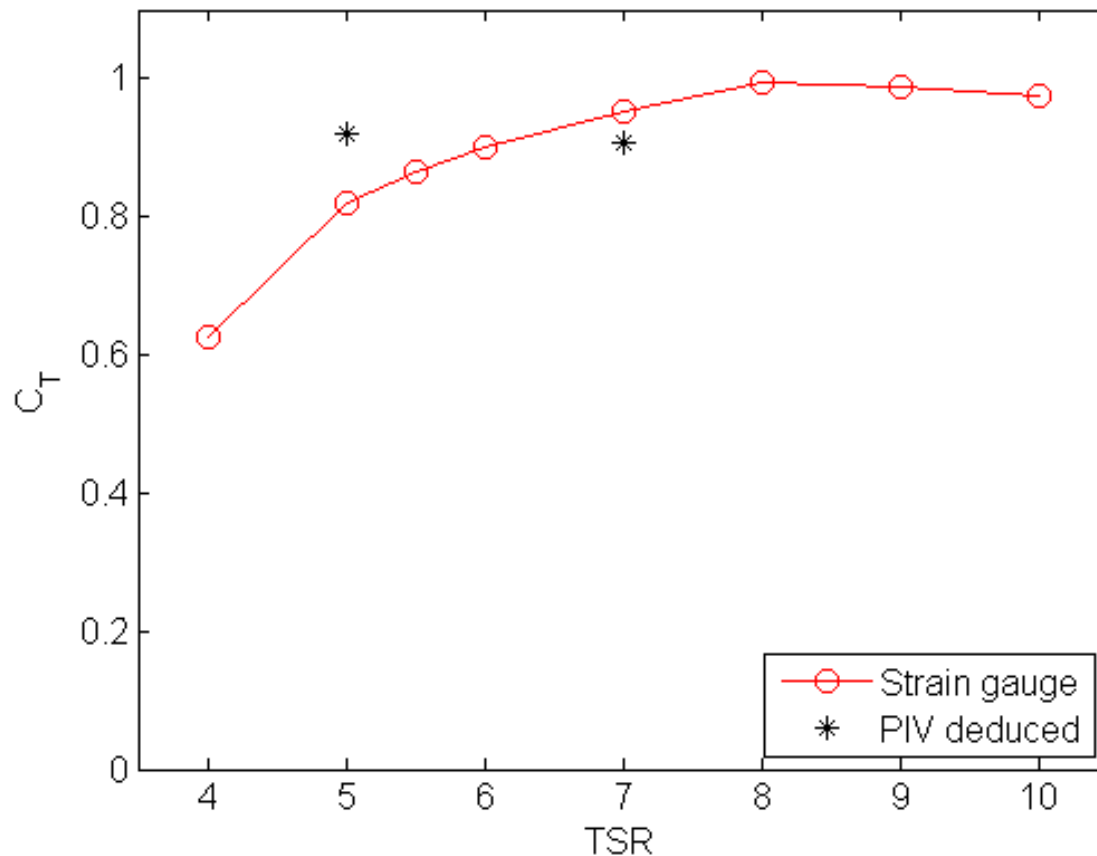


Rotation of the wake



Thrust measurements

C_T measurements as a function of the TSR

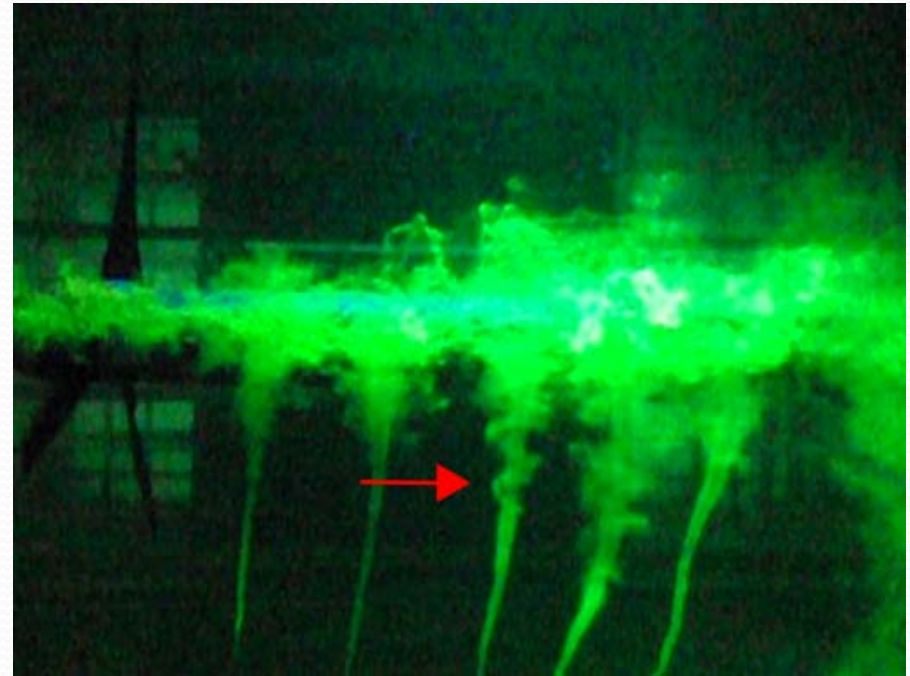
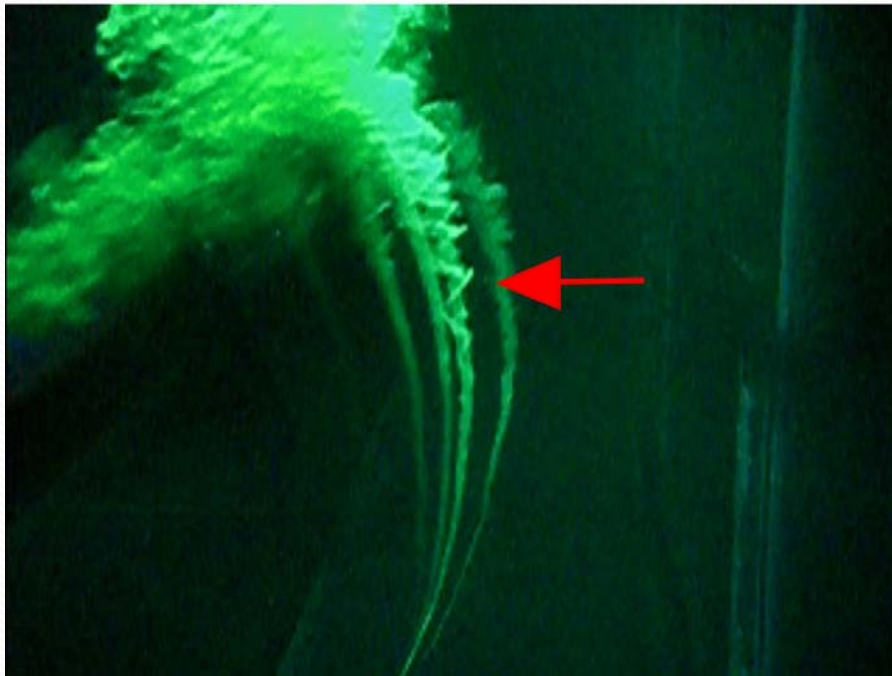


$$T = \dot{m}(V_0 - u_1)$$

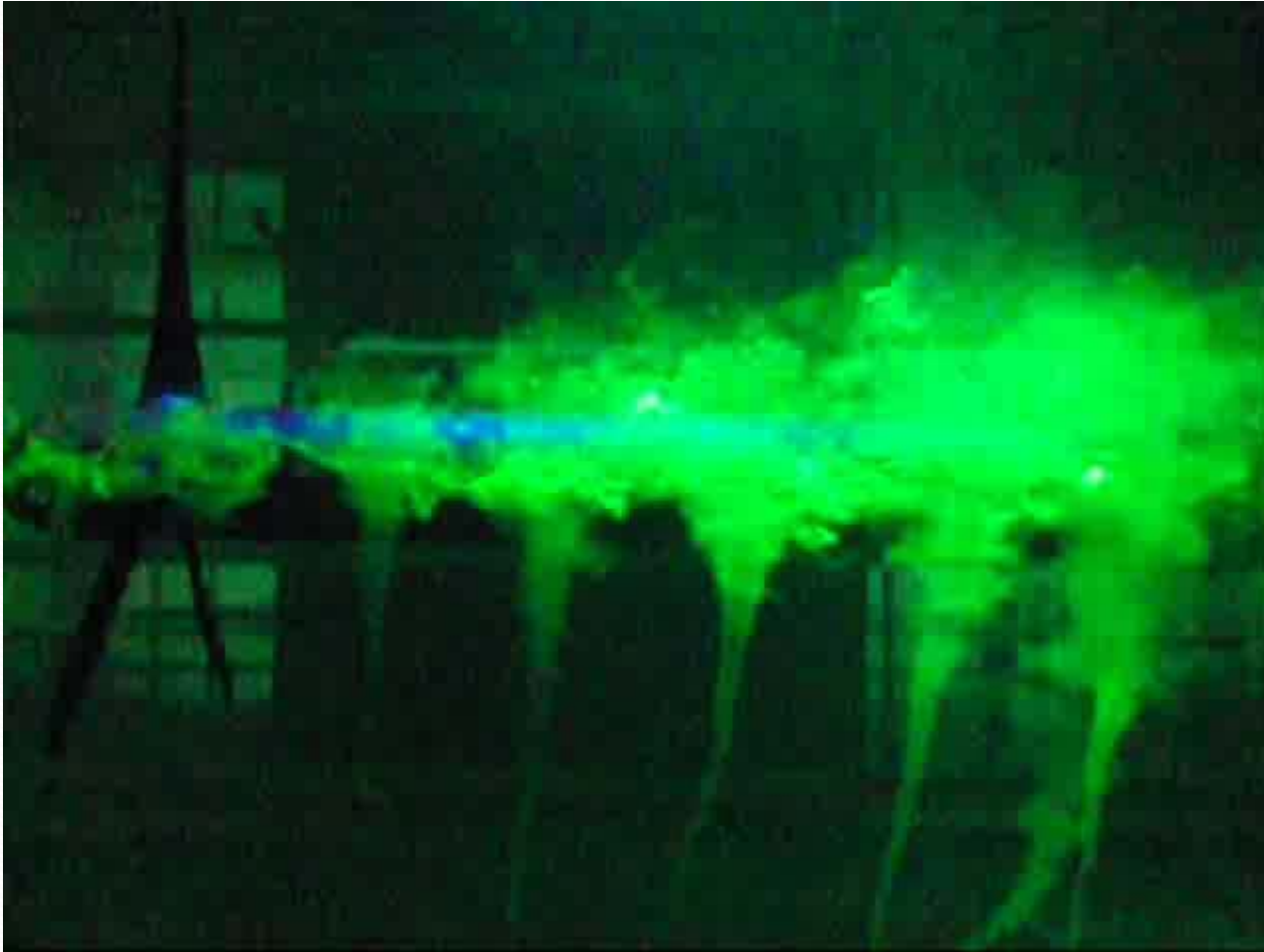
$$C_T = \frac{T}{\frac{1}{2}\rho V_0^2 A}$$

Sub tubes in tip vortices

- Sub tubes in visualisation videos



Visualisation with upstream injection



Summary

- Experimental facilities were found useable
- Nice visualisation technique of the helical structure
- Vector maps in 2D and stereo of the flow structure
- Full mapping of the mean flow in the wake at TSR 4-7
- Wake expansion at different TSR's
- 3D mapping of the wake near the rotor plane
- Strain gauge measurements needs improvment
- New measurements is planed spring 2011 - improvment of PIV data