# CFD Computations of the NM80 Rotor in Yaw


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## Purpose

We want to improve the engineering models that are the backbone of the aeroelastic codes.

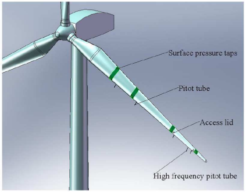
- By validating CFD codes with experiments
- Using CFD codes to study various effects separately
- Based on CFD results improve understanding and empirical models

The present work is mainly on mutual validation of CFD and experiments.

# DanAero Setup

DanAero experimental setup:

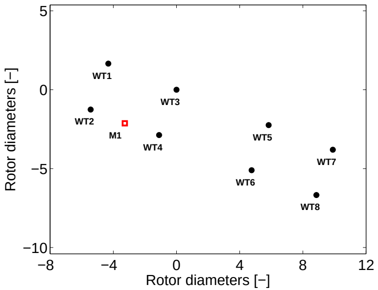
- The DanAero experiment features a 3 blade modern wind turbine in the ABL
- Pressure measurements at four stations are available [13, 19, 30, 37]
- Pitot tubes, strain gauges, microphones, met mast inflow measurements, Lidar measurements




## DanAero

Location and park configuration:

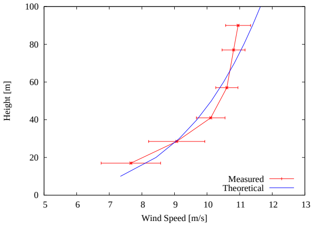
- The experimental turbine (WT3) is part of a small park
- The park is close by the cost

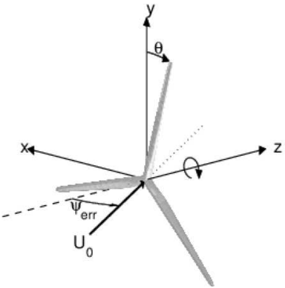



## DanAero

Selected yaw case

- Wind from South South-East ($\sim 155^\circ$)
- Weak shear $\sim U_\infty \left(\frac{z}{H}\right)^{0.2}$, with $U\infty = 10.3[\mathrm{m/s}]$ and $H = 57[\mathrm{m}]$
- Negative yaw error of 17.1 degrees defined according to the drawing below
- The RPM is 16.2

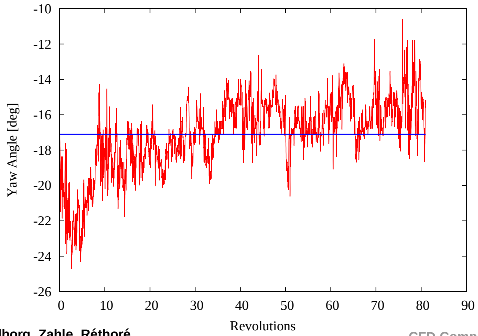


## DanAero

Some of the issues of ABL experiments

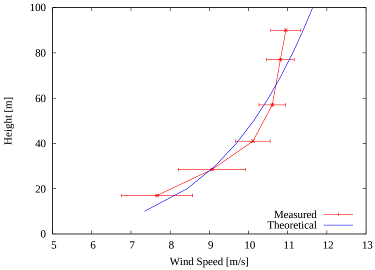
- The theoretical velocity profile do not fit the measured profile well at all heights
- We suspect that the actual profile has an growing internal boundary layer due to the close-by shore
- Due to the unsteady nature of the ABL, the yaw error is not constant.

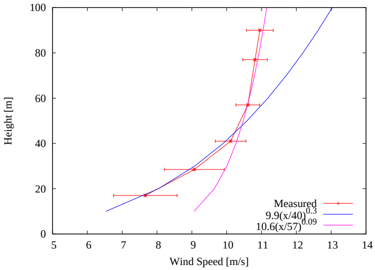


# Experimental

## DanAero

Better approximation of the vertical shear:

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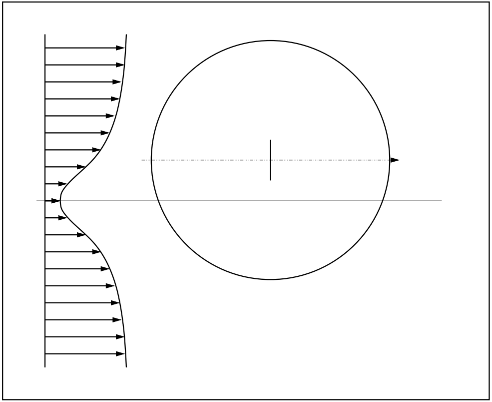
## In-house flow solver, EllipSys3D.

- Incompressible Navier-Stokes equations
- Rotation enforced through a moving grid option
- Turbulence is modelled by $k - \omega$ SST model
- Fully turbulent simulations
- Second order accurate in times
- Convective terms is modelled by QUICK
- Time-step 1600 per revolution, with 4 sub-iterations
- The computations are accelerated by using a three level grid sequence [1, 4, 8 $\sim$ 10] revolutions

## Problem Setup

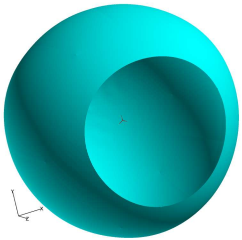
$$U(z) = U_\infty \left( \frac{|x+57| \tanh((\frac{x+57}{10})^4) + 4(1 - \tanh((\frac{x+57}{10})^4))}{57} \right)^{0.2}$$

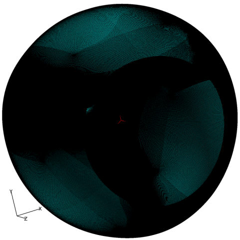


# Numerical Setup

## Computational Grid

- The domain is $\sim$ 20 rotor diameters in diameter
- O-O-Topology of 432 blocks of $64^3$ $\sim$ 113 Million points

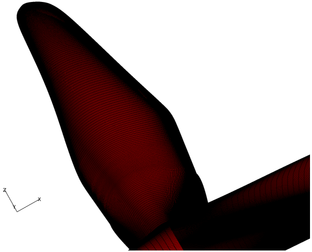


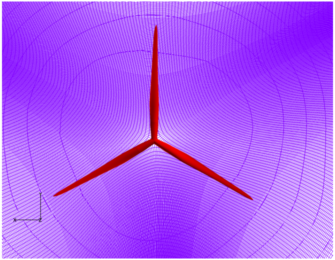


# Numerical Setup

## Computational Grid

- Chord-wise 512, Span-wise 256, Normal 256
- The wall normal $y^+$ is less than two on the blade surface



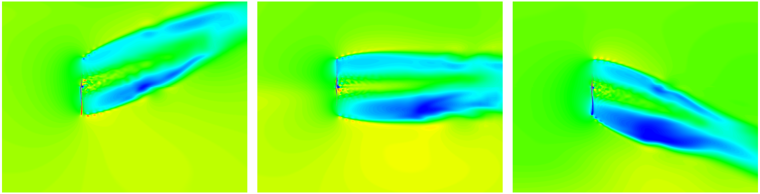


# Results

## Wake geometry

The three most relevant cases:

Shear +Yaw	Pure Shear	Shear -Yaw



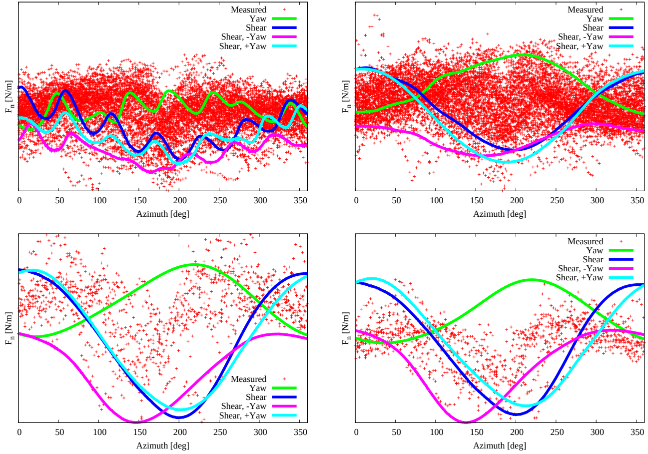
# Results

## Normal Forces

The Azimuth variation of the normal forces

r=13 [m]

r=19 [m]




r=30 [m]

r=37 [m]

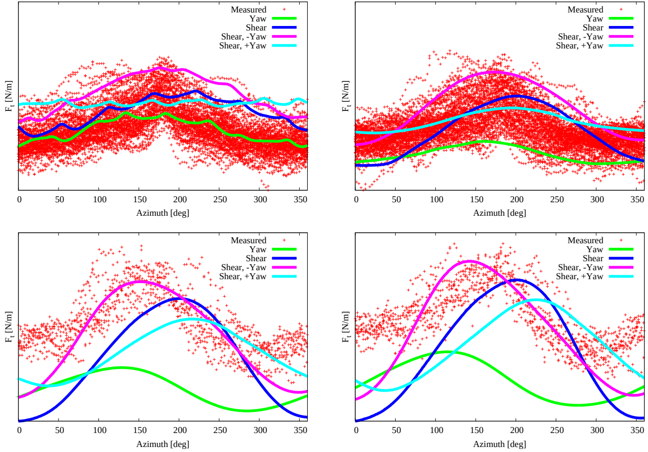
# Results

## Tangential Forces

The Azimuth variation of the Tangential forces

r=13 [m]

r=19 [m]

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# Results

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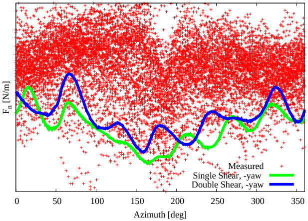


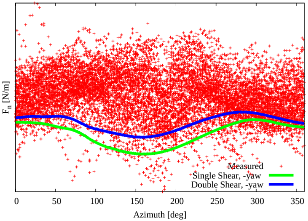


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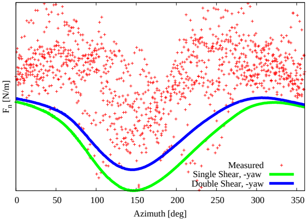


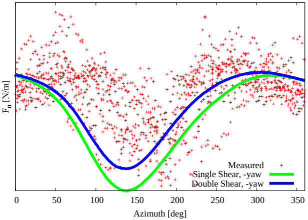


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# Tangential Forces

The Azimuth variation of the Tangential forces

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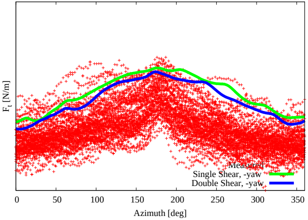


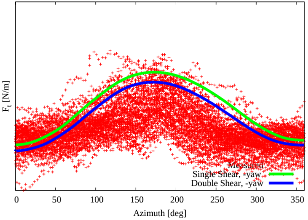


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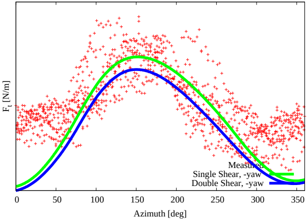
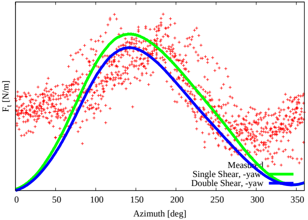


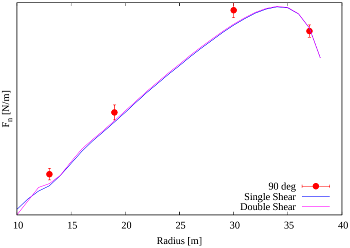




r=37 [m]

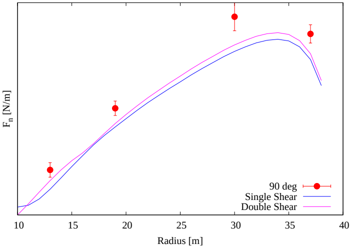
# Effect of double shear

The Azimuth variation of the normal forces

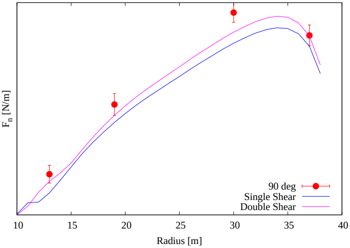
0 deg



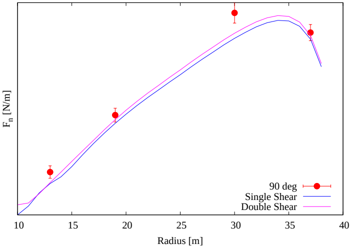

90 deg




180 deg



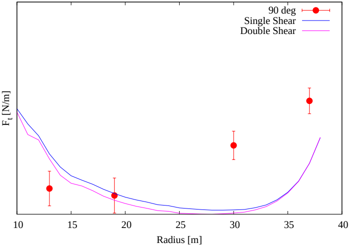

270 deg



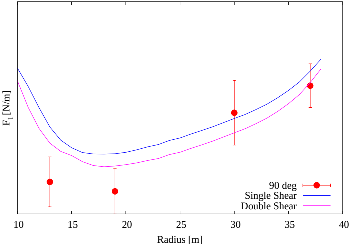
# Effect of double shear

The Azimuth variation of the tangential forces

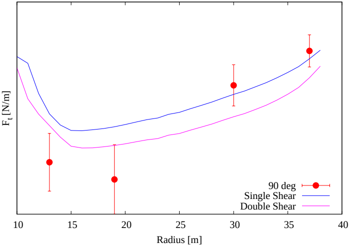
0 deg



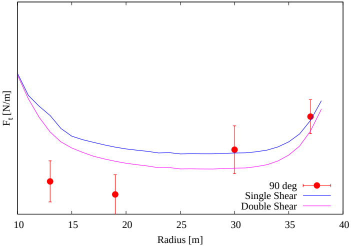

90 deg




180 deg




270 deg



## Conclusion and outlook

- Generally the azimuthal variation in the measurements are captured
- For the low yaw angle in the present case, shear is the dominant effect
- The improvement by including the double shear is minor
- The effect of the neglected tilt angle needs to be evaluated
- In the future we plan to look at higher yaw angles