

Challenges in High Reynolds Number Flows for Large Offshore Wind Turbines

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Outline

- Consequences of upscaling in rotor aerodynamics
- Unavailability of high Reynolds numbers measurements for wind turbine airfoils
- Possible effects of high Re number
- Computed high Reynolds number effects on airfoils
- Need for validation
- AVATAR measurements in DNW-HDG high pressure tunnel
- Conclusions
- Final Remarks

How large is a 20MW wind turbine blade? Very!!!



Consequences of Upscaling on Aerodynamics



UPWIND project:

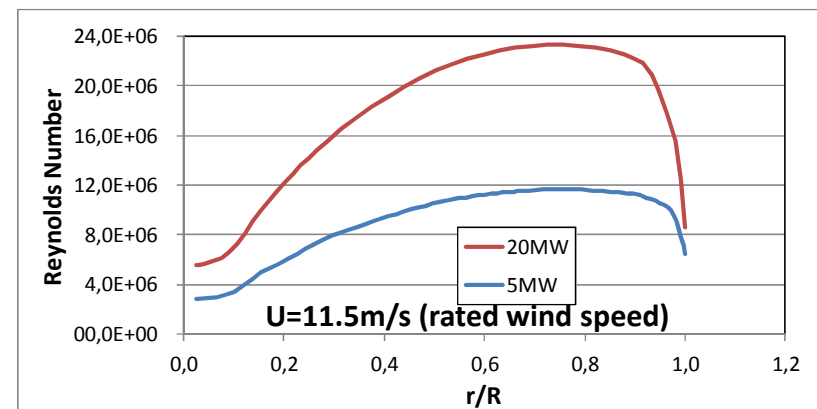
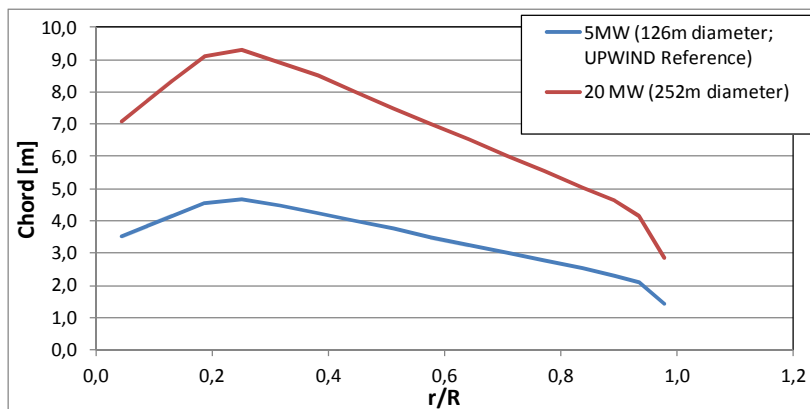
Upscaling from 5MW reference turbine to 20MW wind turbine with Classical Similarity Rules:

- Tip speed is constant
- Rotational speed is therefore inversely proportional to rotor diameter growth
- Local velocities along the blade stay the same.
- Dimensions of the blades are scaled linearly

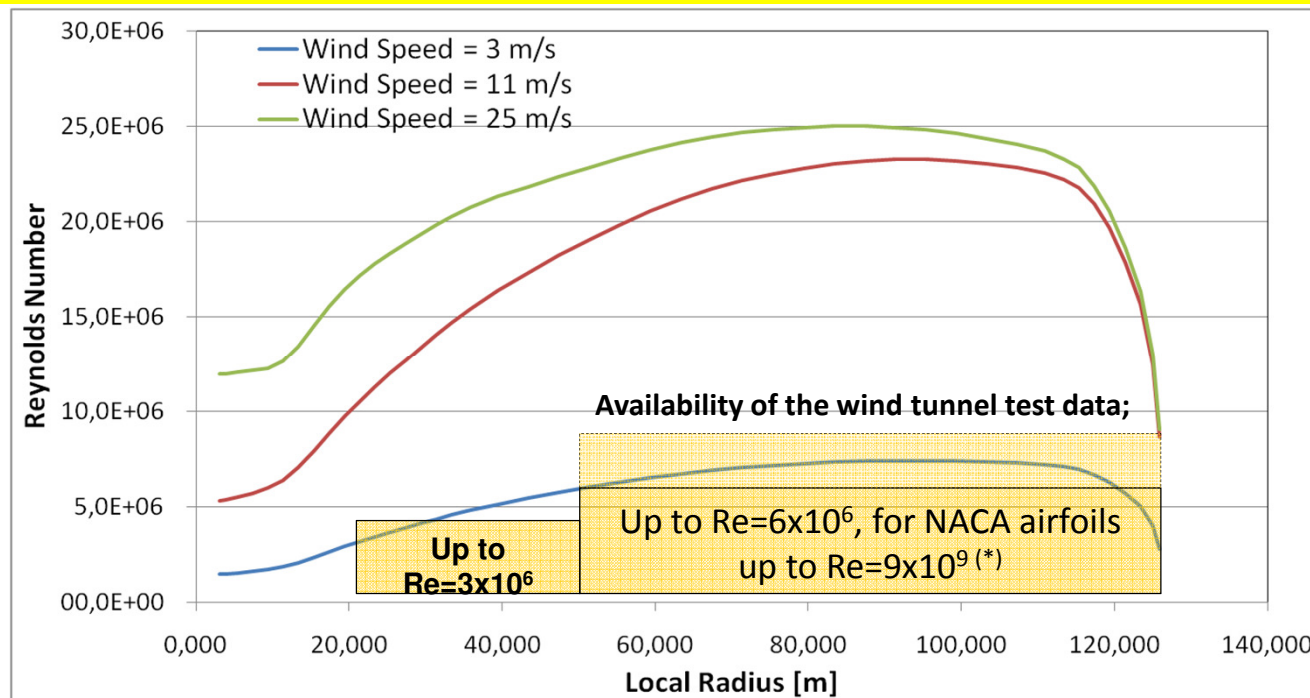
The only change in the aerodynamics is the increase in the local Reynolds numbers!

$$Re = \frac{Uc}{\nu}$$

U = local velocity
c = chord length
 ν = kinematic viscosity



Availability of C_l , C_d and C_m data of the wind turbine airfoils for high Reynolds numbers

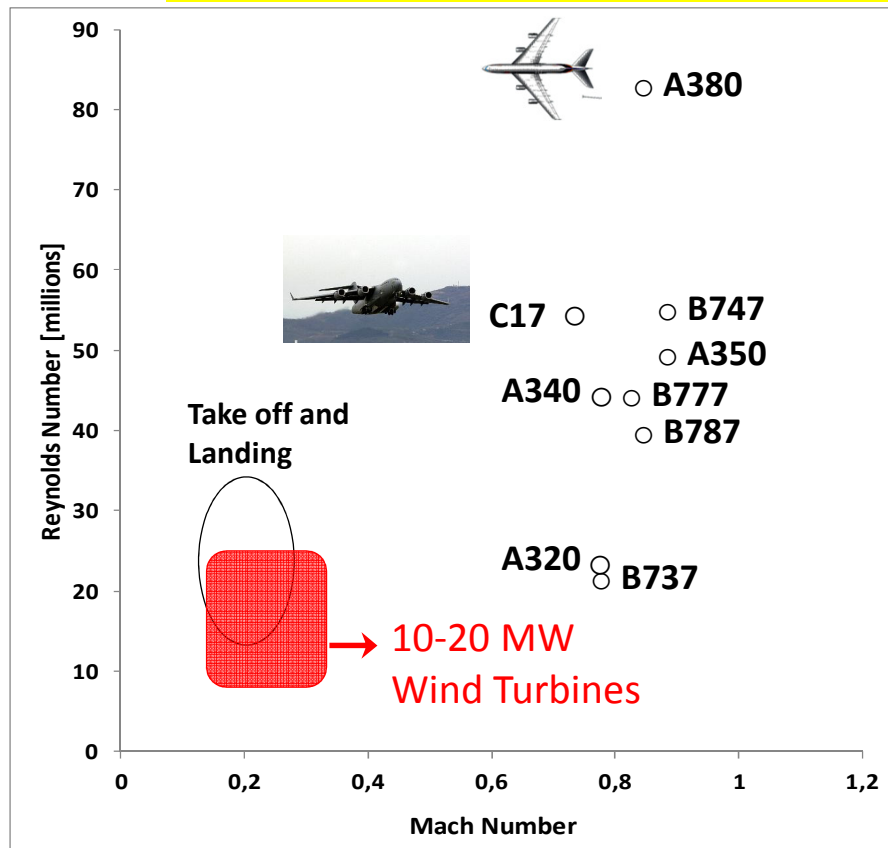


The effects of very high Reynolds numbers?

(*) **Some tests are available for high Re numbers at low Mach numbers of thin NACA profiles coming from 1940's**

1- Loftin, K.L., Jr., Bursnall, W.J., "Effects of Variations in Reynolds Number Between 3.0×10^6 and 25×10^6 upon the Aerodynamic Characteristics of a number of NACA 6-Series Airfoil Sections", NACA-TN-1773, 1948

High Reynolds numbers on aircrafts



Source : <http://www.etw.de>; reproduced.

⇒ Transport aircraft airfoils are for transonic speed (Ma about 0.8). wind turbine airfoils are for low subsonic speed (Ma about 0.3).

⇒ Wind turbine airfoils are thicker.

⇒ During the take off and landing, flaps and/slots are extracted.

⇒ High Reynolds data are absolutely needed for large WT designs. MEASUREMENTS!!



Source of the image: <http://en.wikipedia.org/>

High Reynolds number effects on airfoils

Reynolds Number Effects: Background

Two basic (and perhaps contradictory) effects, depending on airfoil shape

- 1) Generally thinner boundary layer as a result of higher Re number and less decambering, **but**:
- 2) Earlier laminar to turbulent boundary layer transition, which tends to thicken the boundary layer. The transition position is very difficult to predict but depends on the pressure distribution and shear and hence on the airfoil shape!

Hence, prediction methods **must** be validated by measurements

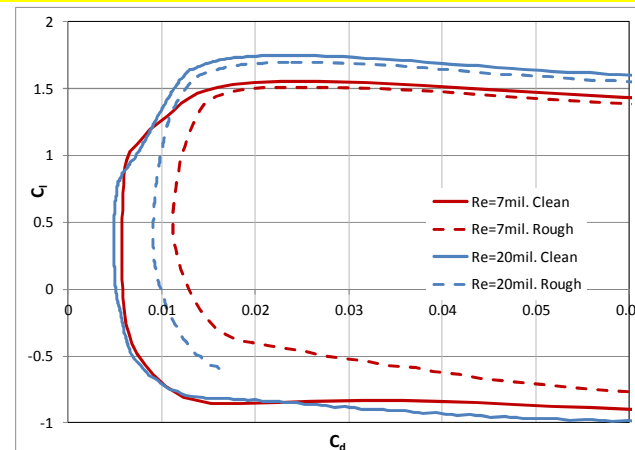
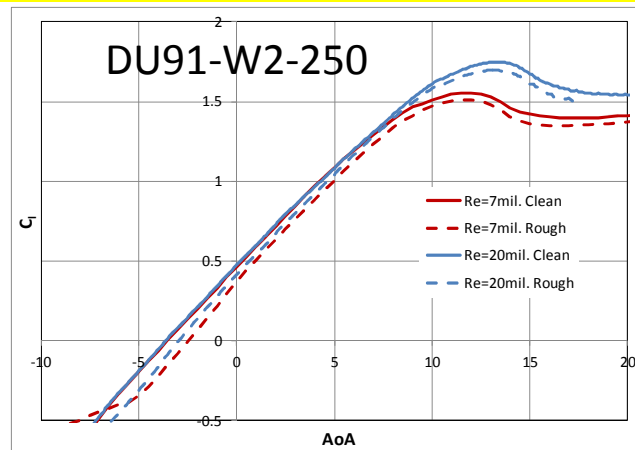
Motivation:

- We simply don't know if present aerodynamic models are good enough to design 10MW+ turbines
 - “No mature industry will ever design a MEuro machine with *unvalidated tools*” (M. Stettner, GE Global Research)
- 10MW+ rotors violate assumptions in current aerodynamic tools, e.g.:
 - Reynolds number effects,
 - Compressibility effects
 - Flow transition and separation,
 - (More) flexible blades
- **Hence 10MW+ designs fall outside the validated range of current state of the art tools.**

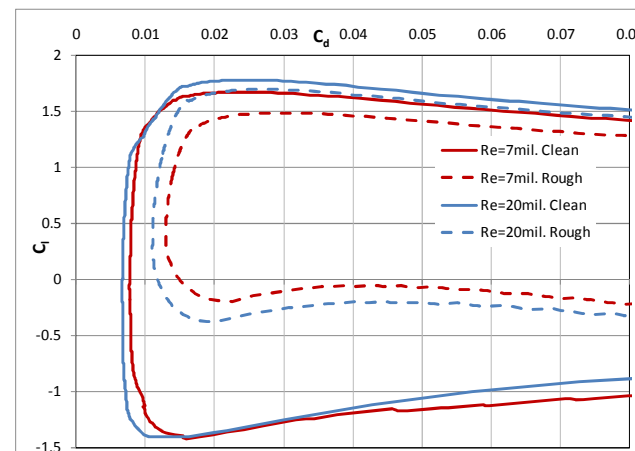
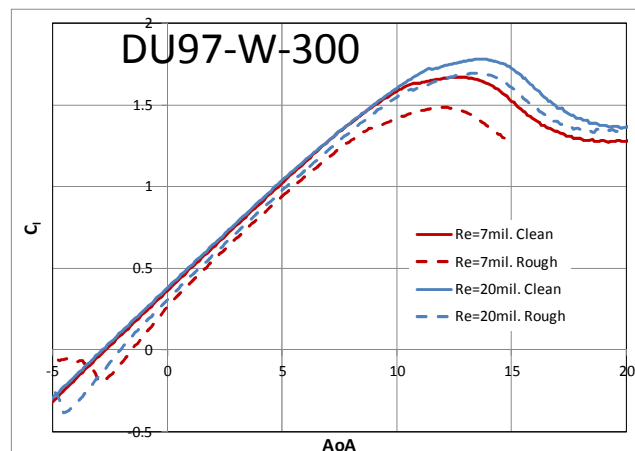
Avatar: Main objective

To bring the aerodynamic and fluid-structure models to a next level and calibrate them for all relevant aspects of large (10MW+) wind turbines

High Reynolds number effects on C_l and C_d of thick airfoils (predicted by RFOIL, e^N method for transition)



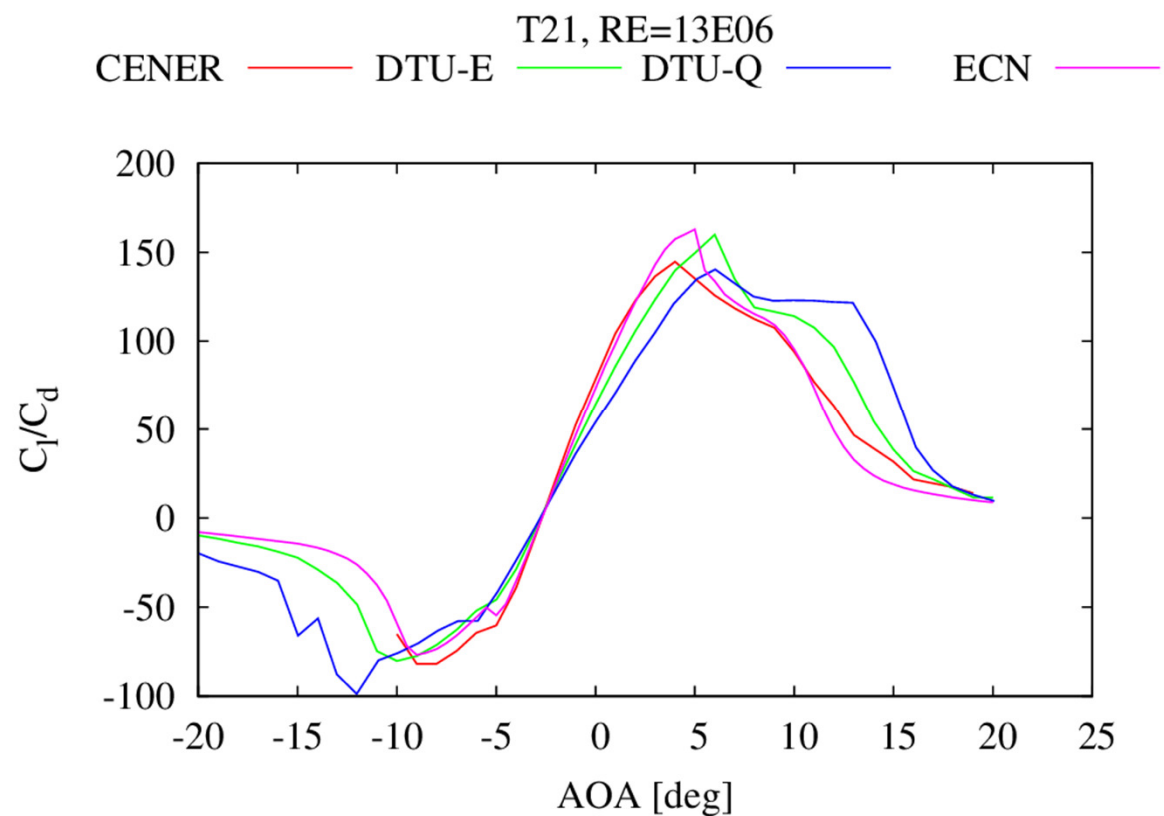
NB: only usable measurements found in literature for high Re are for a 18% thick symmetrical airfoil, Re = 20M.



AVATAR: Comparison results ECN/other partners

Large differences in computed 2D Polars show the need for model improvement at high Reynolds numbers

Courtesy: N Sorensen



Need for validation by measurement: ECN

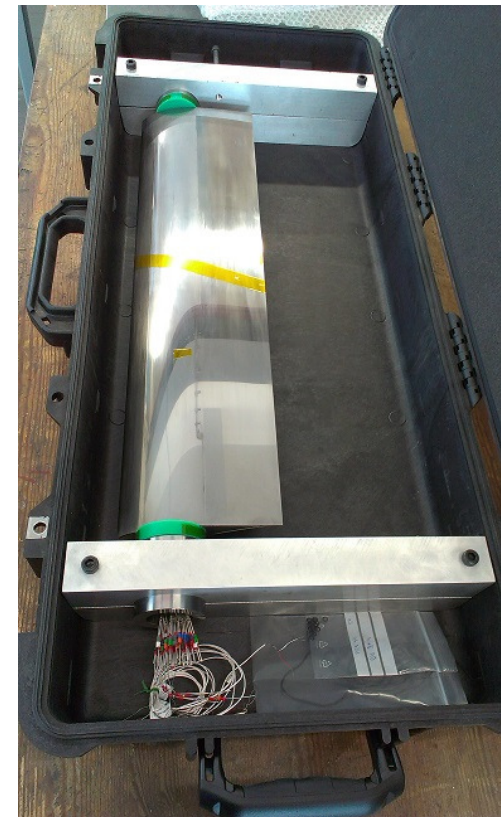
the AVATAR project

- A high Re effect assessment was done using RFOIL
- Different partners in the AVATAR project use 2D CFD with existing transition models
 - Differences are large
- Results must be validated to be used with confidence in designs.
- There is a possibility that the high Re effects enable thicker airfoils without drag penalties, so that weight increase can be limited for the very large blades and gravitational loads can be reduced.
- The AVATAR project includes measurements in the DNW-HDG high pressure wind tunnel, from $Re = 3M$ upto $18M$, DU00-W-212 section. In order to check Re influence, lower Re measurements (upto $6M$) will be performed in LM wind tunnel.

AVATAR measurements

Measurements are scheduled to start this very week, with the following **special features**:

- Concurrent measurement of the wind tunnel turbulent SPECTRUM with a hot film at entrance
- Estimation of transition location using embedded Kulite pressure sensors as high frequency microphones
- Pressure distribution measurements (90 sensors)
- Wake rake for drag determination, sidewise traversabel
- Flourescent oil flow visualization
- Profile: DU00-W-212, $c=15$ cm



Conclusions

- Due to the growing sizes of the rotors, higher Reynolds numbers (up to 25 million) are introduced.
- There is a lack of measurement data at high Reynolds numbers of the thick wind turbine airfoils at incompressible conditions.
- RFOIL is used in order to estimate the effects of Reynolds numbers.
- Within the AVATAR project, measurements will be performed in the DNW-HDG wind tunnel in Göttingen, to validate or correct the desing calculations
- Results are forthcoming, measurements starting this week.

Final Remarks

- Reynolds number is reduced with slender blades. It is increased again with higher tip speed operations.
- Those effects should already be included in the existing or the next generation (5-10 MW) wind turbines!
- More detailed design work is necessary to be performed in order to design the best airfoils with right thickness. (stall, dynamic effects, stability etc.)
- There are only a few atmospheric wind tunnels in the world that are able to reach such high Re numbers in incompressible flow - lower than $Mach=0.3$. In this tunnels, the chord length of the model should be extremely large! Therefore the number of facilities to be used for this purpose is quite limited.



Thank you for your attention

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Questions...

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