Economical and Operational Merits of Offshore Multi-Megawatt Downwind Turbines

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Motivation

- Downwind turbines offer substantial potential to lower the cost of wind-generated electricity, and are well suited for operation on offshore floating platforms.
- As the risk of blade-tower collisions is greatly reduced lighter, more flexible blades can be used.
- Lighter blades and smaller rotor overhang distances than on upwind turbines provide for a less costly wind energy system.
- Further the restoring moment of a downwind rotor that tends to align the turbine with the incoming flow, improves the overall stability of a floating offshore platform, further reducing costs.

Computational Methods

- Full-rotor Navier-Stokes simulations of Hitachi 5MW offshore downwind wind turbine were undertaken.
- The outer computational domain, based on work in [1], is spherical with a cylindrical subdomain including the rotor. The overall node number is 16 million and average y^+ on blade surface is 1.4.

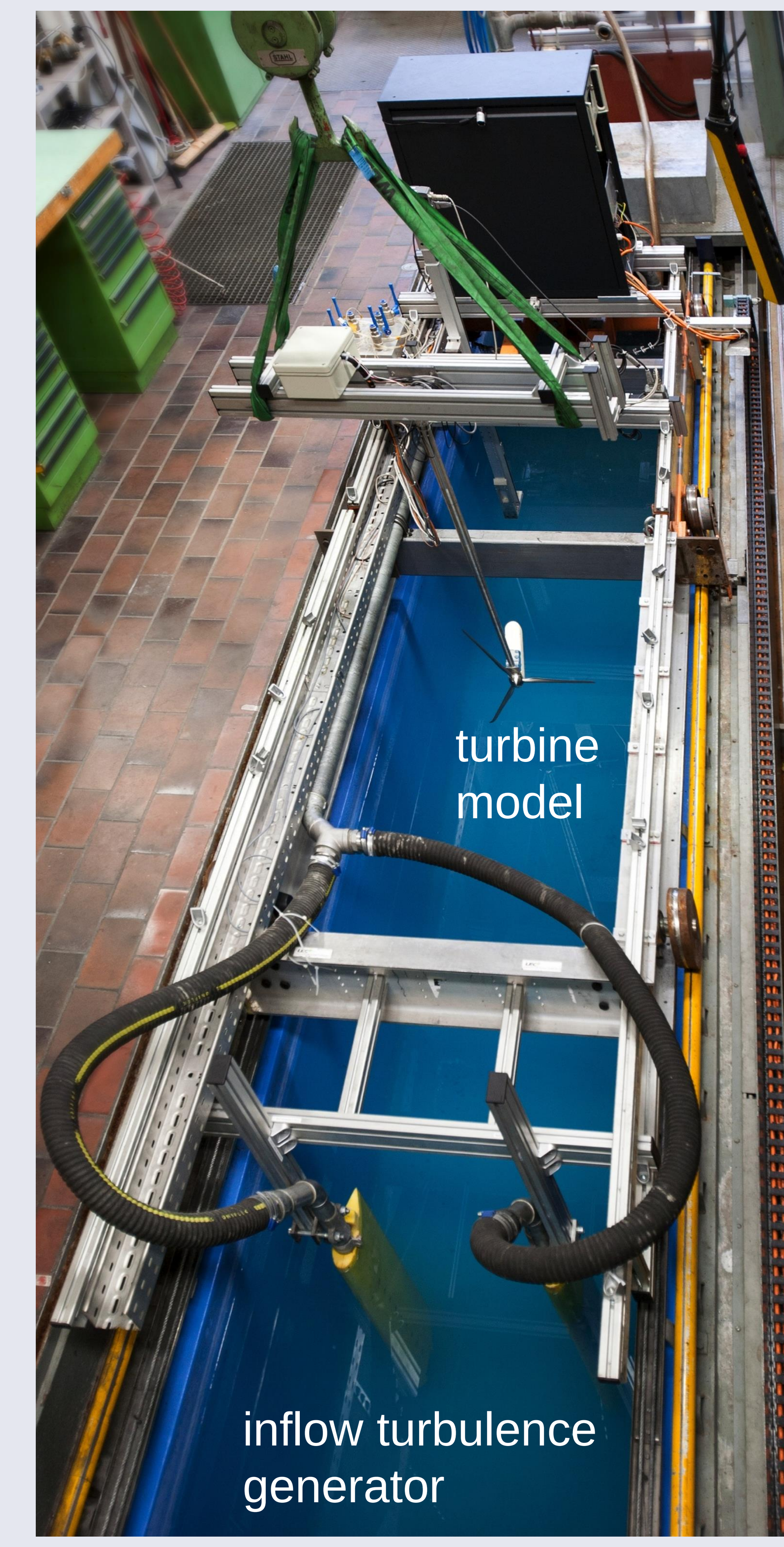
Hitachi 5MW downwind turbine

Experimental Methods

- Experiments are performed in the ETH Wind Turbine Test Facility (WEST) in well-controlled flow con-ditions .
- The turbine model is a 1:160-scale model of a Hitachi 2MW downwind turbine and allows for performance, tower twist and bending moment measurements.
- The fully auto-mated water towing tank facility allows the specification of the inflow turbulence.
- The charac-teristics of the model turbine are shown below.

Hitachi 2MW downwind turbine. Courtesy of Wind Power Ltd.

Rotor diameter	0.5 m
Reynolds number	1.1×10^5
Test parameters	Up- / downwind rotor orientation Rotor tilt & cone Nacelle shape



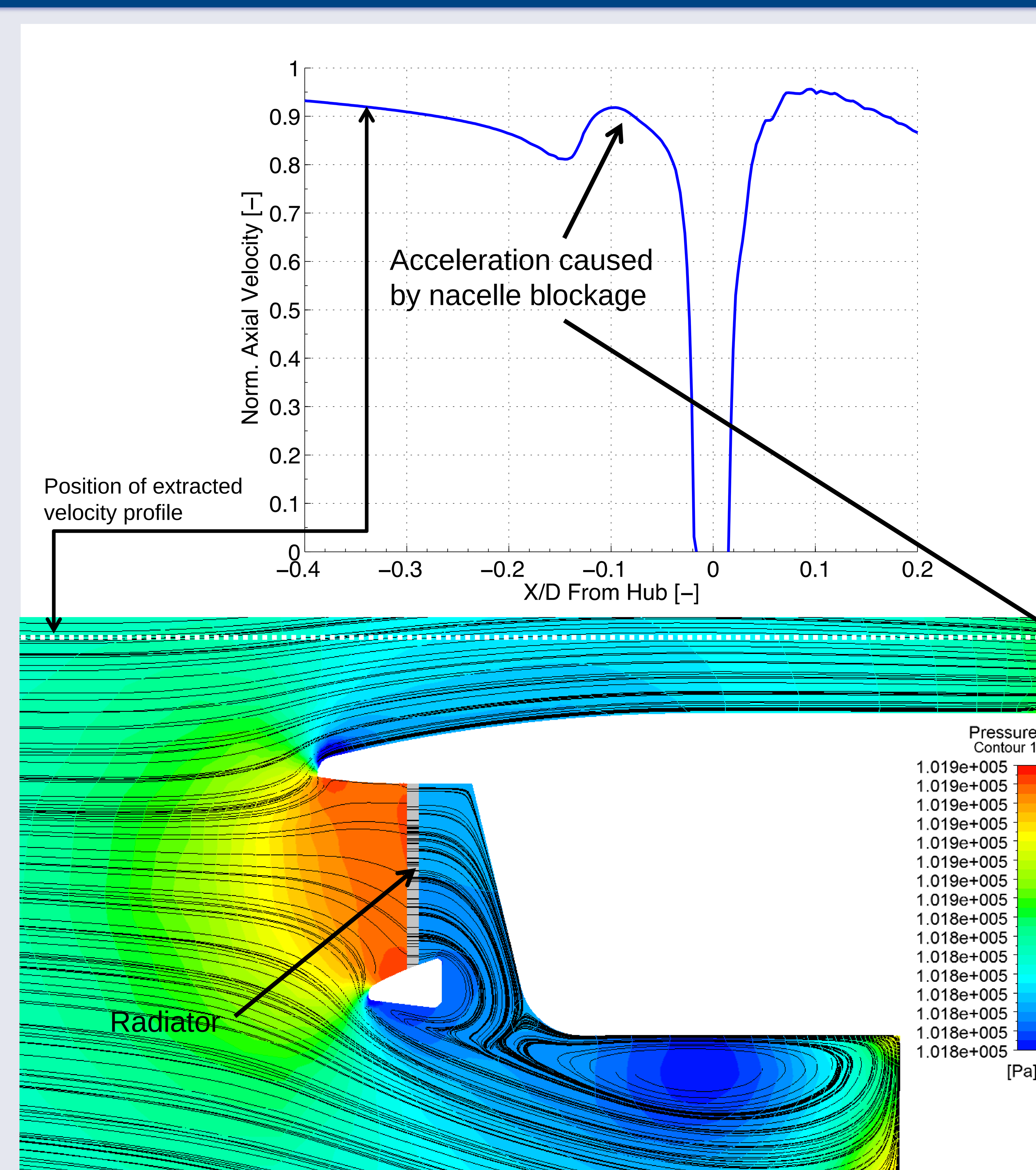
Bird's eye view of ETH Wind Turbine Test Facility (WEST Facility)

Results

- The simulations on the Hitachi 5MW wind turbine show that the nacelle has a favourable blockage effect, which results in higher axial velocities ahead of the rotor and higher flow incidences on the blade, both of which yield a higher power of downwind turbine configurations compared to upwind turbine configurations.
- Computational and experimental results on the Hitachi 2MW show advantageous performance for the downind configuration:

	Computation [2]	**Experiment** [3]
	Downwind	
Power coefficient c_P	100%	100%
Thrust coefficient c_T	100%	100%
	Upwind	
Power coefficient c_P	97%	95%
Thrust coefficient c_T	97%	97%

- The radiator, that is installed in the more upstream part of the nacelle, provides for efficient passive cooling of the nacelle of the 5MW offshore downwind wind turbine and does not negatively affect the favourable blockage effect of the nacelle.



Top: Streamwise distribution of axial velocity 3.5m above hub height of Hitachi 5MW turbine
Bottom: Sectional view of upstream part of Hitachi 5MW turbine with pressure contour and streamlines

Conclusions

- The nacelle positioned upstream of the rotor of downwind turbines provides for a favourable blockage effect which leads to higher axial velocities entering the rotor plane. This effect was observed in simulations on the Hitachi 2MW and 5MW wind turbine and experimentally.
- The nacelle blockage effect leads to higher turbine power output and larger, more inboard, blade loading on downwind turbines.
- Together with their inherent yaw stability and the significantly lower risk of a blade striking the tower, this makes downwind turbines promising candidates for next generation floating offshore turbines.

References

[1] Tsalicoglou C., Jafari S., Chokani N., Abhari R.S., 2015, "RANS Computations of MEXICO Rotor in Uniform and Yawed Inflow," Journal of Engineering for Gas Turbines and Power, 136(1), 011202.
[2] Frau, E., Kress, C., Chokani, N., and Abhari R.S., 2015, "Comparison of Performance and Unsteady Loads of Multi-Megawatt Downwind and Upwind Turbines," Journal of Solar Energy Engineering: Including Wind Energy and Building Energy Conservation, SOL-14-1278, to appear.
[3] Kress, C., Chokani, N., Abhari, R.S., 2015, "Downwind Wind Turbine Yaw Stability and Performance," under review.