ENERGY

Validation and verification of new aerodynamics in Bladed 4.8

Menno Kloosterman

10 November 2016

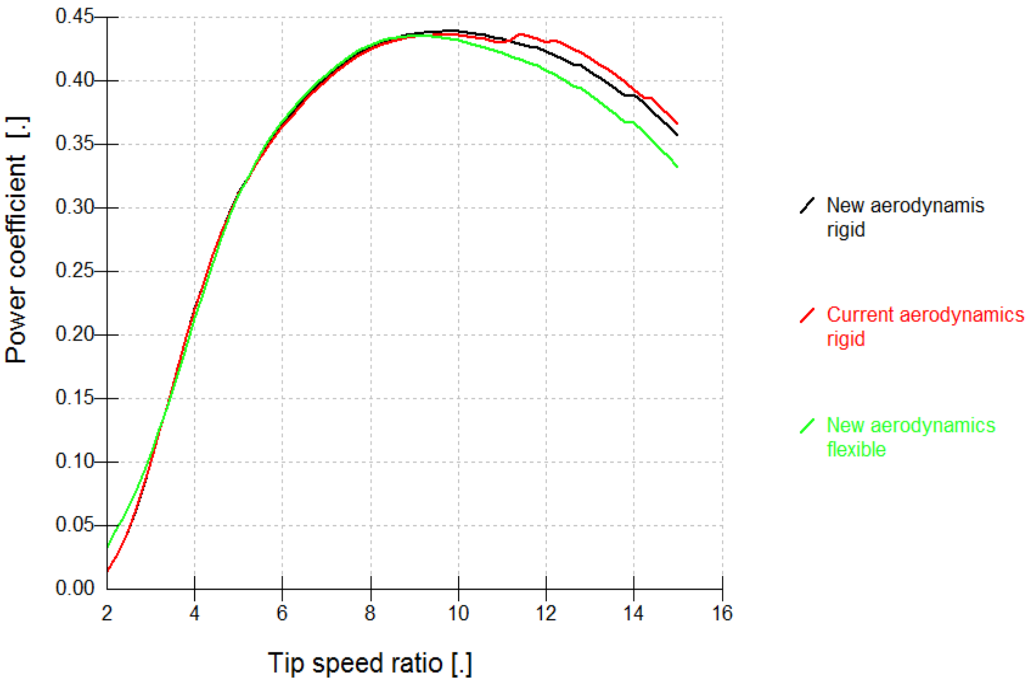
Ungraded

Introduction

- Motivation for development:
  - Creating a generic interface between structural dynamics and aerodynamics
  - More modular and maintainable code
  - Include new engineering models
- Beta release in Bladed 4.7, standard model in Bladed 4.8
- Verification and validation work has been carried out and is still ongoing.
- This presentation focusses on internal verification that has been carried out.

Steady calculations – Performance coefficients

- In Bladed 4.8, flexibilities can be turned on for performance coefficients
- Difference in maximum power coefficient of 0.3% between old and new aerodynamics
- When rotor cone is excluded the difference reduces to 0.03%
- In Bladed 4.8 the power coefficient is computed relative to the coned rotor diameter
- Near high TSR (~11.5) additional differences due to root aerofoil with aggressive stalling behaviour

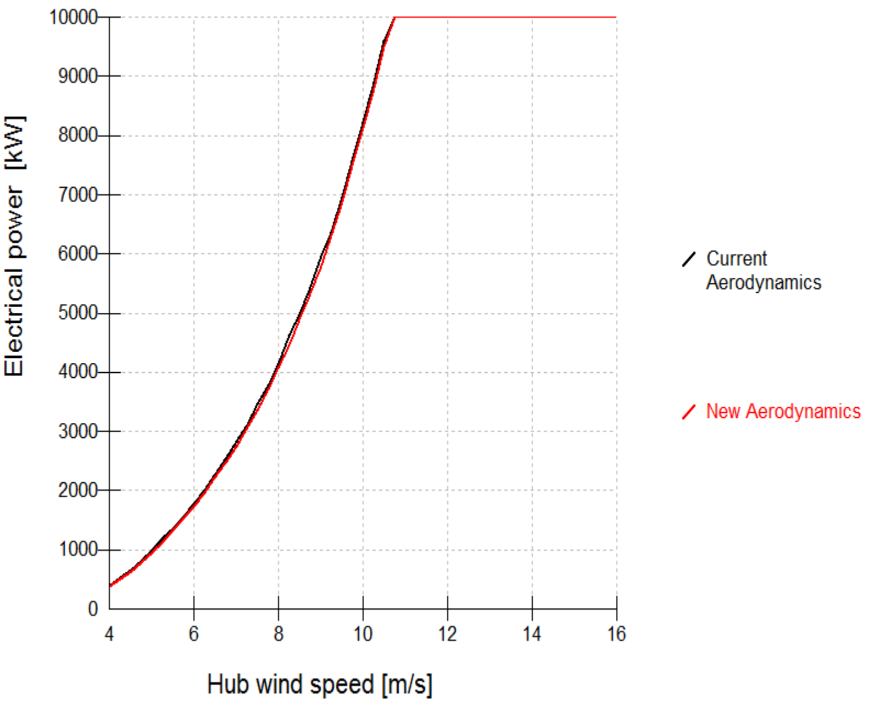


DTU 10MW RWT, rotor speed= 9.6rpm, pitch=0°

Ungraded

Steady Calculations – Steady operational loads

- Differences in energy capture between 0.6-1.3%
- Differences reduce when removing cone/tilt and when switching off blade flexibilities.

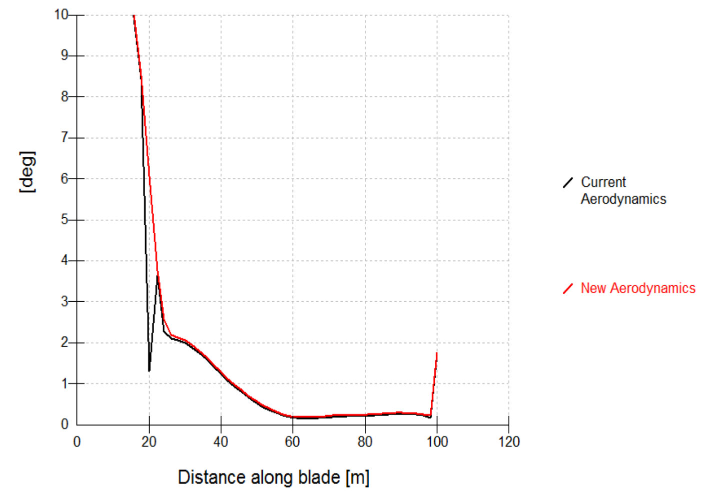


DTU 10MW RWT, 9 blade modes

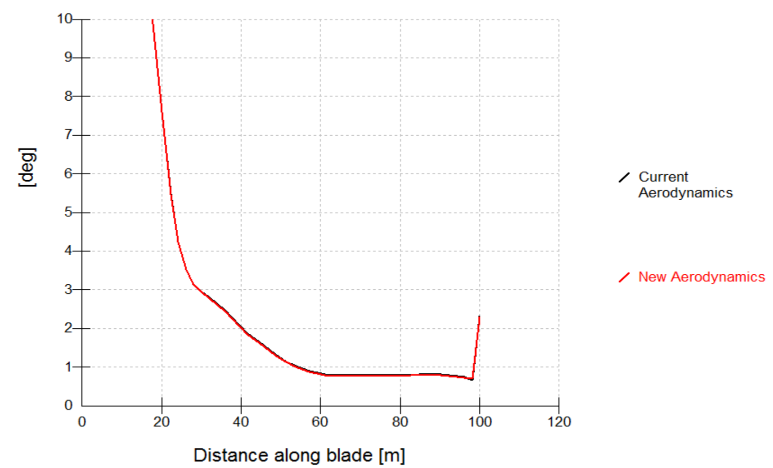
Ungraded

Steady Calculations – Steady operational loads (continued)

- Distributed inflow parameters generally agree well
- Near the root and for lower wind speeds one of the root aerofoils causes a distinct difference in angle of attack and subsequently lift/drag.



DTU 10MW RWT, 9 blade modes, 8 m/s

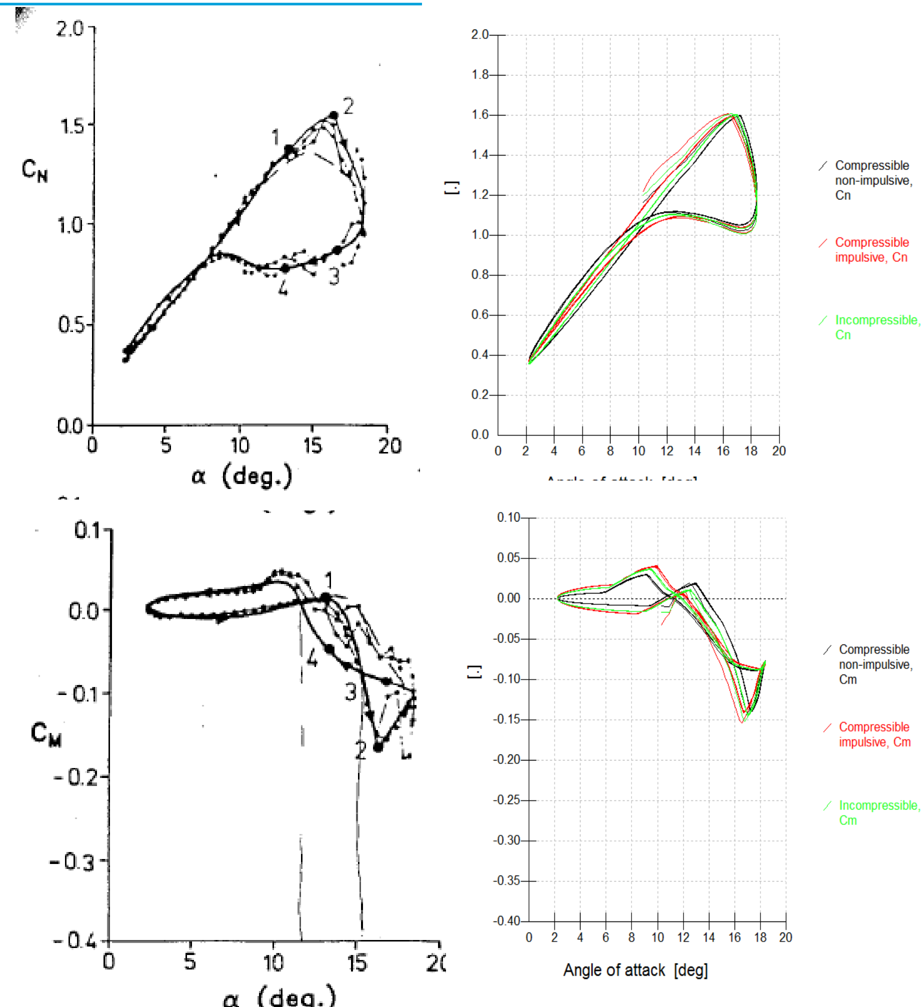


DTU 10MW RWT, 9 blade modes, 10 m/s

Ungraded

Verification of dynamic models – Dynamic stall

- Benchmarking exercises have been carried out, comparing the predictions of the dynamic stall model against Beddoes-Leishman experiments
- Good agreement in peak lift coefficient, and detachment location of leading-edge vortex
- Reattachment delay not modelled in Bladed (Points 3-4 in original figure)



Beddoes-Leishman Bladed

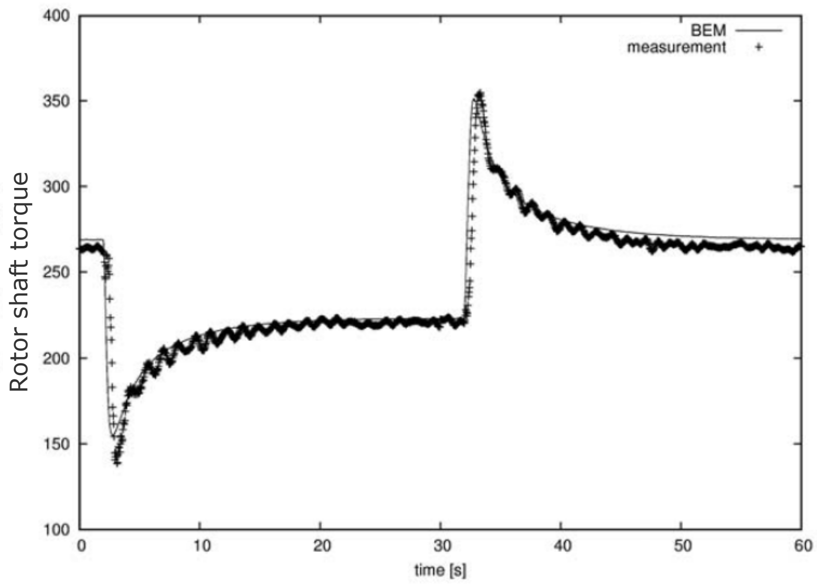
Source: Leishman J.G. and Beddoes T. S. , "A semi-empirical model for dynamic stall", *Journal of the American Helicopter Society*, July 1989

Ungraded

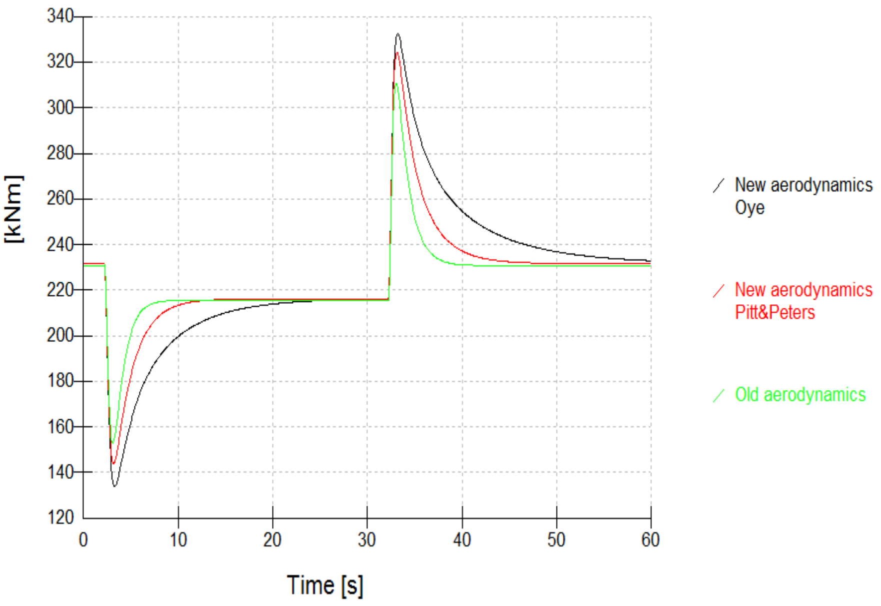
DNV·GL

Verification of dynamic models – Dynamic wake

- Rerunning of Tjaeroeborg pitch step case with different dynamic wake models
- The new aerodynamics has the option to choose between Pitt&Peters (used in old aero) and Øye
- Time lag for the Øye model is larger than Pitt&Peters and gives a better match with measurements of the Tjaereborg pitch step experiments



Measurements



Bladed

Ungraded

Source: Øye, S., "TUDK model". In *Joint Investigation of Dynamic Inflow Effects and Implementation of an Engineering Method*, Appendix N, edited by H. Snel and J.G. Schepers, Petten, 1995

Rerunning full load sets – Fatigue loading

- Four models of multi MW projects are rerun from projects conducted in DNV GL
- Generally differences of DEL in main load components are <5%
- In some models (not reported here) stronger increases are found in Hub Fx fatigue and tower base My. This is suspected to be due to the higher time lag in the dynamic wake model.

Turbine	Blade root My (m=10)	Blade root Mx (m=10)	Hub My(m=4)	Hub Fx (m=4)	Yaw bearing My (m=4)	Yaw bearing Mx (m=4)	Tower base My (m=4)
3MW onshore	-2.9%	0.2%	-0.4%	1.5%	-1.8%	-0.8%	?
2MW onshore	-2.0%	-7.9%	-2.3%	2.3%	-0.5%	1.9%	1.6%
2.5MW onshore	0.0%	1.1%	1.4%	1.4%	0.1%	1.5%	0.3%
6MW offshore	2.1%	0.5%	2.2%	0.9%	1.8%	1.2%	1.2%

Ungraded

Rerunning full load sets – Ultimate loading

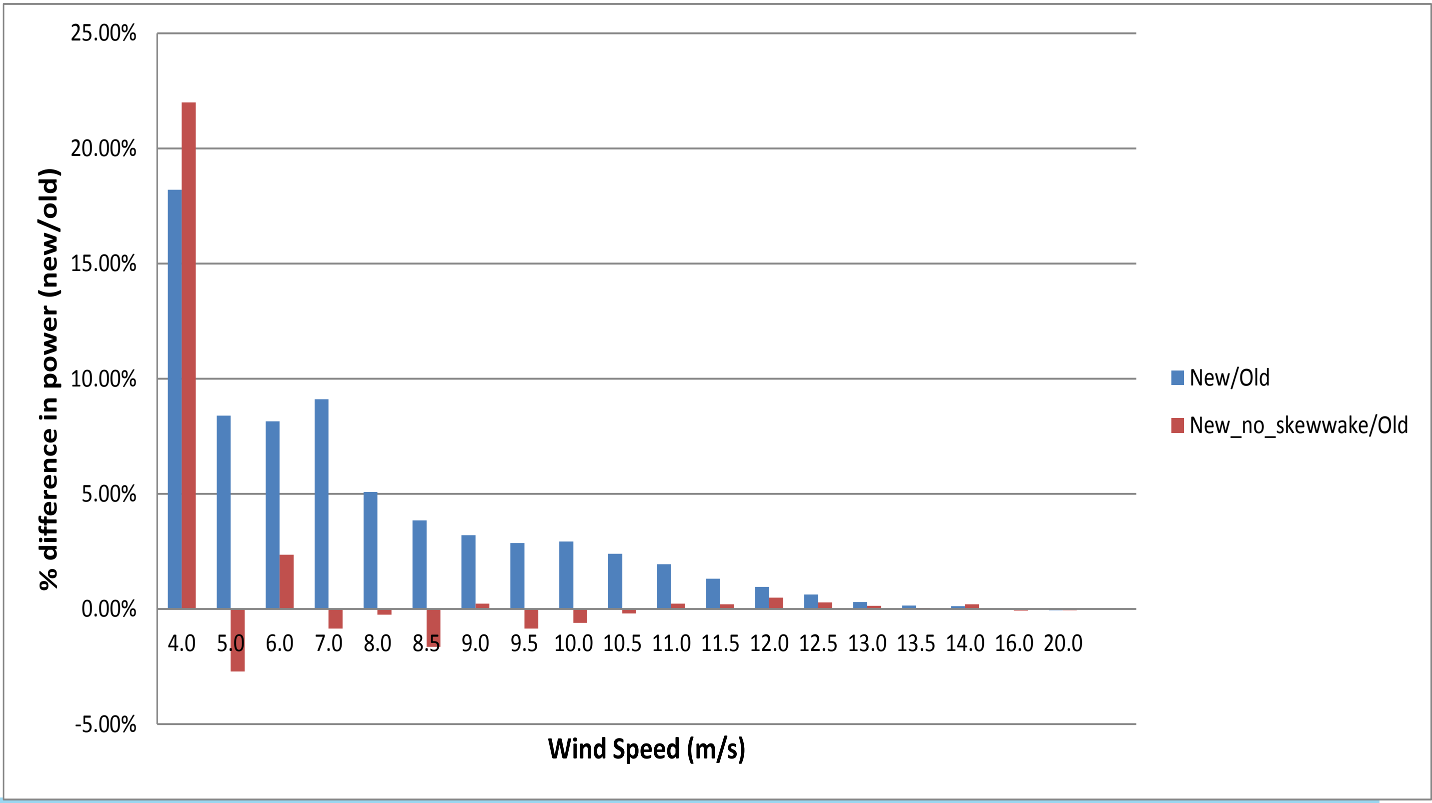
- Cases driven by gust + direction change (dlc1.4) are often affected
- This is caused by the new skew wake model and momentum model which gives higher rotor loading at large yaw angles.
- In quite a number of cases the edgewise modes in dlc6.2 require additional damping as instabilities occurred at +/-30° inflow

Turbine	Blade root Mxy	Blade root Mz	Hub Myz	Hub Fx	Yaw bearing Mxy	Yaw bearing Mz	Tower base Mxy	TCA
3MW onshore	-2.65%	4.82%	-3.79%	-0.08%	4.16%	-0.97%	7.94%	23.8%
2MW onshore	-0.86%	2.31%	6.32%	-1.15%	5.05%	21.86%	1.97%	-2.2%
2.5MW onshore	-0.9%	0.3%	-3.4%	-0.5%	-7%	9.7%	2.6%	-2.4%
6MW offshore	To be confirmed							

Ungraded

Dynamic power curve

- In the dynamic case, larger differences in power capture are seen than in the steady case
- Differences especially noticeable for the low wind speeds
- Switching off the skew wake model and using the axial momentum theory the differences reduce.

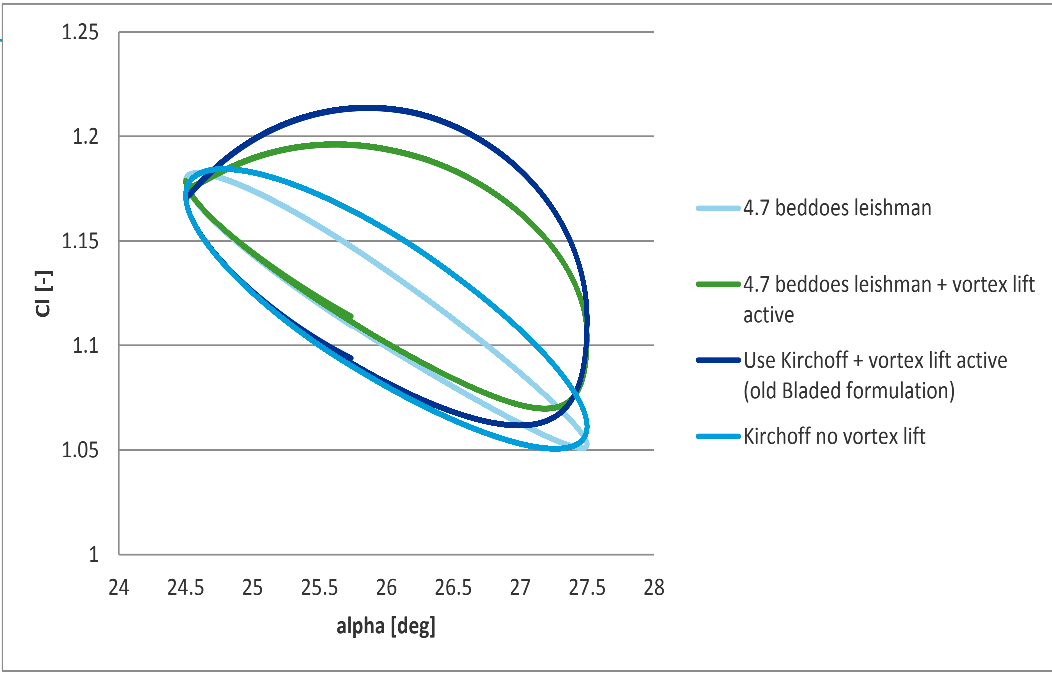


3MW onshore turbine

Ungraded

Edgewise instabilities at 30°

- In dlc6.2 an increase in edgewise instabilities is noticed compared to old aerodynamics.
- This especially occurs at +/-30° angle of attack
- In new aerodynamics the vortex lift term is not active when angles of attack are continuously high
- Also, the original Kirchoff relation is no longer used.
- This leads to lower damping in stalled conditions.



comparison in unsteady lift coefficient of new aerodynamics, $\alpha = 26^{\circ} + 1.5^{\circ} * \sin(1.257\pi t)$, $V_{\infty} = 50$m/s, c=1m

Original Kirchoff (old aero) $$Cn = Cn_{\alpha}\left(\frac{1+\sqrt{f}}{2}\right)^2(\alpha - \alpha_0)$$

New aerodynamics $$Cn = Cn_{\alpha}(\alpha - \alpha_0)f + Cn^{fs}(\alpha)(1-f)$$

Ungraded

Main conclusions

- In steady computations in old aerodynamics, the cone angle is ignored giving leading to differences with new aerodynamics
- New dynamic stall models produce a good match with original Beddoes-Leishman experiments
- New dynamic wake model gives a slower wake recovery than the legacy Pitt&Peters model
- Fatigue load differences generally small, although significant differences in hub Fx have been reported in other instances
- Extreme loads that are driven by gust + direction change are typically increasing
- In idling cases in dlc6.2 edgewise instabilities occur more frequently requiring additional modal damping.
- In low wind speeds significant differences in dynamic power curve are found. This is caused by the new Momentum model and Skew Wake model.

Ungraded

www.dnvgl.com

SAFER, SMARTER, GREENER

Ungraded