Improvements in ECN Wake Model

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H. Özdemir
M.C. Versteeg (University of Twente)
A.J. Brand

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Improvements in ECN wake model

Hüseyin Özdemir
M.C. Versteeg
A.J. Brand

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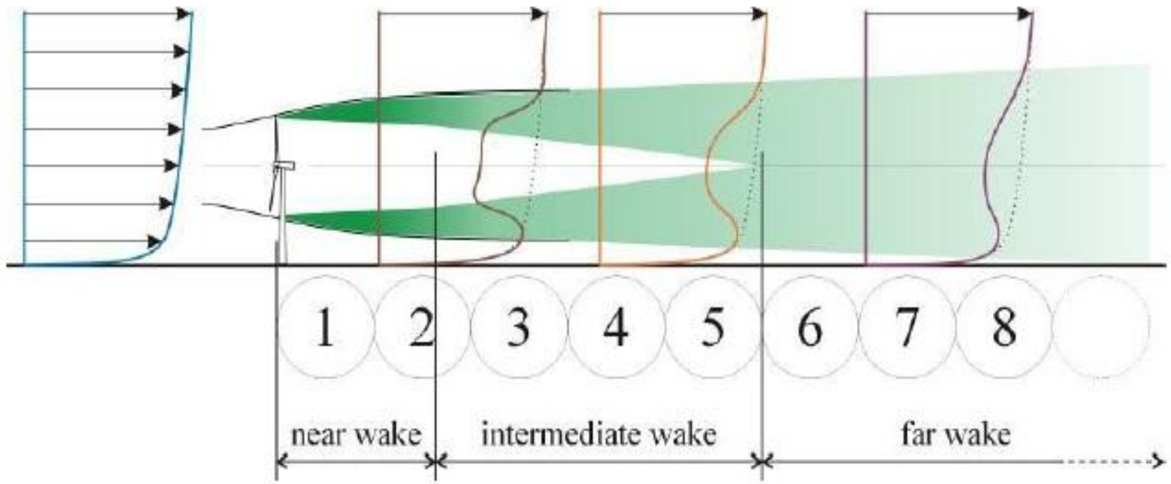
Plan

- Overview of ECN wake model
- Near-wake model
- ABL stability model: preliminary results
- Accuracy studies
- Conclusions

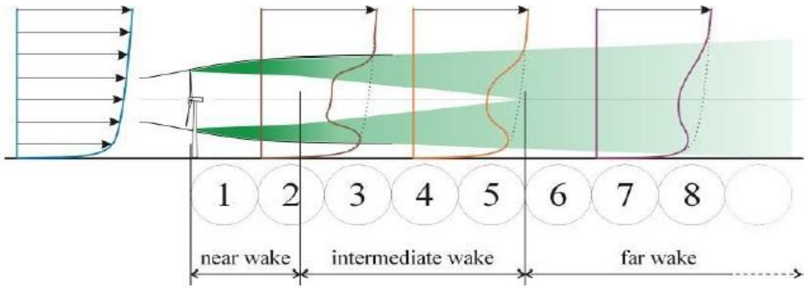
ECN wake model

Structure of a wake



There is dominancy of the flow in the wake direction!

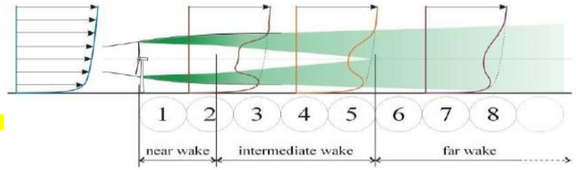
Structure of a wake



Pressure gradient in the wake direction is stronger

Pressure gradient in the wake direction can be neglected

Structure of a wake



- **In whole wake:** Dominancy of the flow in the wake direction.
- **In the far wake region:** Pressure gradient in the wake direction can be neglected
- **In the near wake region:** Pressure gradient in the wake direction is strong
- **Wind turbine:** Can be modeled as perturbation to the mean flow

  - **Parabolized Navier-Stokes** equations can be applied
  - Background (mean) flow should be described

WakeFarm model

- Parabolized Navier-Stokes equations:
  - Steady PNS equations (cont. + momentum + energy for temperature)
  - k-ε model for the turbulent transport coefficients
  - Upstream cannot be affected by the flow downstream
- Solution is written in perturbation form:

$$u = u_0 + u'$$

Non-uniform background flow:

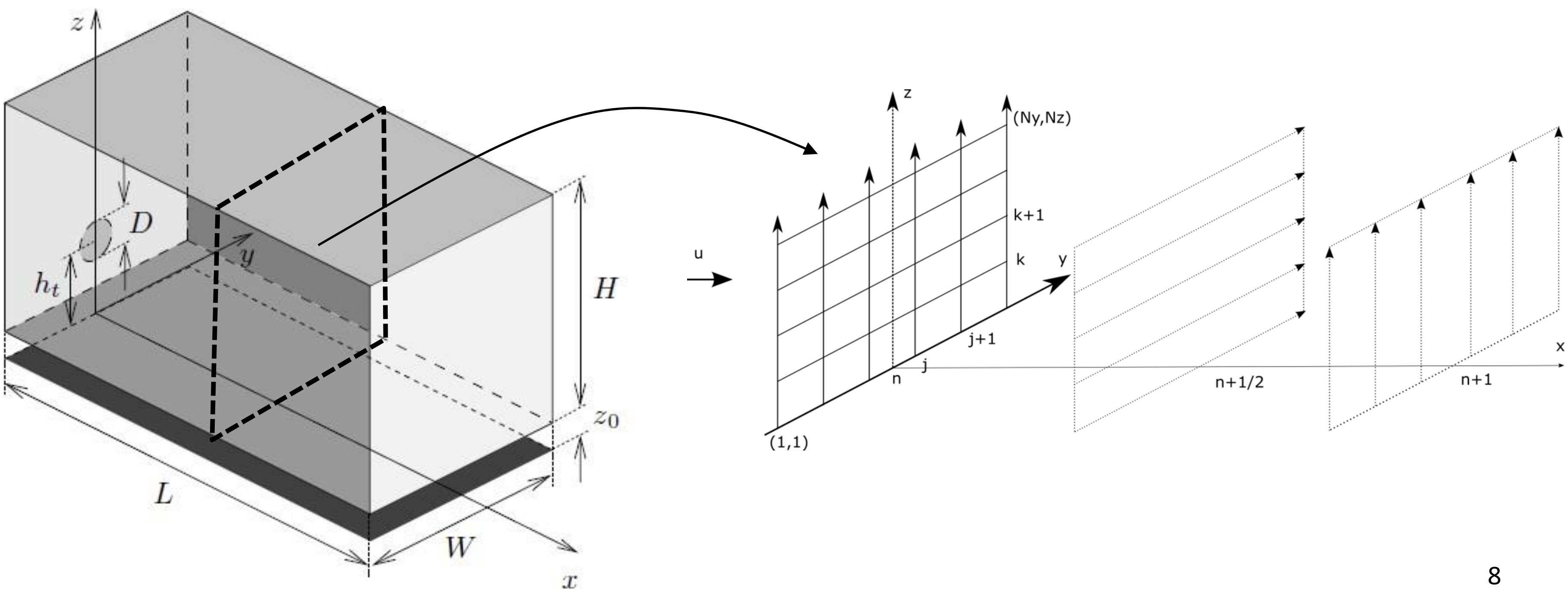
✓ near-wake effects

✓ atmospheric boundary layer effects

Perturbation caused by the wind turbine on to the background flow

WakeFarm: Numerical method

- ADI finite-difference scheme
- SIMPLE pressure correction method (v and w)

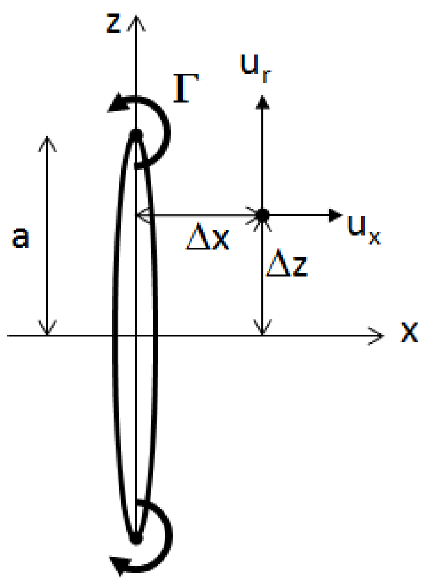


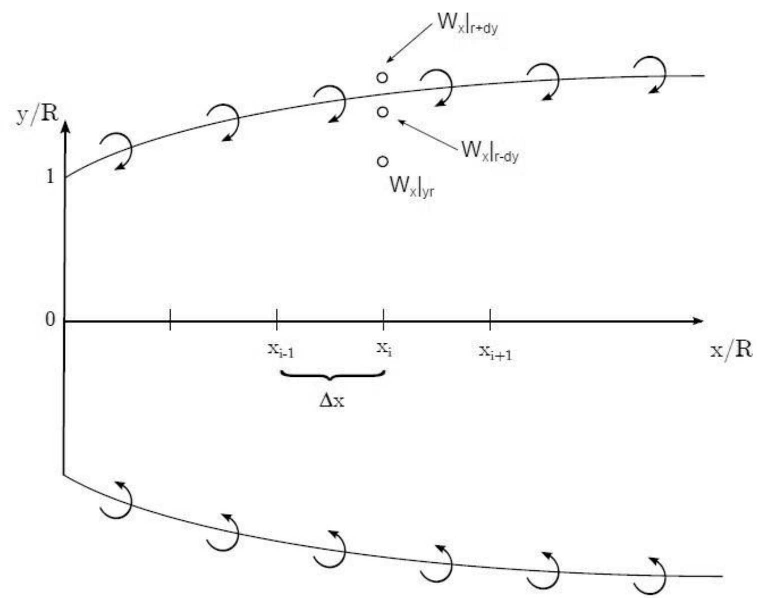
Near-wake model

Near-wake model

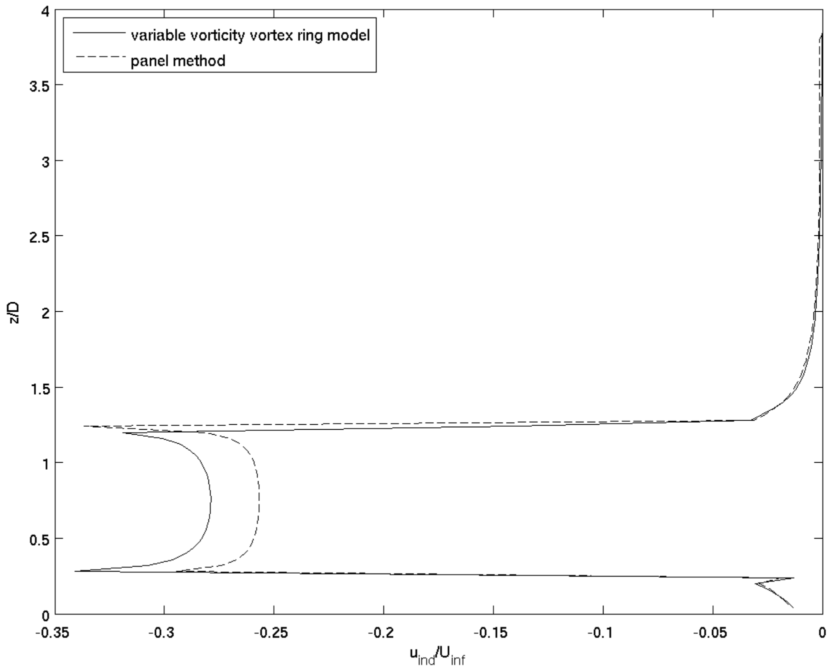
- Free vortex-wake model
- Biot-Savart law
- Semi-analytic vortex ring solution

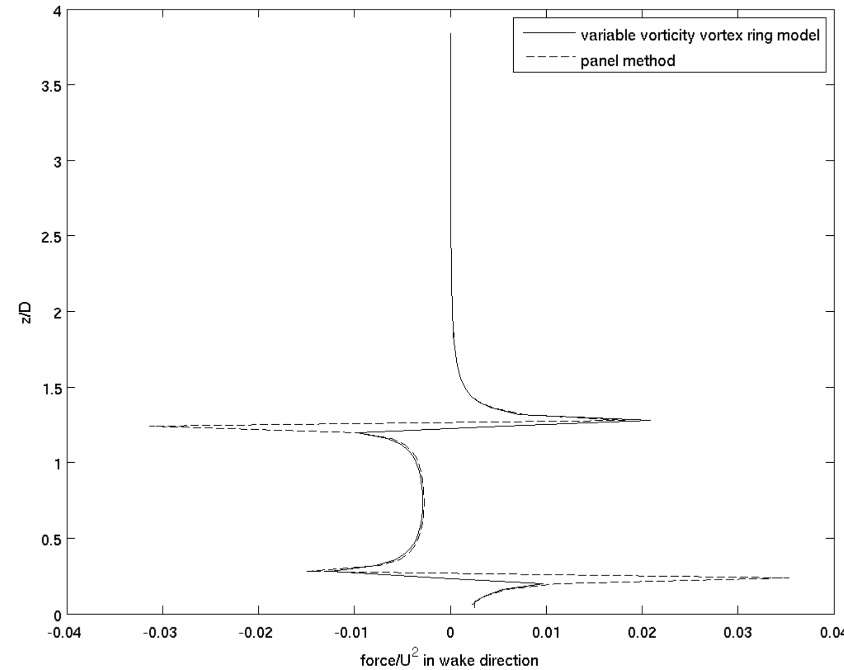
$$\Gamma = \frac{U_\infty^2}{2U_{tube}} 4a(1-a) = \frac{U_\infty^2}{2U_{tube}} C_T$$



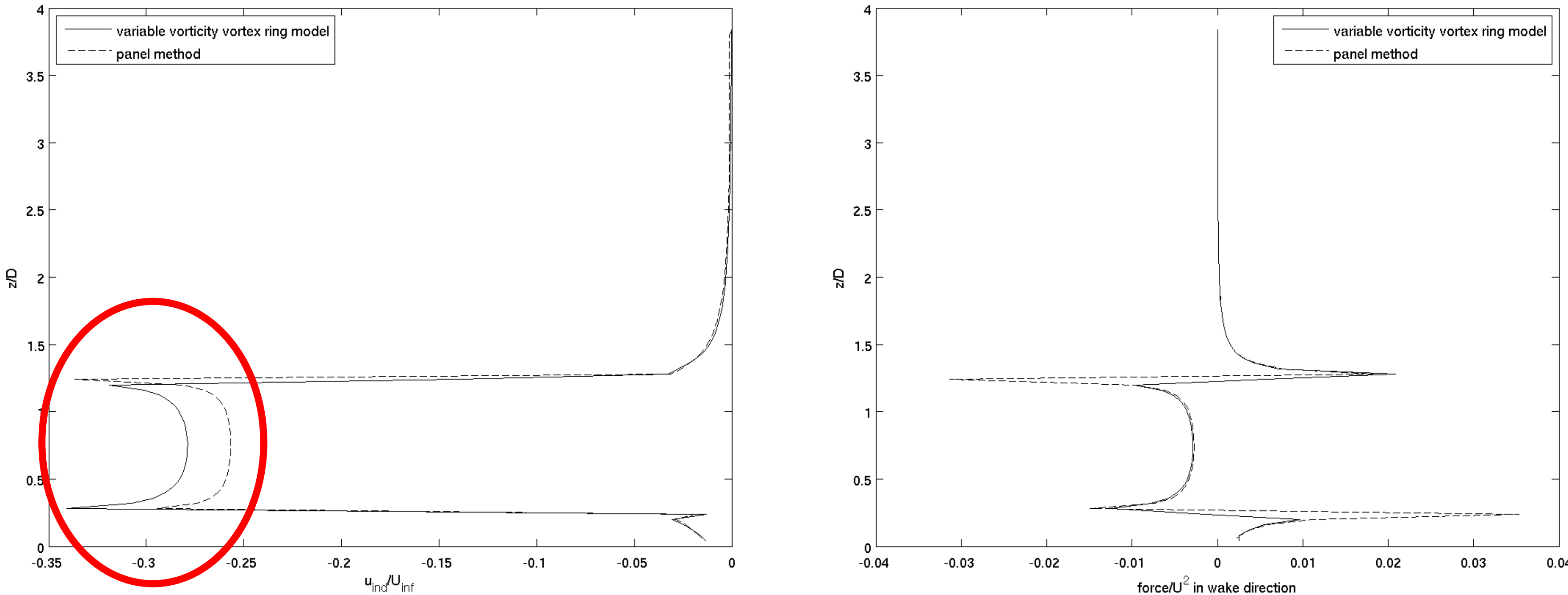


Comparison of near-wake models

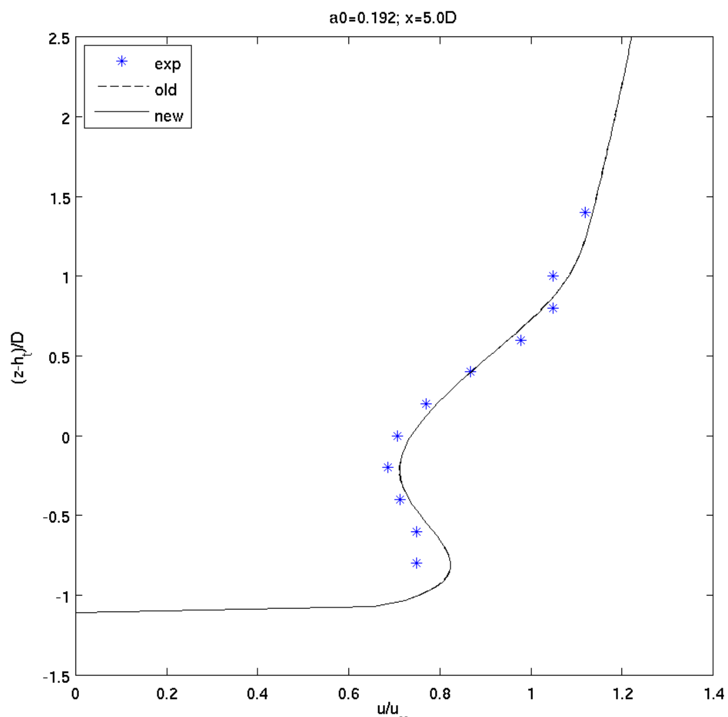


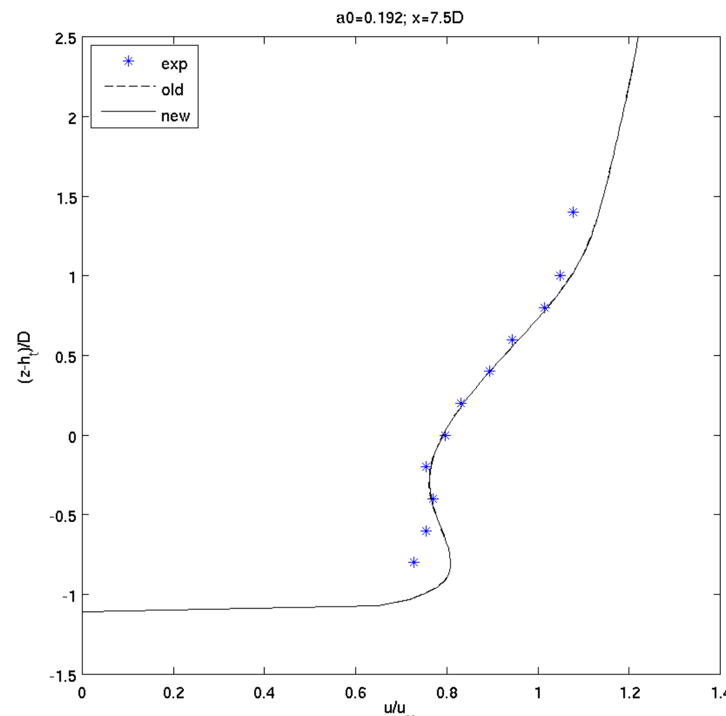


Comparison of near wake models

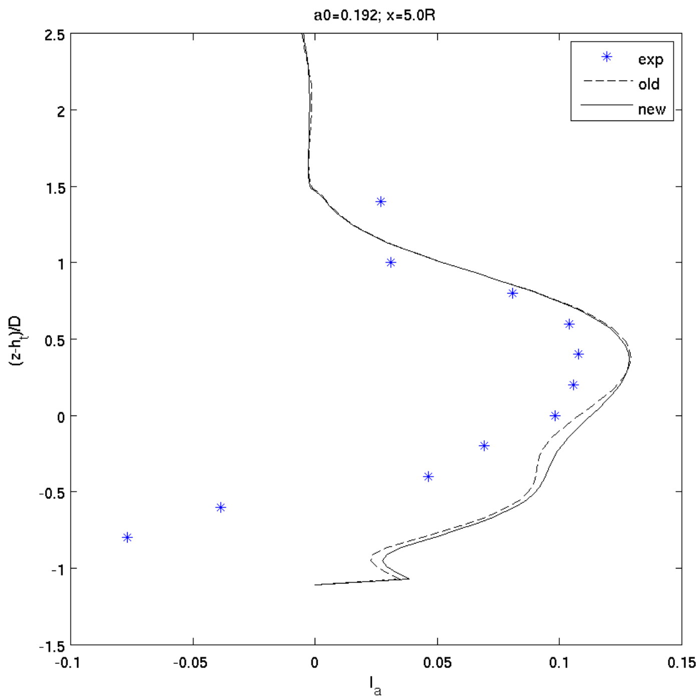


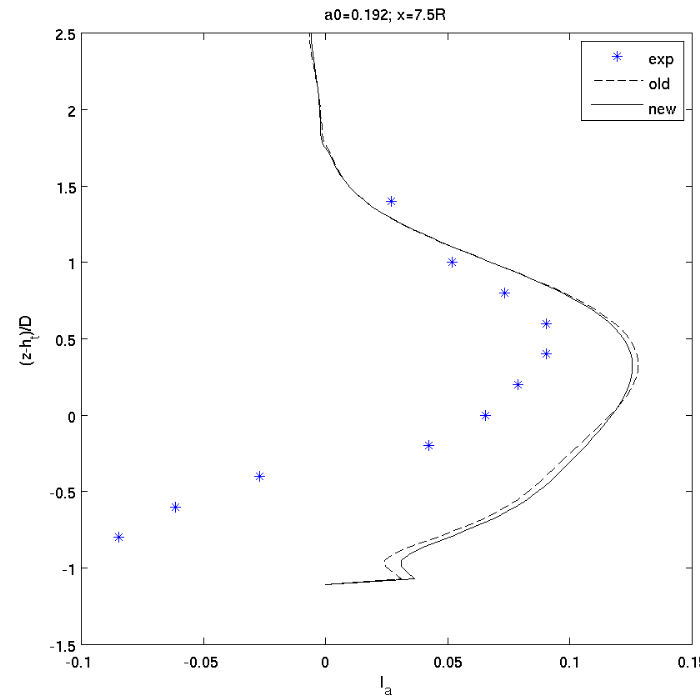
Near-wake model: Marchwood measurements



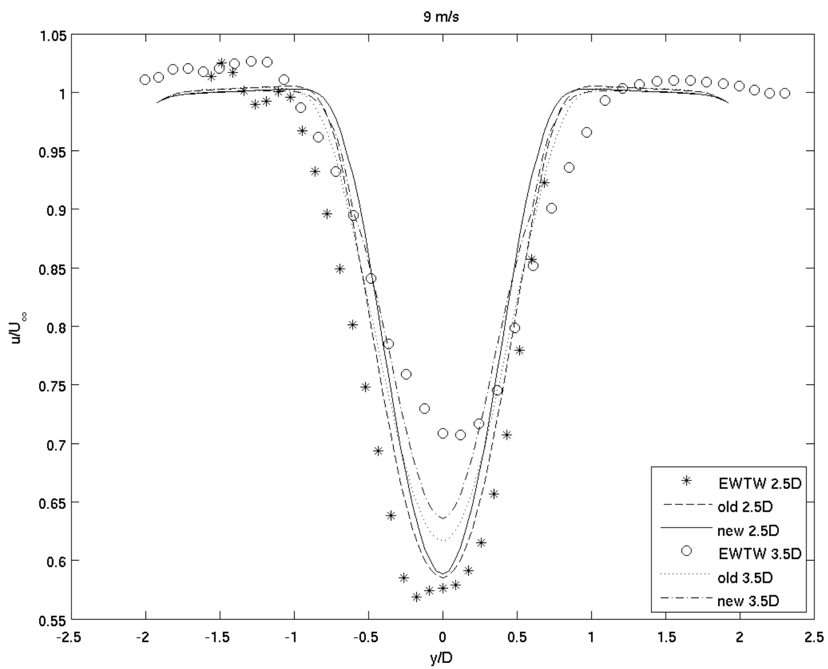


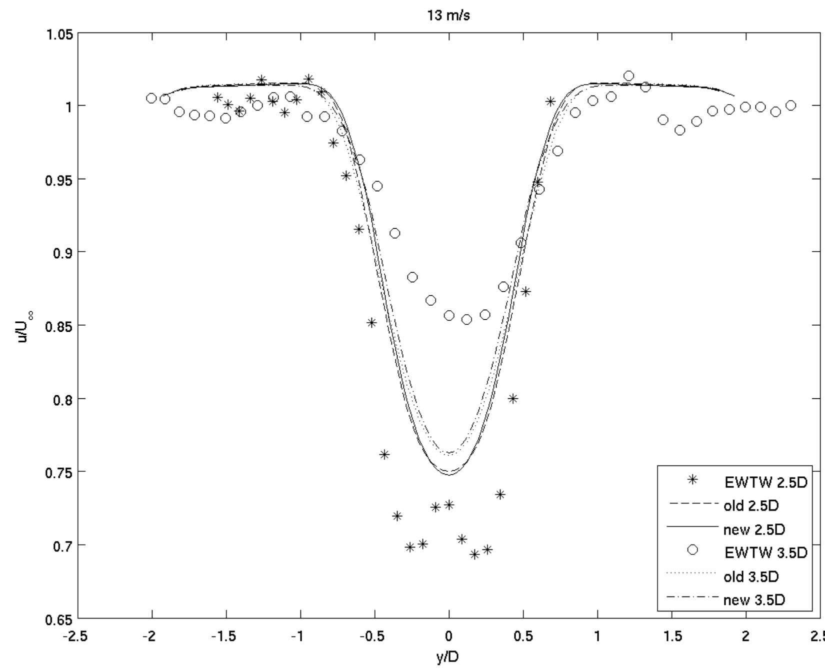
Near-wake model: Marchwood measurements





Near-wake model: EWTW measurements



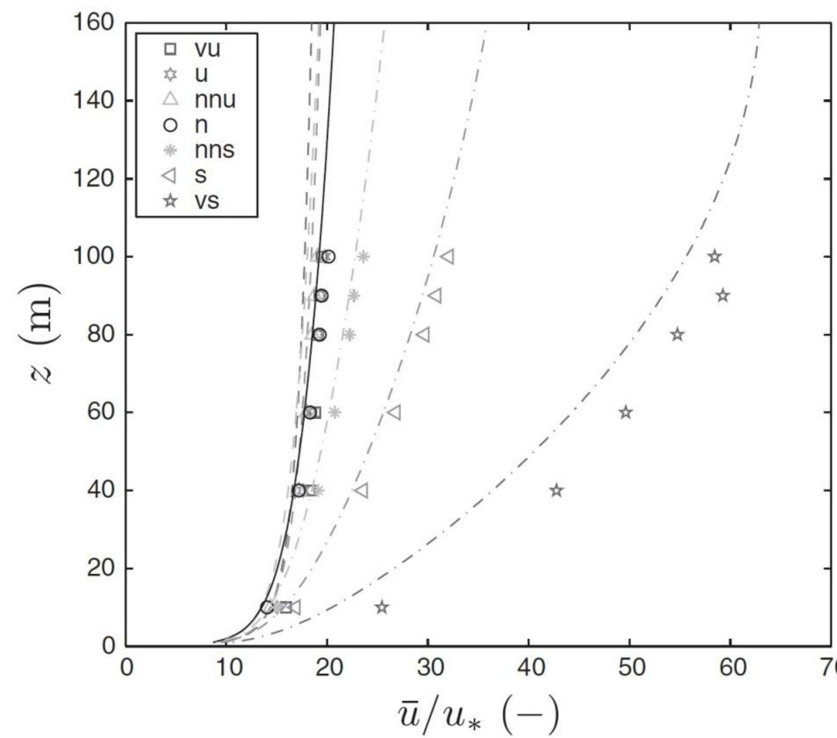


Atmospheric Boundary Layer (ABL) stability model

ABL stability model

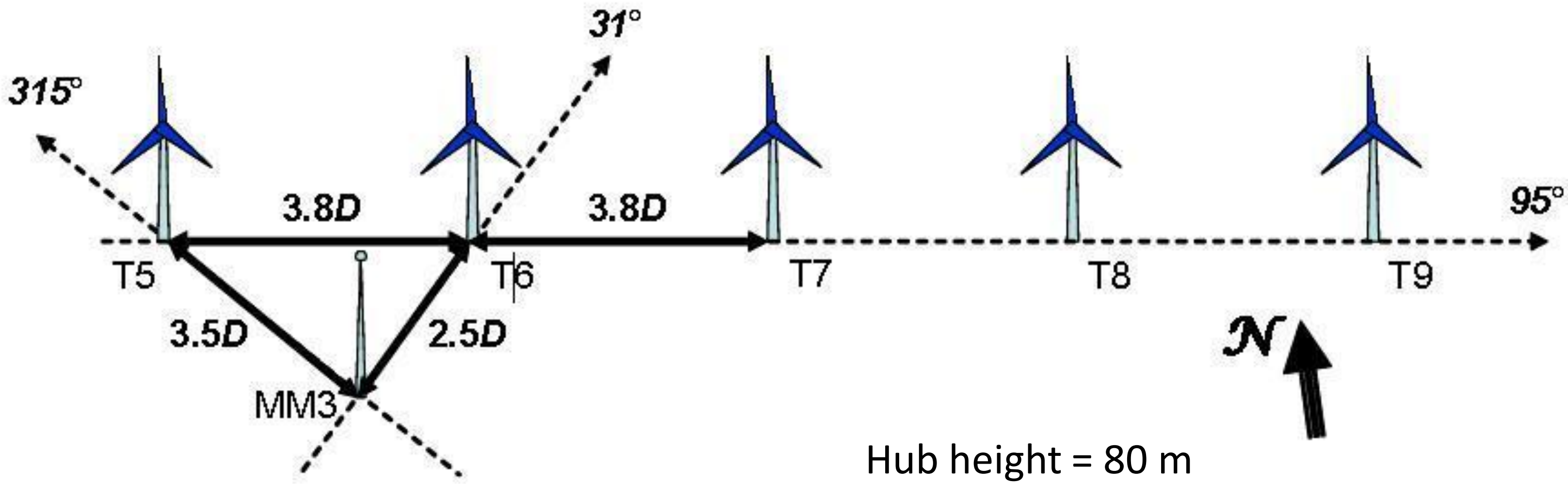
- Surface-layer approximation is mainly valid within 50-60m
- A model including above surface-layer effects is implemented [Gryning etal. Boundary-Layer Meteorology 2007-124, see figure]

$$\frac{1}{l} = \frac{1}{L_{SL}} + \frac{1}{L_{MBL}} + \frac{1}{L_{UBL}}$$



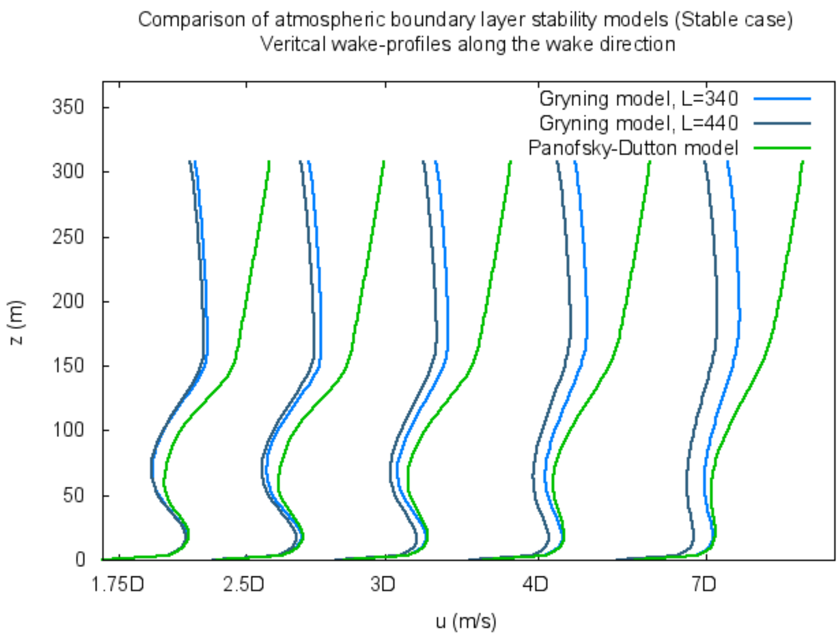
dashed: unstable
solid: neutral
dash-dot: stable

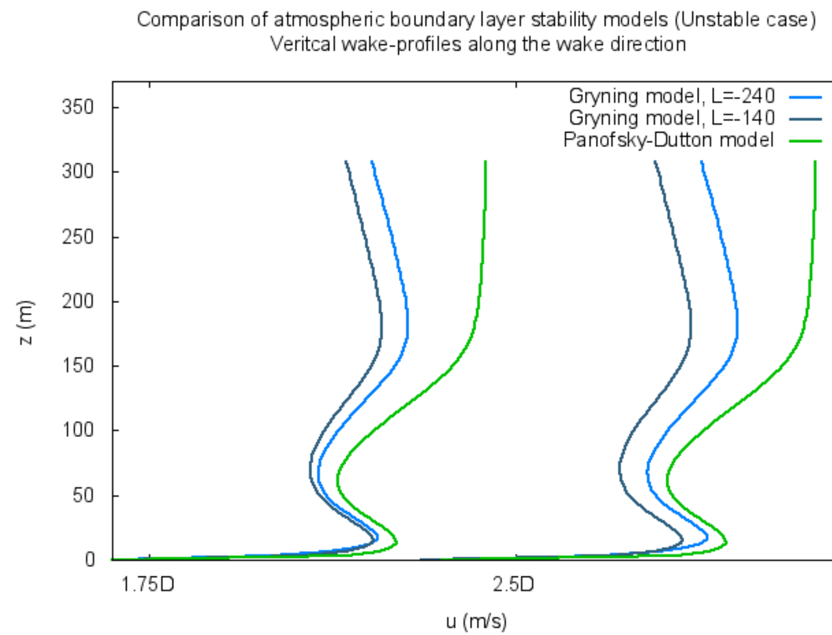
ABL stability model: EWTW measurements



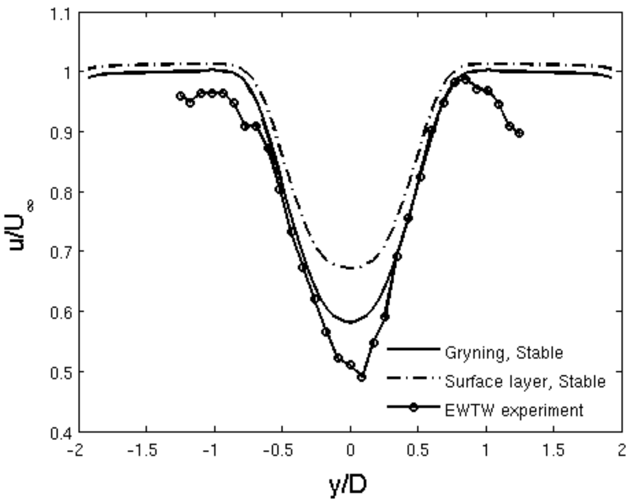
Hub height = 80 m
Diameter = 80 m

ABL stability model: Gryning model

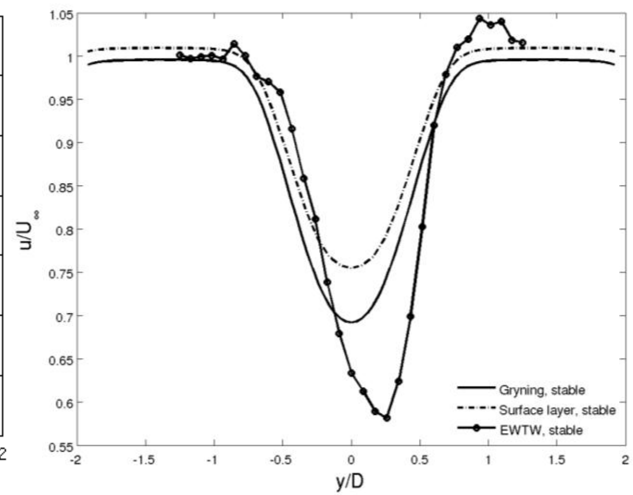




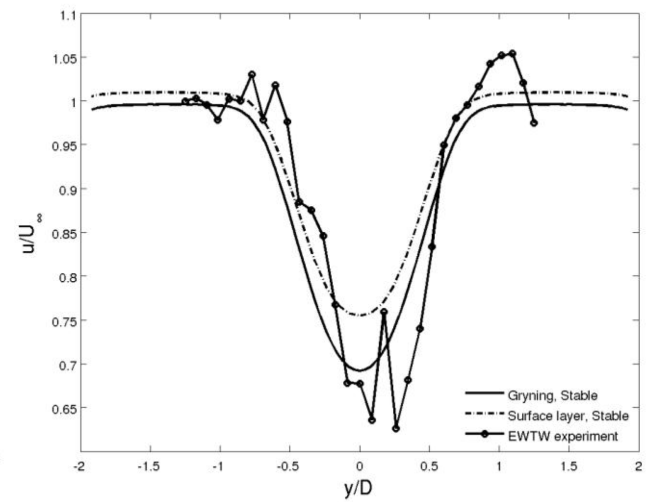
ABL stability model: Gryning model



whole year
whole day



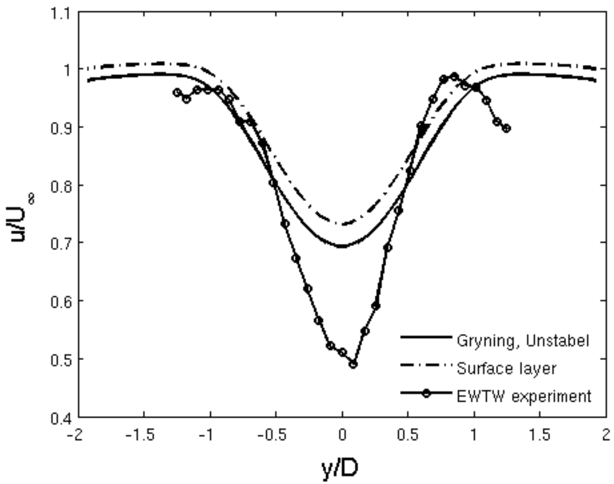
whole year
after sunset

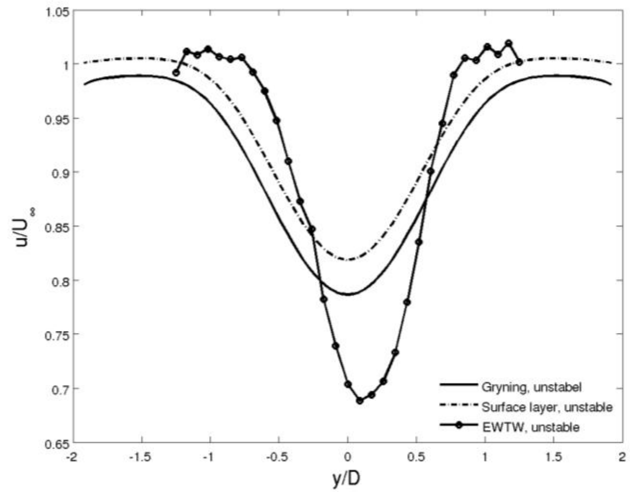


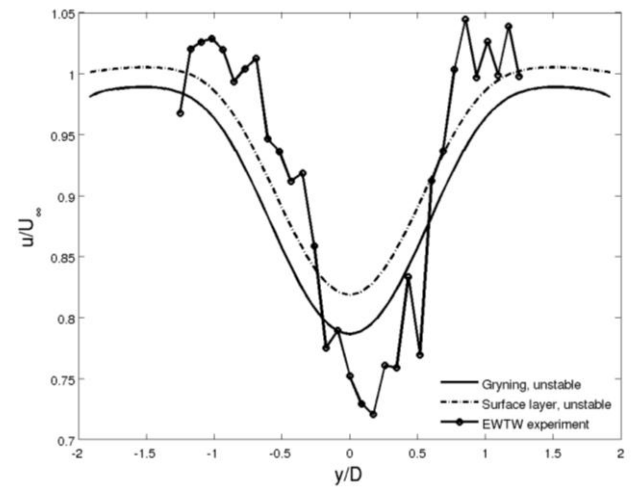
may-august
00:00-04:00h

Comparison of stable cases, at 3.5D downstream.

ABL stability model: Gryning model







whole year
whole day

whole year
after sunset

may-august
12:00-16:00h

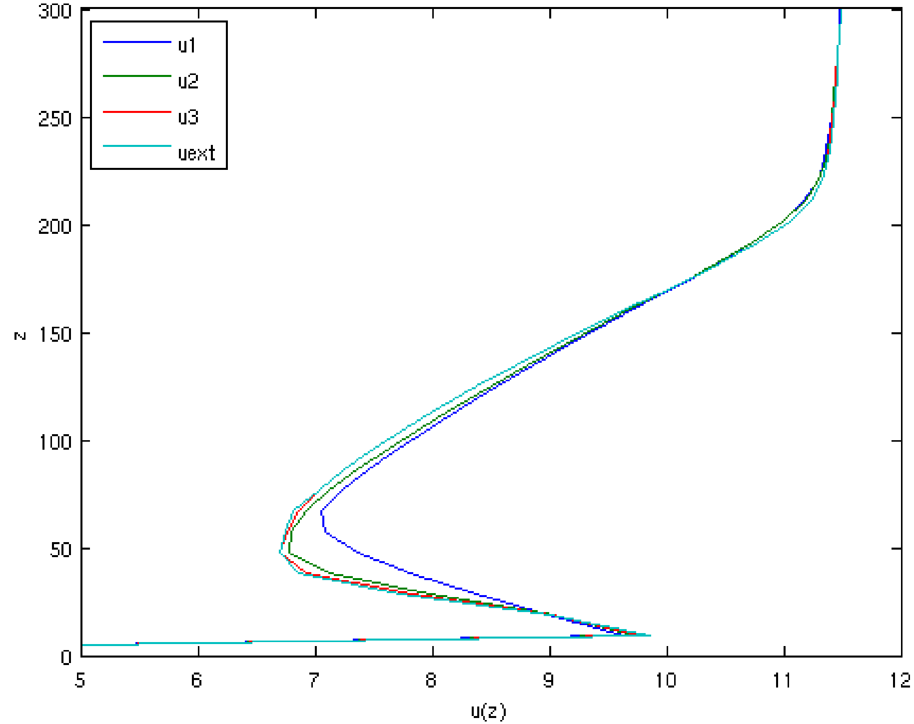
Comparison of unstable cases, at 3.5D downstream.

Numerical accuracy

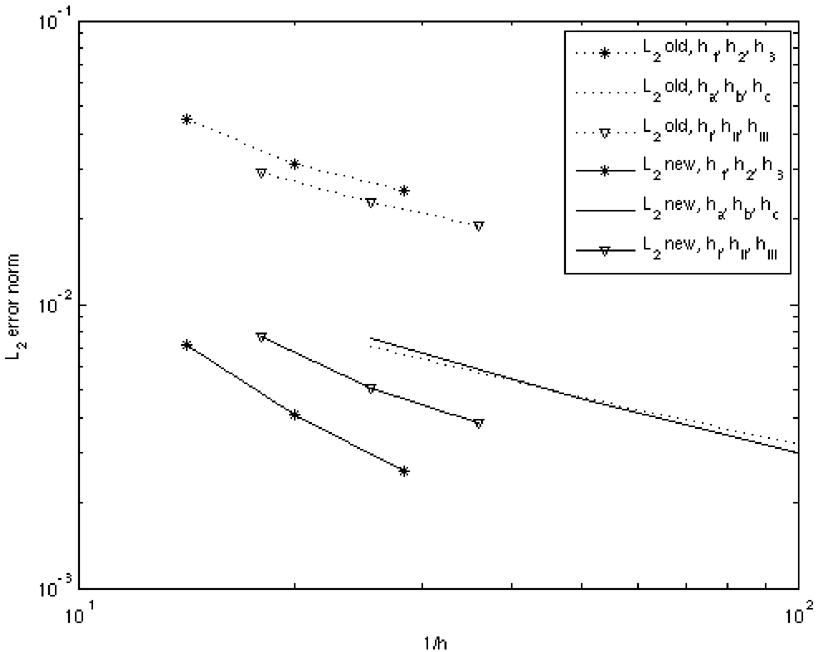
Numerical accuracy

$$\varepsilon = \phi_h - \phi_{ex} = C h_i^{\mathfrak{p}}$$

$$L_2 = \sqrt{\frac{1}{N}\sum_{k}^{N} \varepsilon_k^2}.$$



Numerical accuracy



	$\mathbf{h_i/D}$	x_{end}/D	Nx	Ny	Nz
h_1	$7.07 \cdot 10^{-2}$	7	112	48	48
h_2	$5.00 \cdot 10^{-2}$	7	112	96	96
h_3	$3.53 \cdot 10^{-2}$	7	112	192	192
h_a	$3.92 \cdot 10^{-2}$	1	26	96	96
h_b	$1.98 \cdot 10^{-2}$	1	51	192	192
h_c	$1.00 \cdot 10^{-2}$	1	100	384	384
h_I	$5.55 \cdot 10^{-2}$	1	26	48	48
h_{II}	$3.92 \cdot 10^{-2}$	1	26	96	96
h_{III}	$2.77 \cdot 10^{-2}$	1	26	192	192

Method	Accuracy
P_{12}	*1.5784*
P_{23}	*1.3457*

Conclusions

- Both near-wake and ABL stability model implemented gave optimistic preliminary results

- There is a real need for validation data especially to validate wake models

Thanks

Dank voor uw aandacht

Deze presentatie werd samengesteld in nauwe samenwerking met:

ECN

Westerduinweg 3	P.O. Box 1
1755 LE Petten	1755 ZG Petten
The Netherlands	The Netherlands
T +31 88 515 49 49	info@ecn.nl
F +31 88 515 44 80	**www.ecn.nl**

ECN
Westerduinweg 3
1755 LE Petten
The Netherlands

P.O. Box 1
1755 LE Petten
The Netherlands

T +31 88 515 4949
F +31 88 515 8338
info@ ecn.nl
www.ecn.nl