RANS simulation of a wind turbine wake in the neutral atmospheric pressure-driven boundary layer

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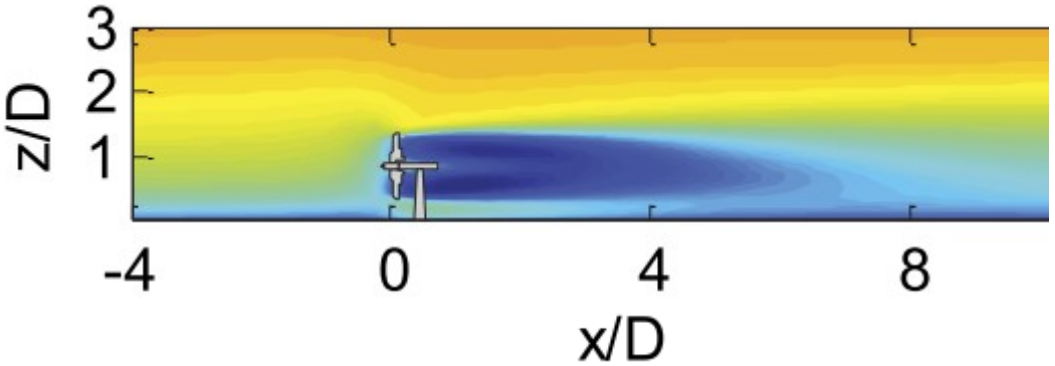
A typical RANS validation

Obtain LES data

Abkar and Porte-Agel (2015)



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Find U_{ref} and I_{ref}

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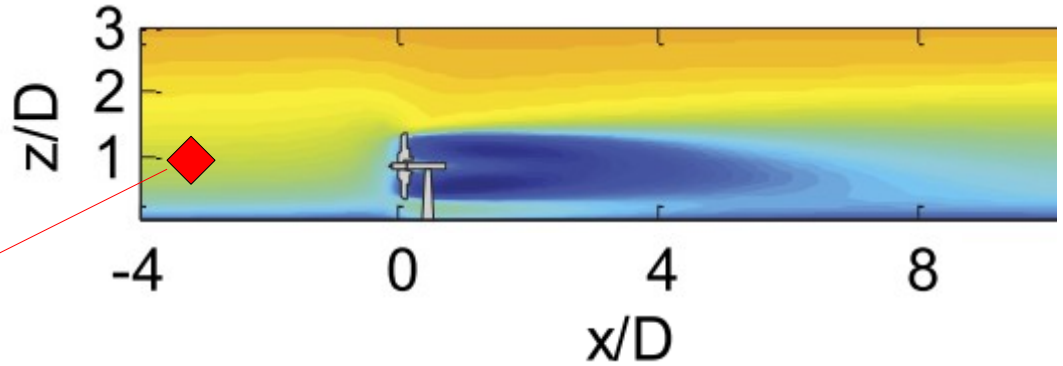

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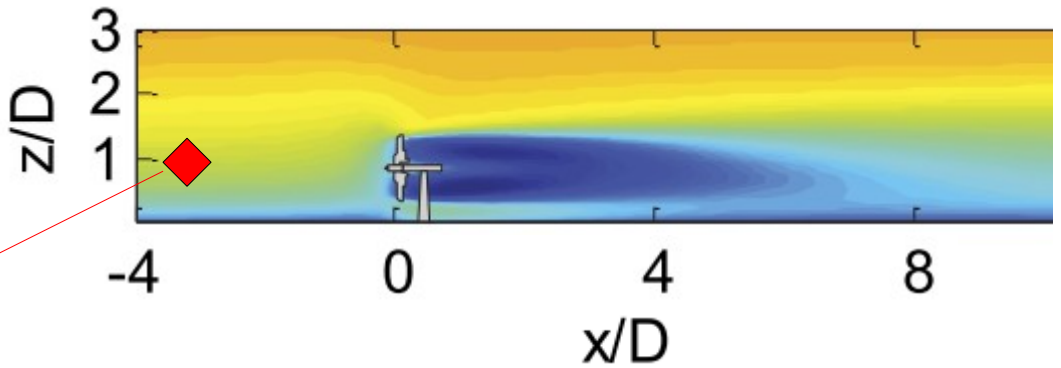

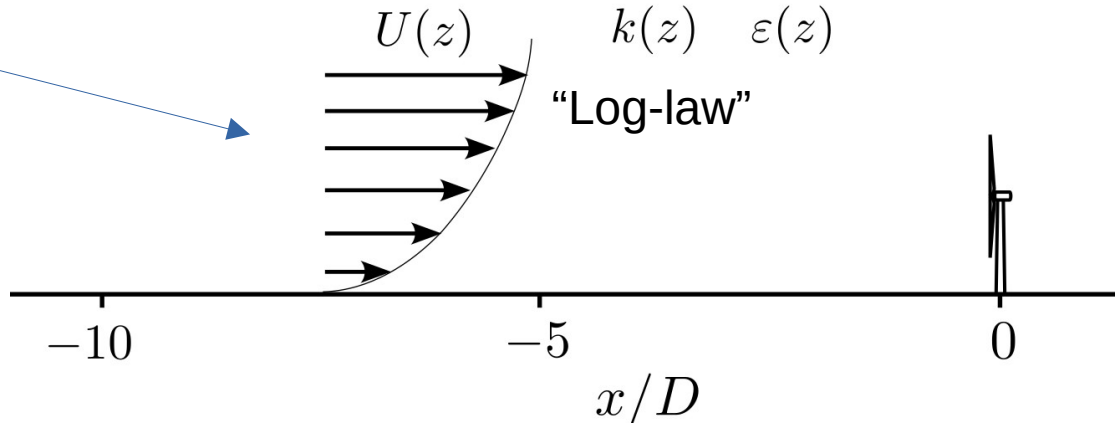

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Construct inflow profiles for RANS

Run RANS and compare results to LES

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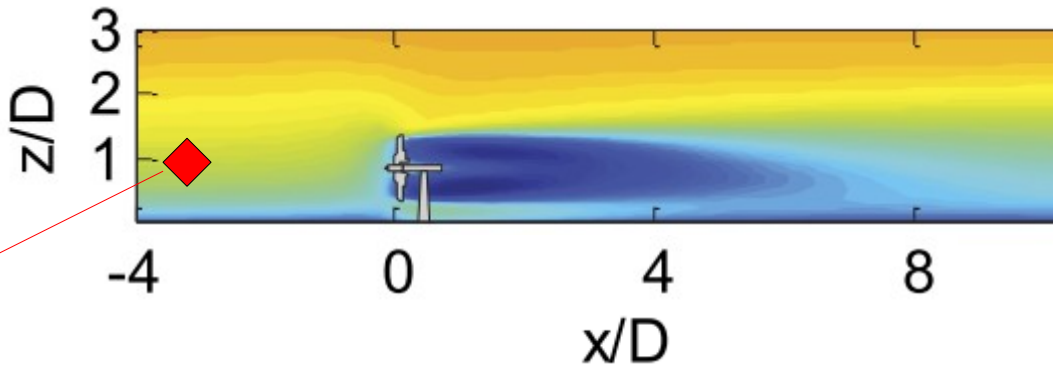

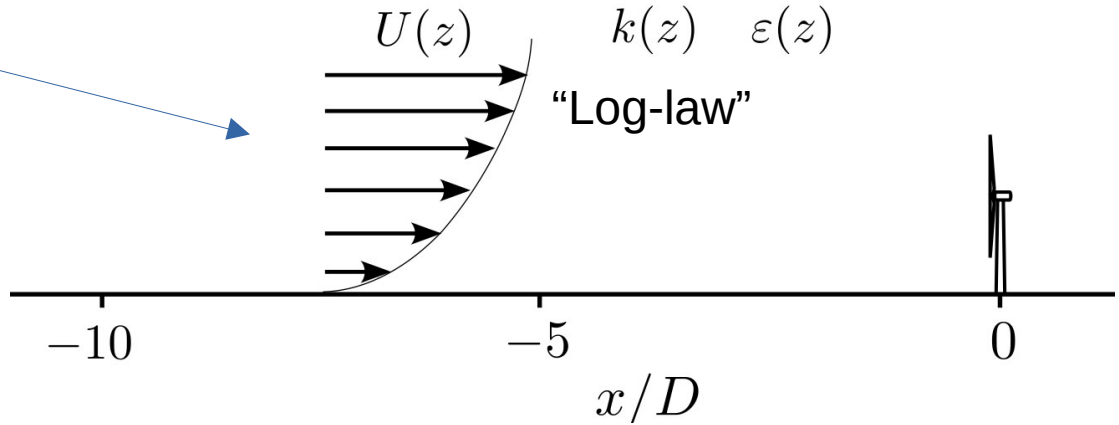

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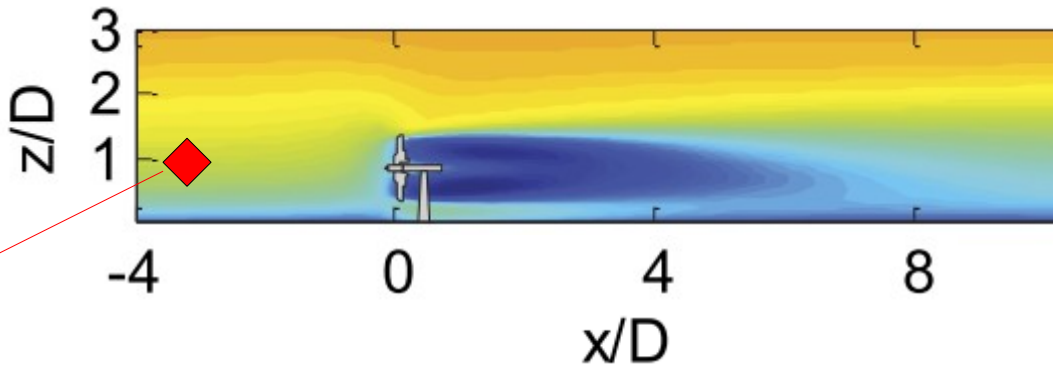
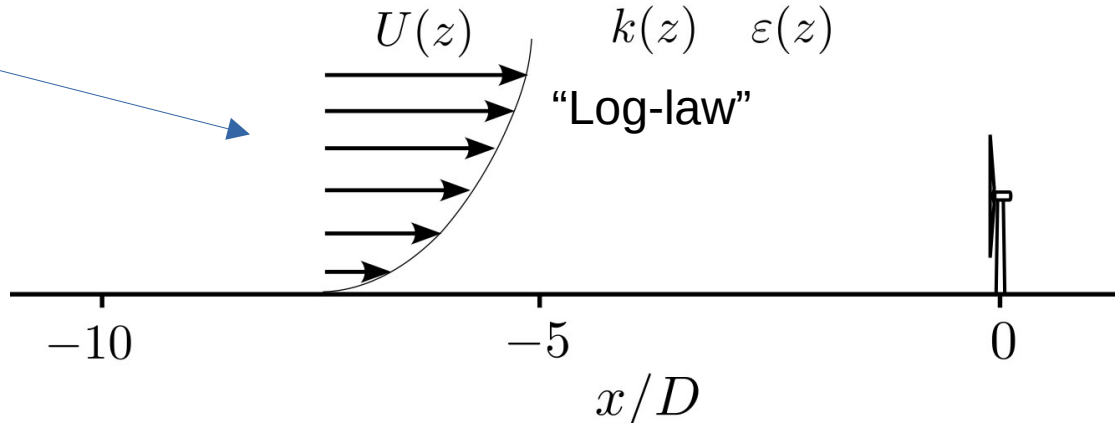




Constructing log-law profile

Aka. “neutral atmospheric surface layer (ASL)”

- The standard inflow in EllipSys3D RANS
- Analytic: Set $(u_*,\ z_0)$ to obtain $(U_{\mathrm{ref}},\ I_{\mathrm{ref}})$

Atmospheric log-law:

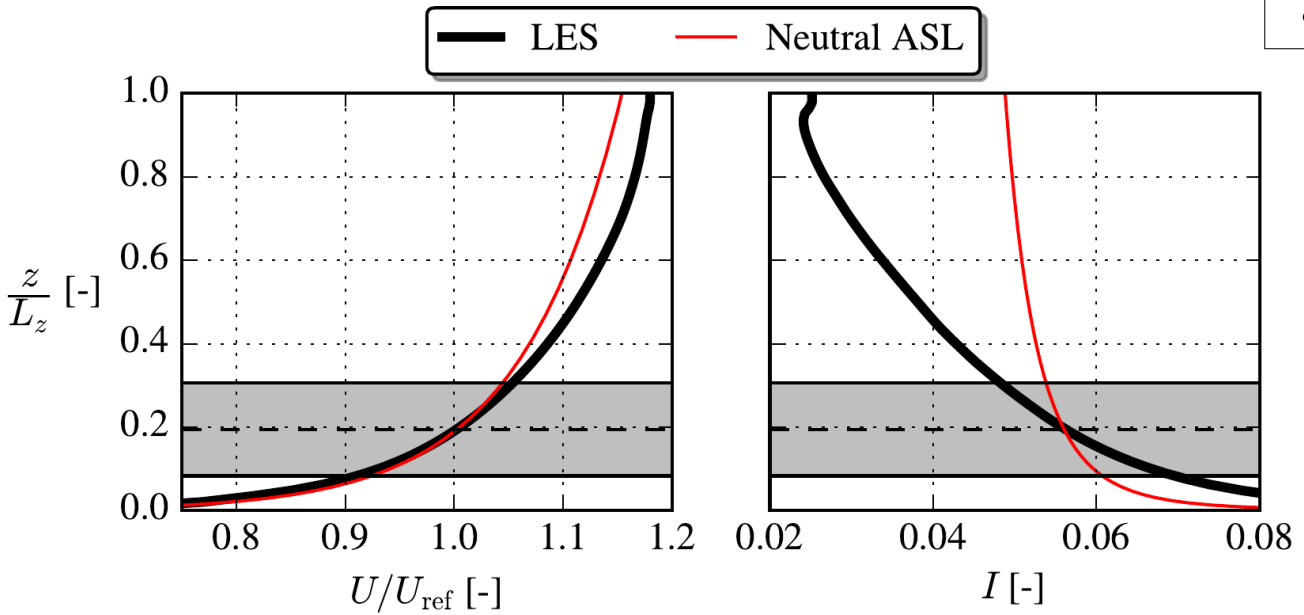
$$U(z) = \frac{u_*}{\kappa}\ln(z/z_0)$$

$$k(z) = u_*^2 C_\mu^{-1/2}$$

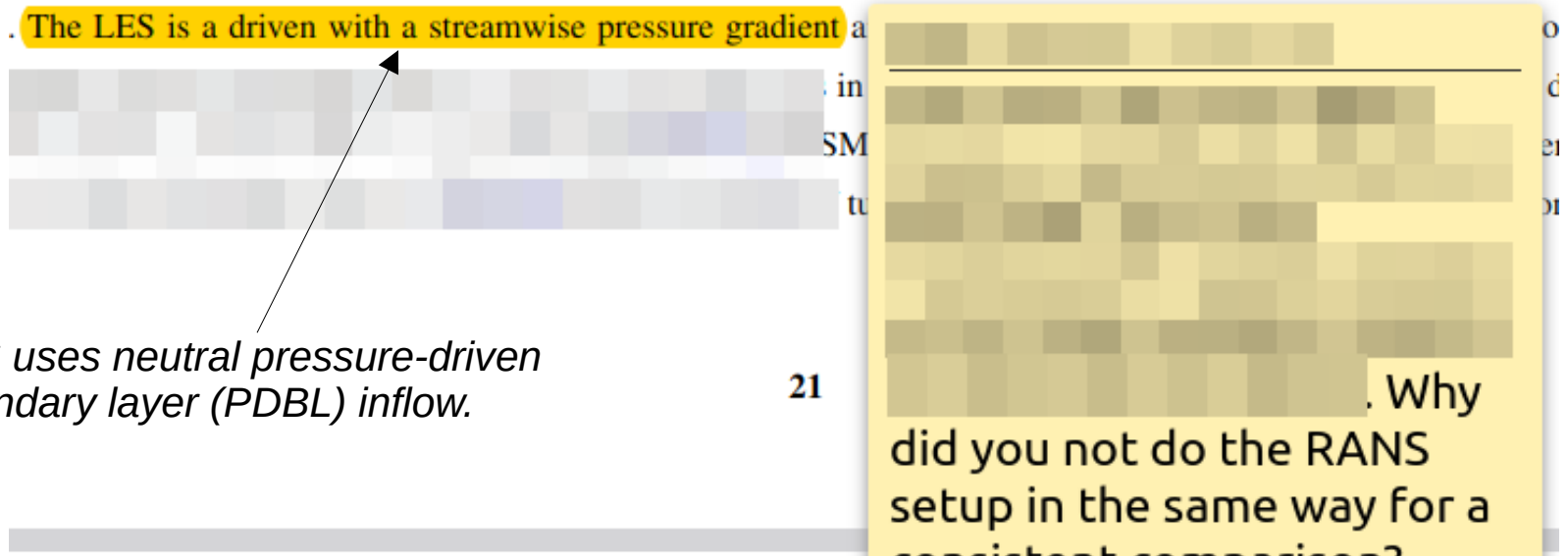
$$\varepsilon(z) = u_*^3 \kappa^{-1} z^{-1}$$

$$\Downarrow$$

$$I(z) = \frac{\sqrt{\frac{2}{3}k}}{U}$$



A “consistent comparison”

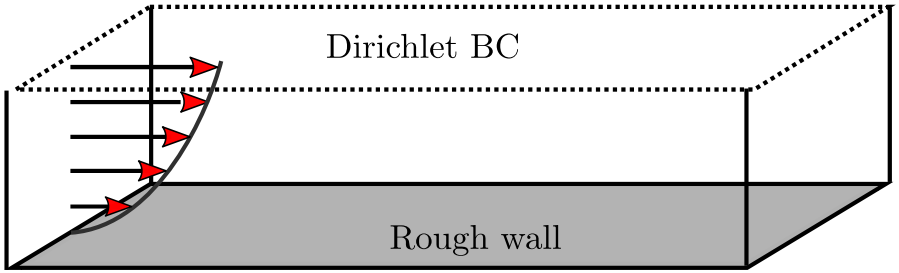


LES uses neutral pressure-driven boundary layer (PDBL) inflow.

⇒ *Also use PDBL in RANS!*

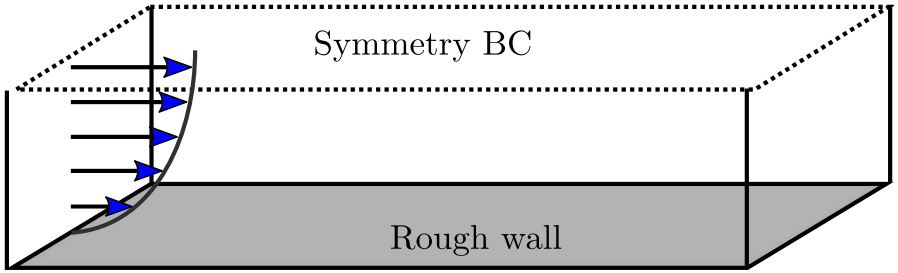
ASL vs PDBL

ASL



- Analytic inflow
- Dirichlet-driven (dP/dx = 0)

PDBL



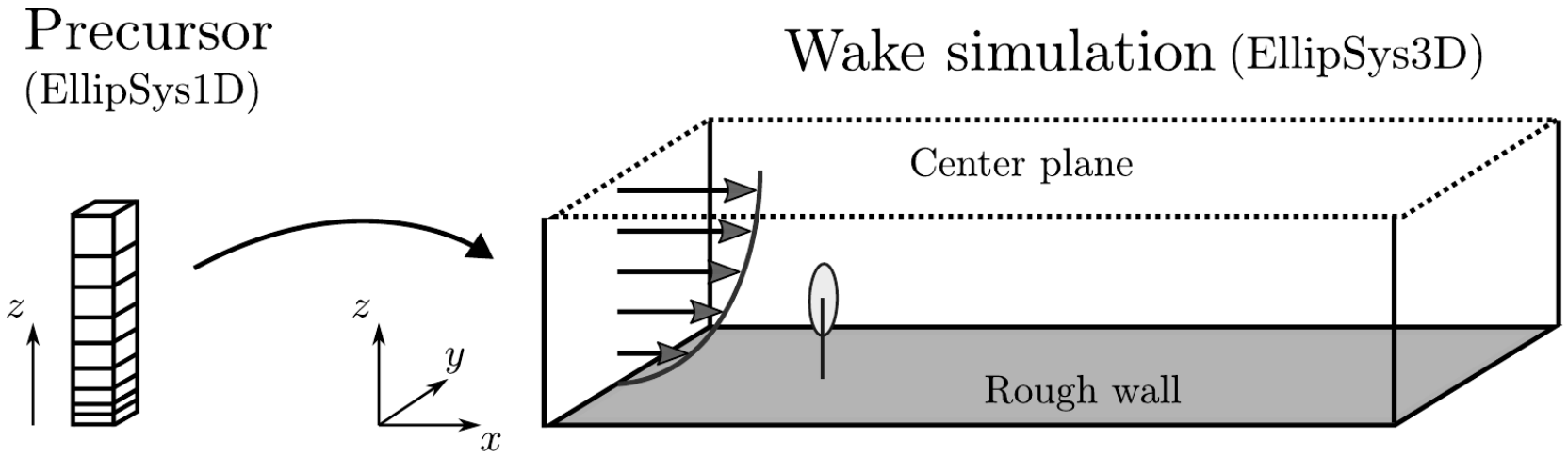
- No analytic inflow (need precursor)
- Pressure-driven (dP/dx < 0)

Different profiles of:

1) *Velocity*
2) *Tubulent kinetic energy (TKE)*
3) *Shear stress*

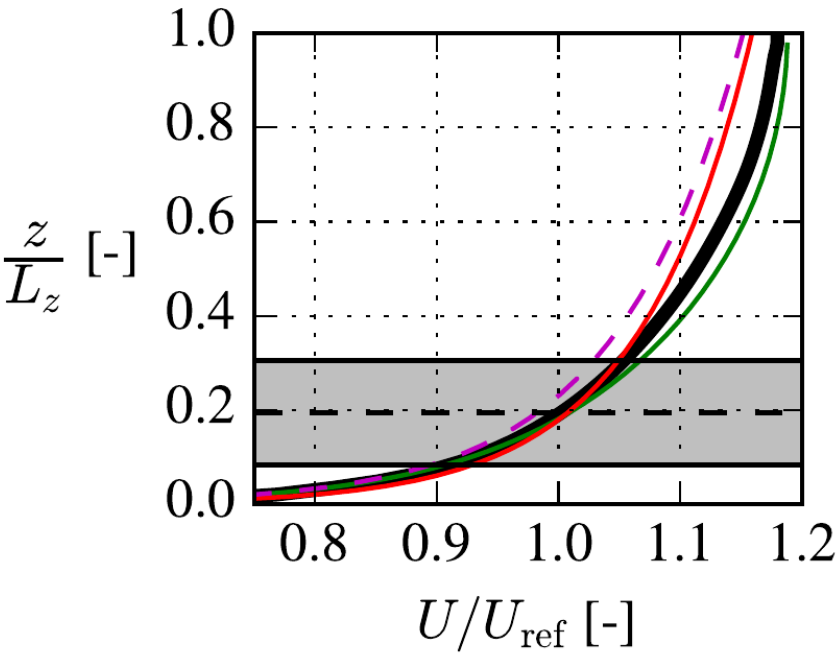
Precursor in RANS

- No analytic solution → need a precursor.
- In RANS we can use a 1D precursor!



ASL vs PDBL: velocity (1/3)

- Similar at low z/L_z



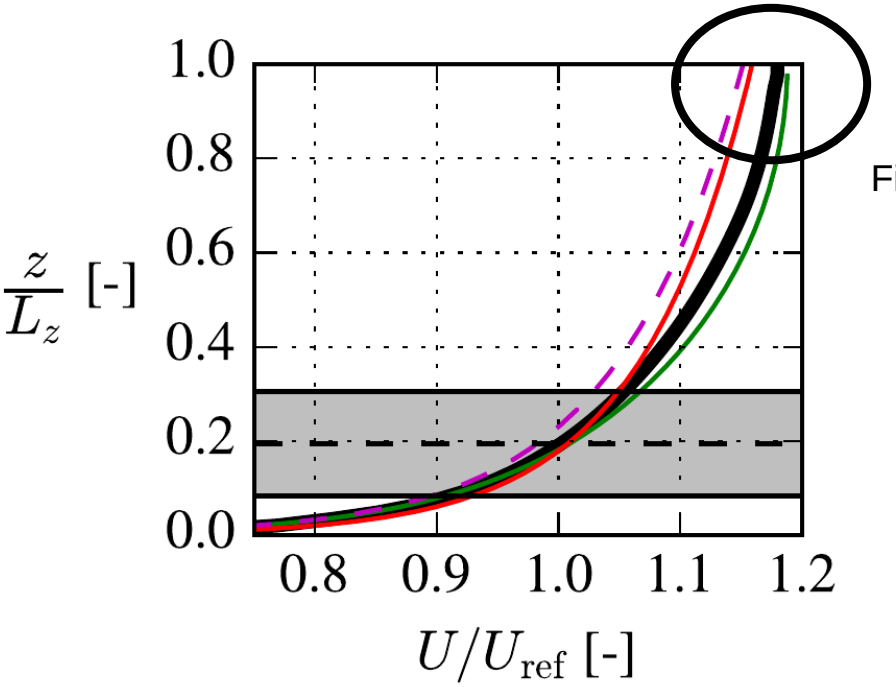
Fidelity

Case	L_z [m]	u_* [m/s]	z_0 [m]
LES PDBL360	360	0.330	0.00500
RANS PDBL360	360	0.330	0.00500
RANS ASL360	-	0.296	0.00128
RANS ASL∞	-	0.330	0.00500

ASL vs PDBL: velocity (1/3)

- Similar at low z/L_z
- Gradient differs at top

$$\left.\frac{dU}{dz}\right|_{z=L_z} = \begin{cases} u_* k^{-1} L_z^{-1} & \text{log-law} \\ 0 & \text{PDBL} \end{cases}$$



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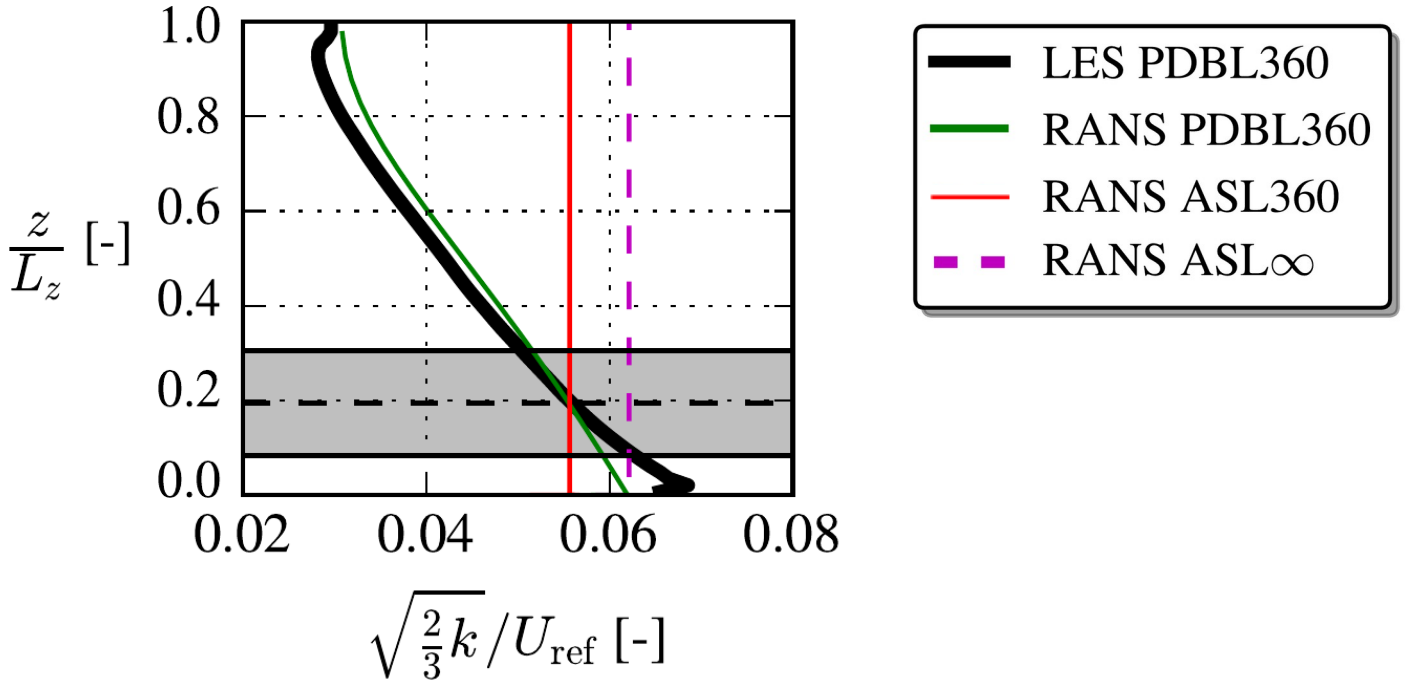
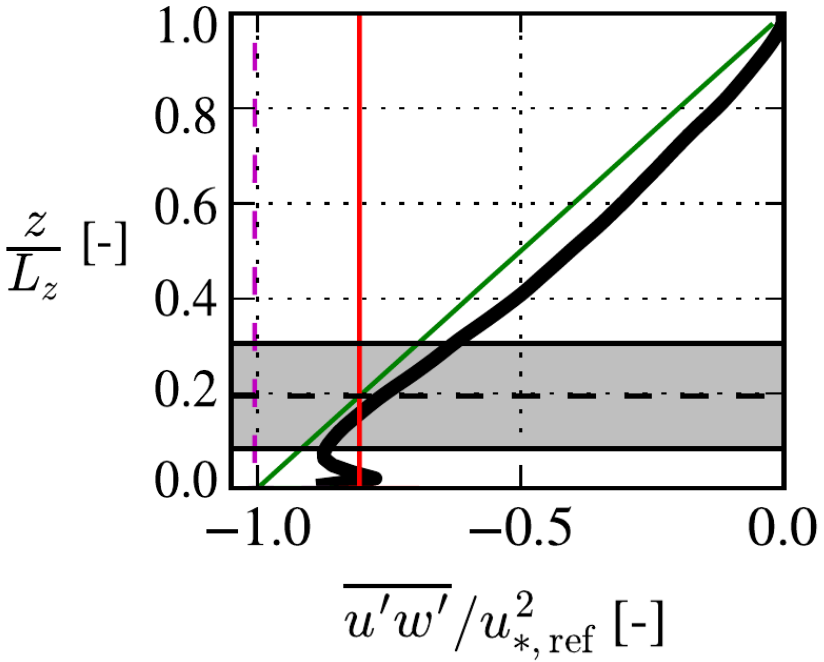
ASL vs PDBL: TKE (2/3)

- TKE decreases with height in a PDBL.
  → Also observed in the real atmosphere.



ASL vs PDBL: shear stress (3/3)

- Shear stress is connected to pressure gradient: $\underbrace{0 = -\frac{1}{\rho}\frac{\partial P}{\partial x} - \frac{\partial \overline{u'w'}}{\partial z}}_{\text{U-mom eq.}}$

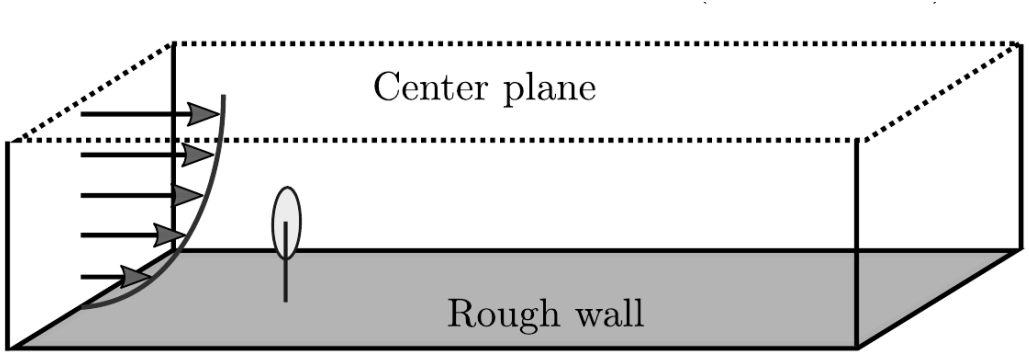


ASL is an asymptotic case of PDBL!

$$\lim_{\substack{\partial P/\partial x \to 0 \\ L_z \to \infty}} \mathrm{PDBL} = \mathrm{ASL}$$

How important for wakes?

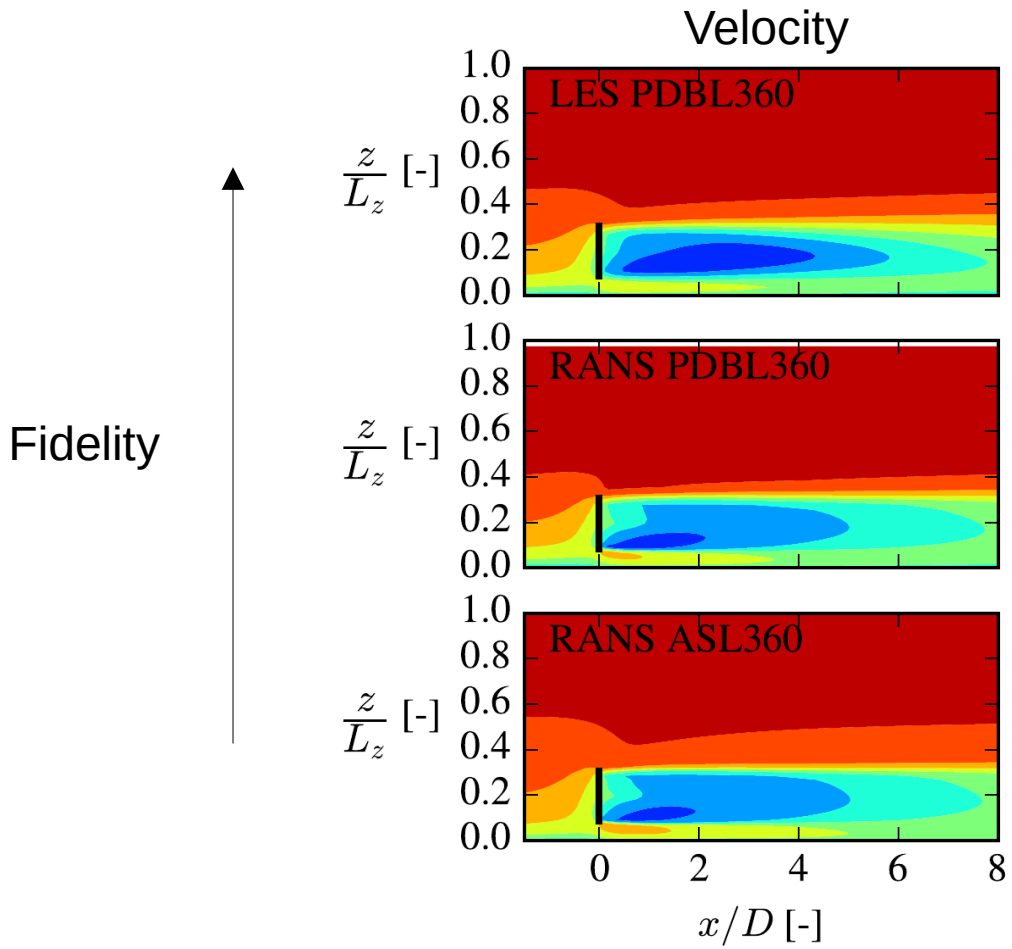
How important is consistent inflow profiles for RANS-to-LES wake comparisons?



(not to scale)

- Single V80 turbine
- U_{ref} = 8 m/s, I_{ref} = 5.6%, C_T=0.77
- Domain size: 60 x 12 x 4.5 D^3
- LES by M. Abkar with pseudo-spectral code
- RANS with EllipSys3D using WJ-EARSM turbulence model

Contours


Velocity
Fidelity
LES PDBL360
RANS PDBL360
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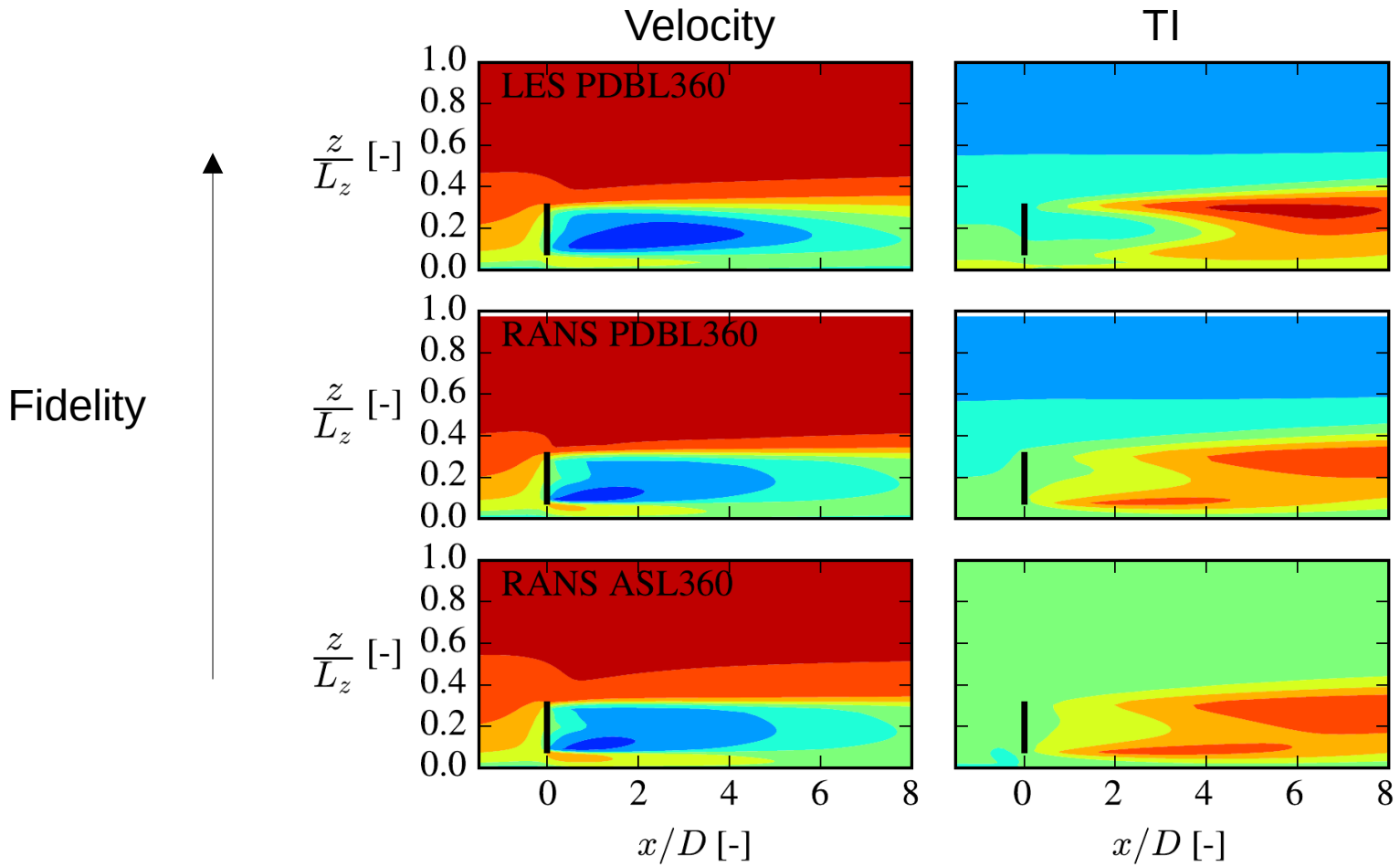
$\frac{z}{L_z}$ [-]
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
x/D [-]

Contours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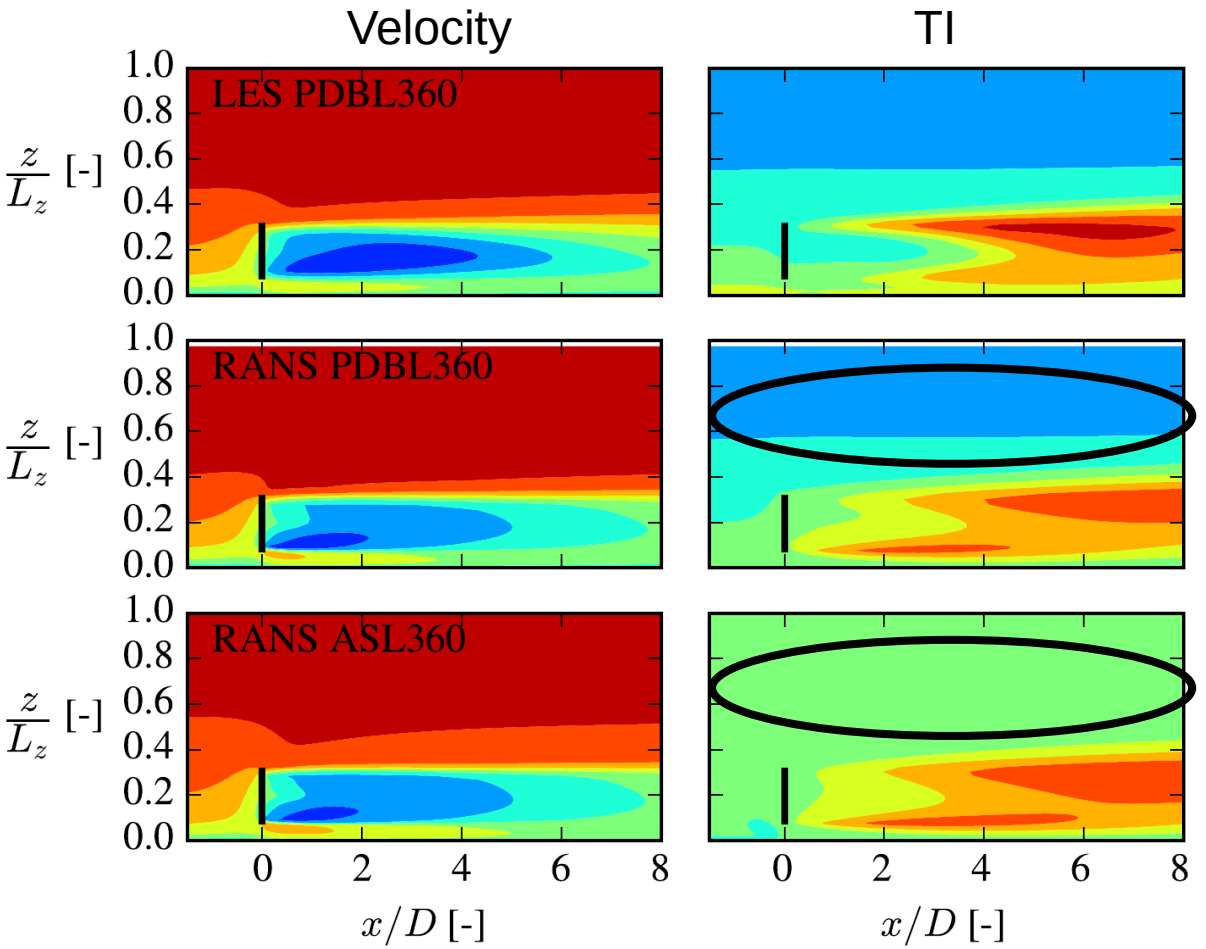


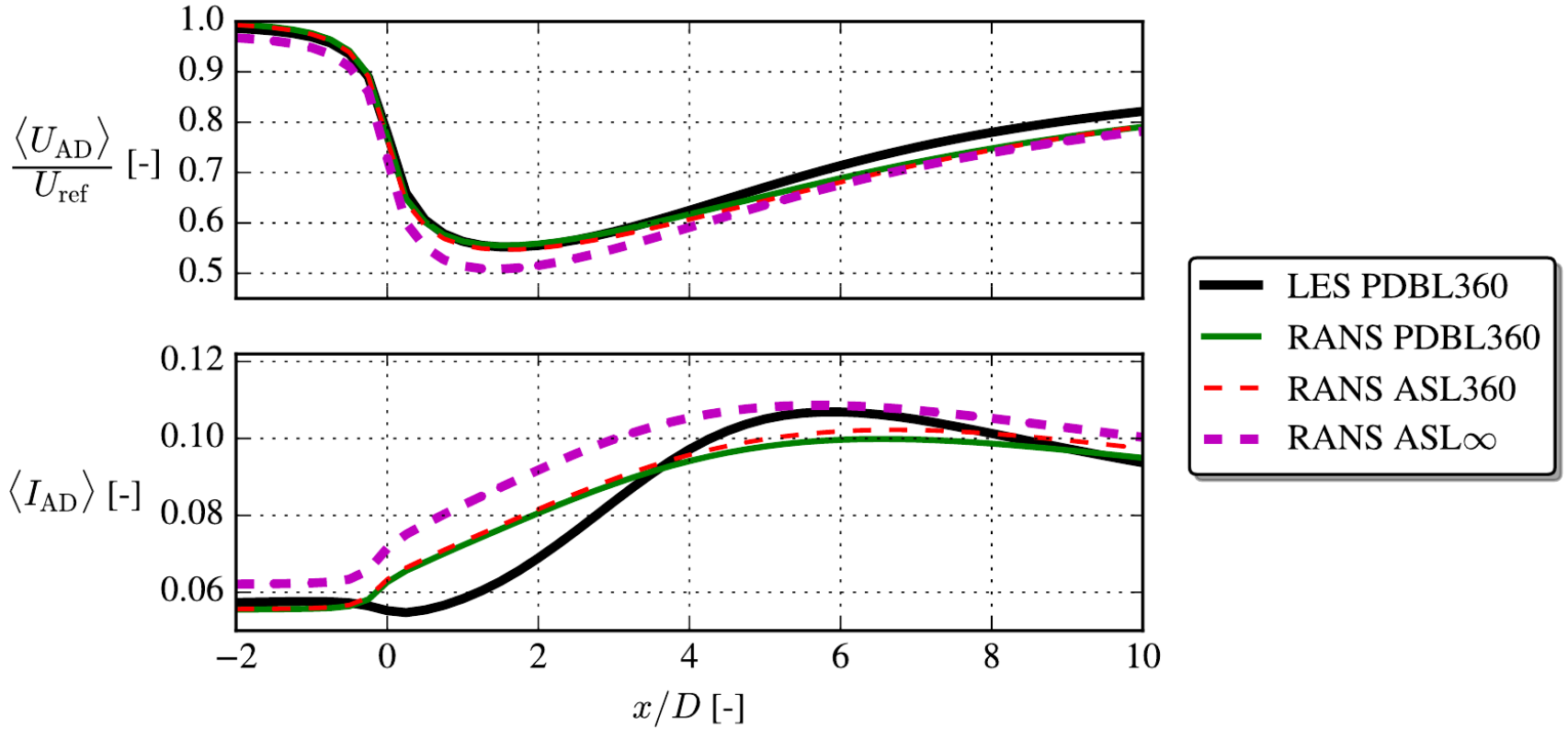
Fidelity

Clear difference between PDBL and ASL.

But <u>wakes</u> are similar!

Disk recovery

- RANS ASL (if correct U_{ref} and I_{ref}) is as good as RANS PDBL for RANS-to-LES wake comparison.



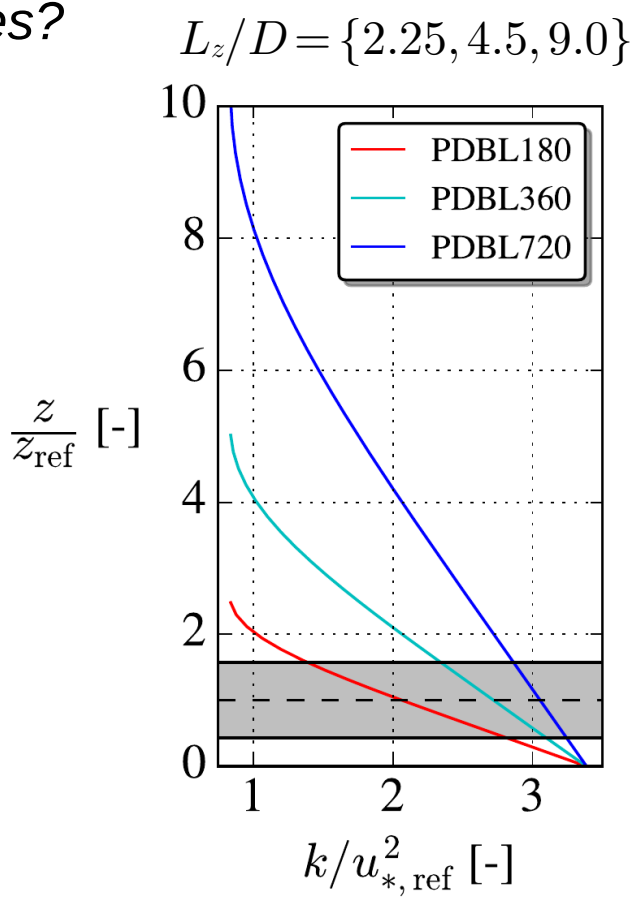
Effect of height-to-diameter, L_z/D

What about other PDBL cases?

The change of TKE (and shear stress) across the wake depends on:

- ABL height, L_z
- Rotor diameter, D

Hypothesis:
For smaller L_z/D, the PDBL and ASL wake results will be less similar.



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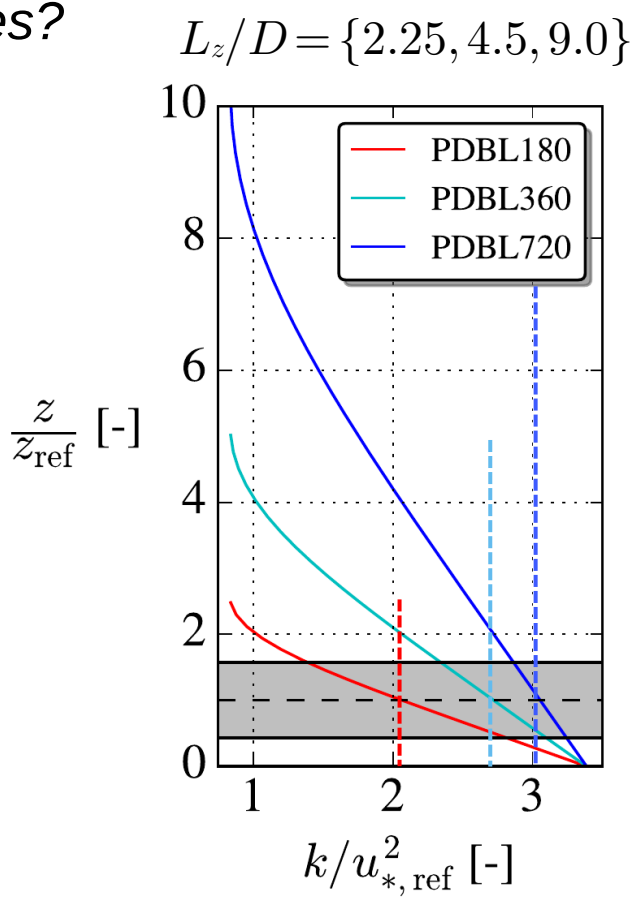

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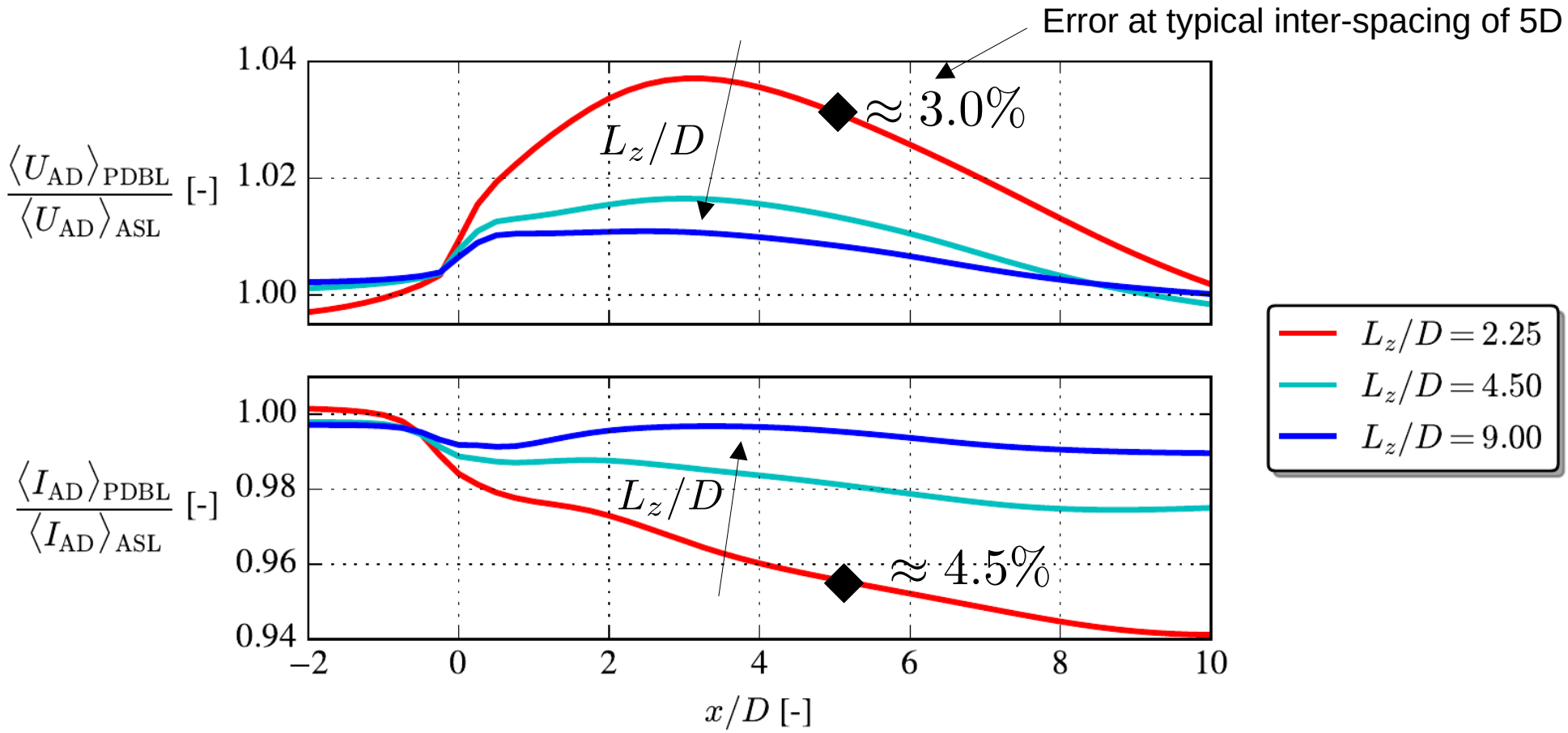


Conclusion

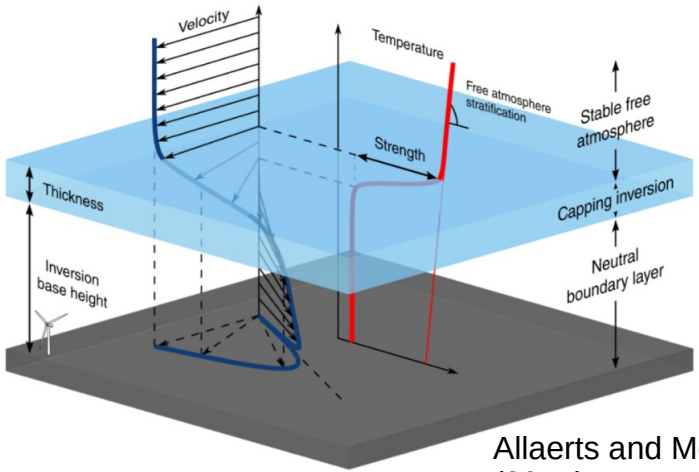
How important is consistent inflow profiles?
(in context of neutral ASL vs PDBL)

1) If correct U_{ref} and I_{ref} , ASL can be “good enough”.
2) Using ASL to model PDBL inflow is better for large L_z/D .
3) ASL is a special case of PDBL.

PDBL is a simple inflow model, but:

- No veer
- “Hard” ABL top

Next step up in “realism”: CNBL



Allaerts and Meyers (2015)