

Sensitivity of the Floating Actuator Line Method to Prescribed Motions

October 2025

Dylan Green

Contents

Motivation: Floating Turbine Wakes

Method: Numerical Methods for floating turbine wakes

Problem: The effect of force smoothing

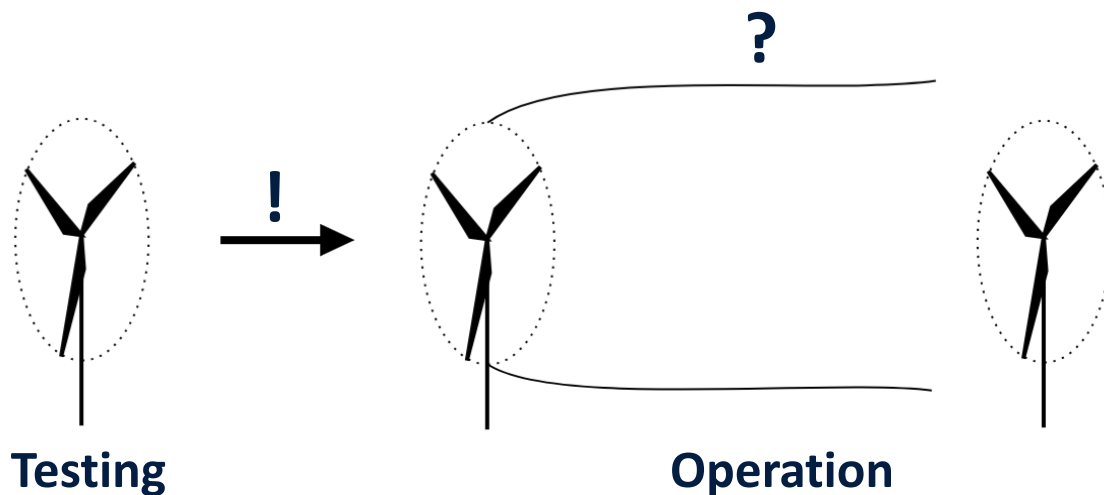
Results

Conclusions

Wake Effects

⚙️ Floating wind is ready for farm-scale deployment

⚙️ Platform motions inject unsteadiness into turbine wakes

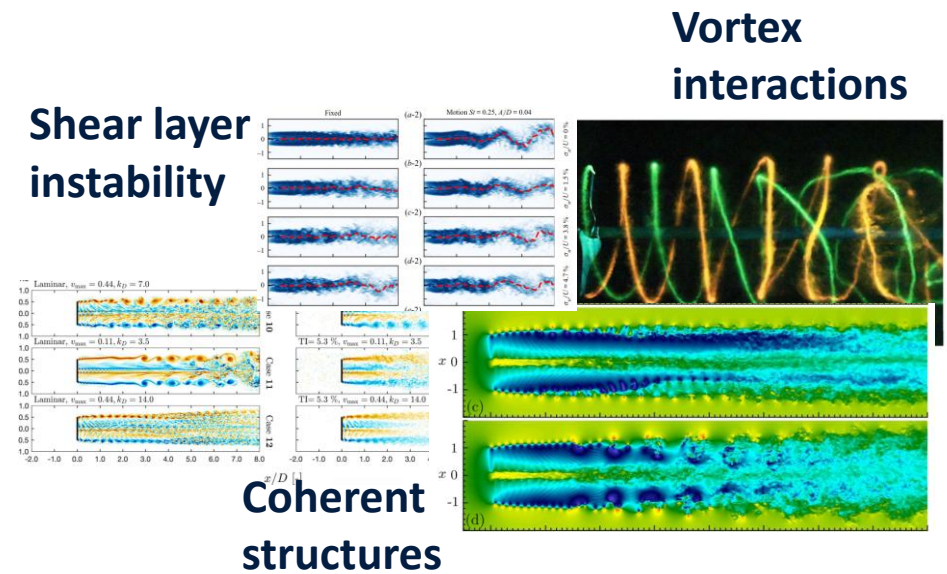


www.offshorewind.biz
Equinor, EDF-ESB Joint Venture Secure 1.5 GW Sites in UK Floating Wind Leasing Round

PLANNING & PERMITTING

June 19, 2025, by Adrijana Buljan

Share this article



Z. Li et al. "Onset of wake meandering for a floating offshore wind turbine under side-to-side motion". Journal of Fluid Mechanics. 2022

Y. Li et al. "Wake Structures and Performance of Wind Turbine Rotor With Harmonic Surging Motions Under Laminar and Turbulent Inflows". Wind Energy. 2025

H. U. Quaranta et al. "Local and global pairing instabilities of two interlaced helical vortices". Journal of Fluid Mechanics. 2019

Kleine, Vitor G., et al. "The stability of wakes of floating wind turbines." Physics of Fluids 34.7 (2022).

Floating Vs Fixed-Bottom Wakes

⚠ Floating turbines **perturb** the typical fixed-bottom turbine wake

⚠ This perturbation experiences nonlinear growth

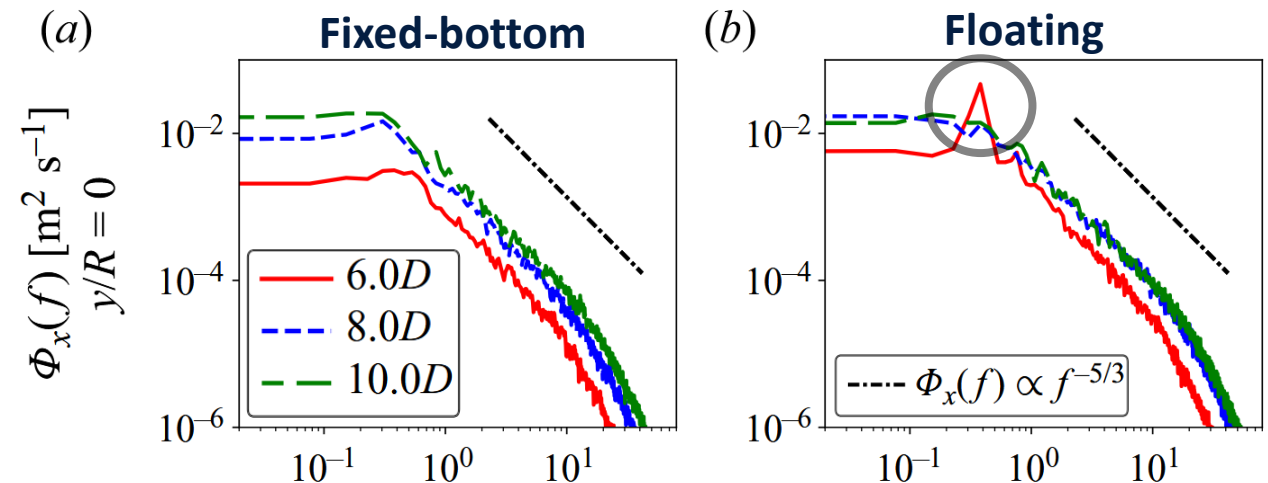
⚠ Accelerated wake breakdown

⚠ Increased wake recovery

⚠ **Farm power gains**

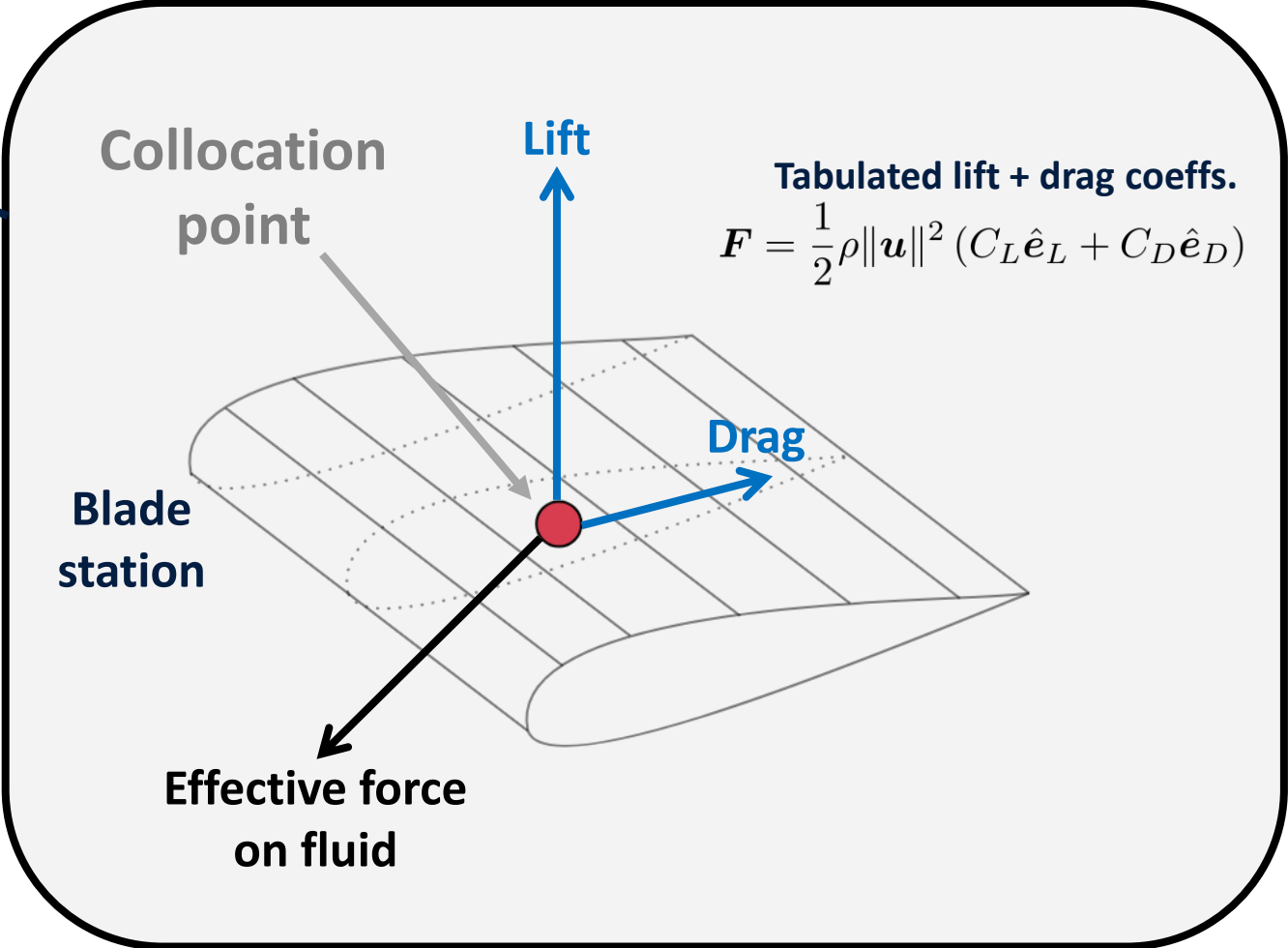
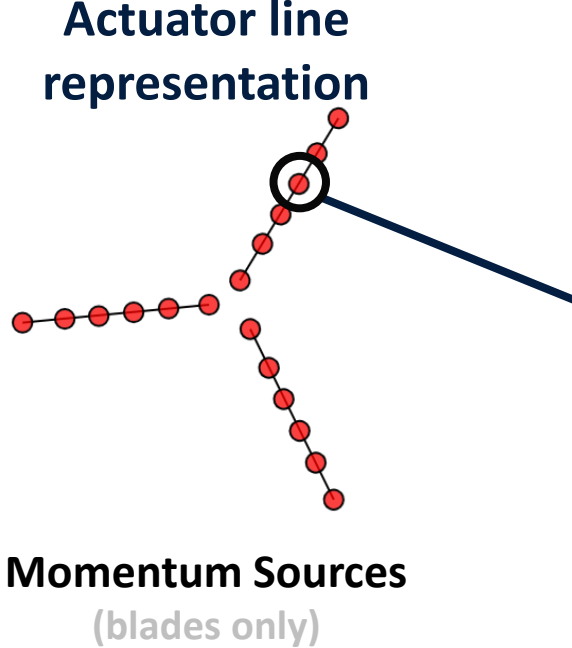
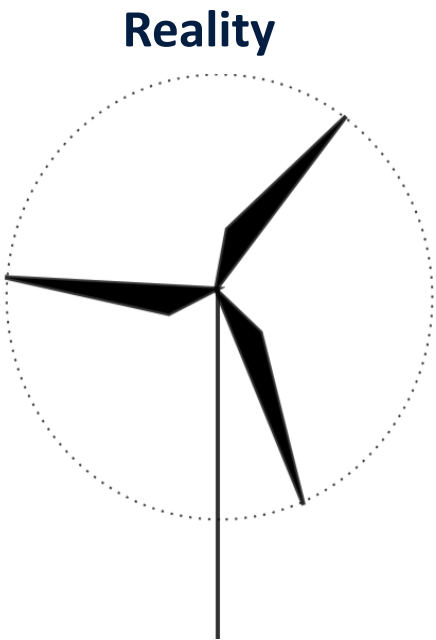
⚠ **Unsteady loading**

Wake power spectra

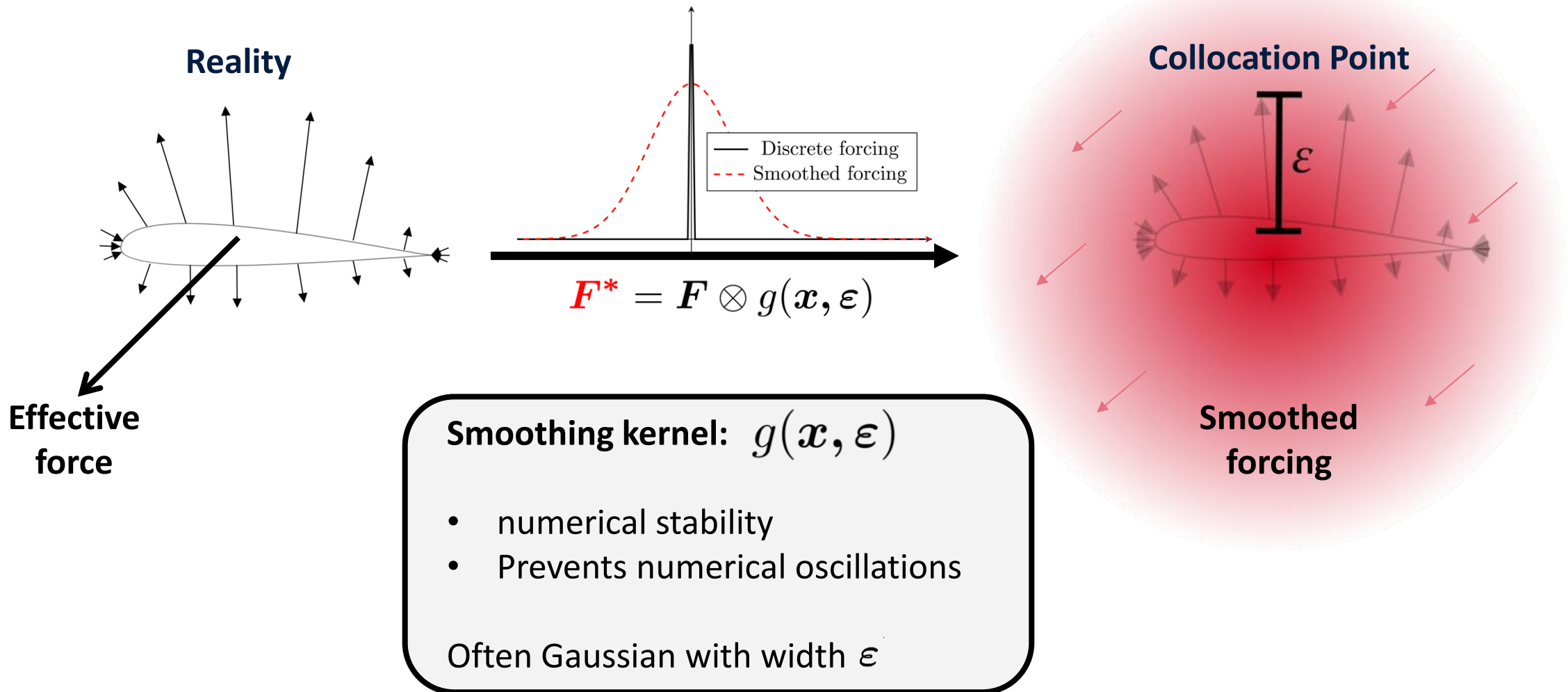


Messmer, Thomas, Michael Hölling, and Joachim Peinke. "Enhanced recovery caused by nonlinear dynamics in the wake of a floating offshore wind turbine." *Journal of Fluid Mechanics* 984, 2024.

Simulation Methods: Actuator Line Method



Forcing Smoothing



Typical Smoothing Lengths

ε is usually a function of cell size, Δ

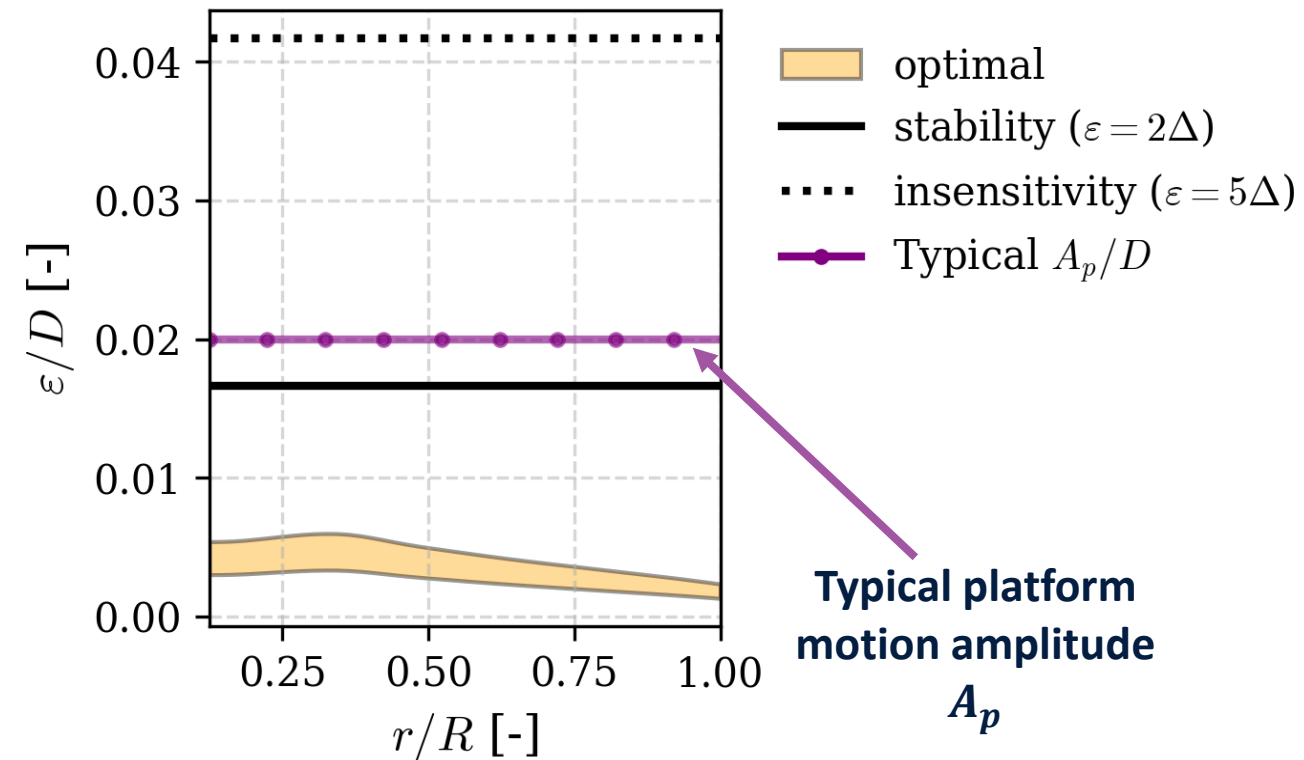
Thrust insensitivity: $\varepsilon > 5\Delta$

Numerical stability: $\varepsilon > 2\Delta$

[1] Analytical optimal $\varepsilon = 0.14c - 0.25c$
(c = chord length) [1]

[1] - Martínez-Tossas et al. "Optimal smoothing length scale for actuator line models of wind turbine blades based on Gaussian body force distribution." *Wind Energy* 20.6, 2017

Example: IEA 15 MW Turbine ($\Delta = D/120$)



Effect of Force Smoothing

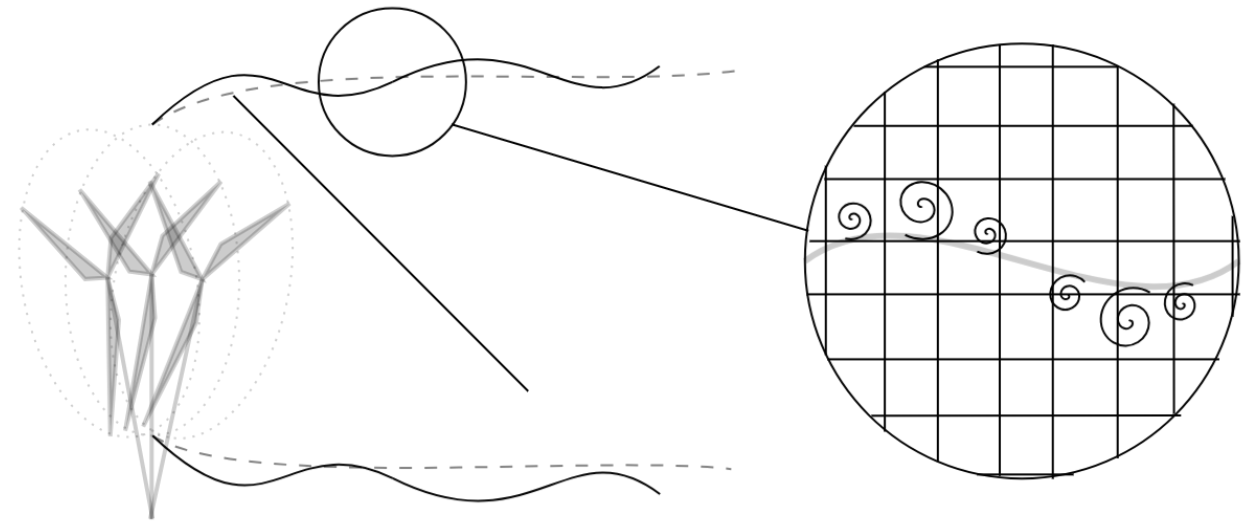
Resolution of wake perturbation is a function of:

- ⇒ Smoothing length ε
- ⇒ Size of perturbation $\sim A_p$ ← Motion amplitude
- ⇒ Spatial resolution Δ

Dimensionless smoothing width:

$$N_\varepsilon = \frac{\varepsilon(\Delta)}{A_p}$$

0 ← *Sharp perturbation* *Diffuse perturbation* → ∞



RQ: How does N_ε affect the wake?

Test Case

† Spatial Resolution $\Delta = \frac{D}{40}$, $\frac{D}{80}$, $\frac{D}{120}$
poor **okay** **good**

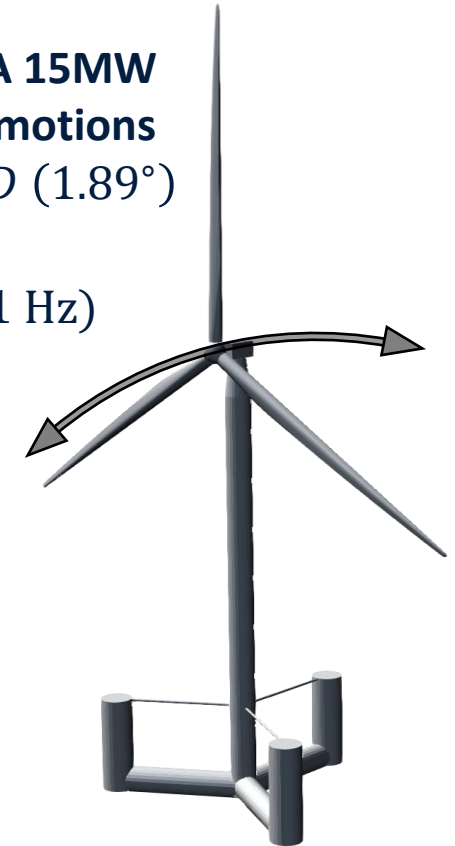
† Mapping length $\varepsilon = 2\Delta$, 4Δ , 8Δ
stability **intermediate** **insensitivity**

**Pitching IEA 15MW
Sinusoidal motions**

$$A_p = 0.02D \text{ (1.89}^\circ\text{)}$$

$$St_p = 0.70$$

$$(f_p = 0.031 \text{ Hz})$$

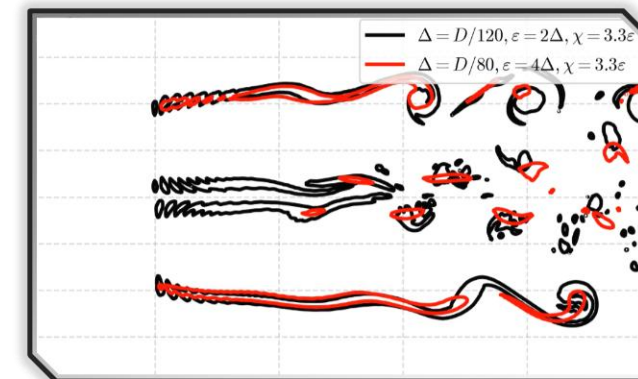
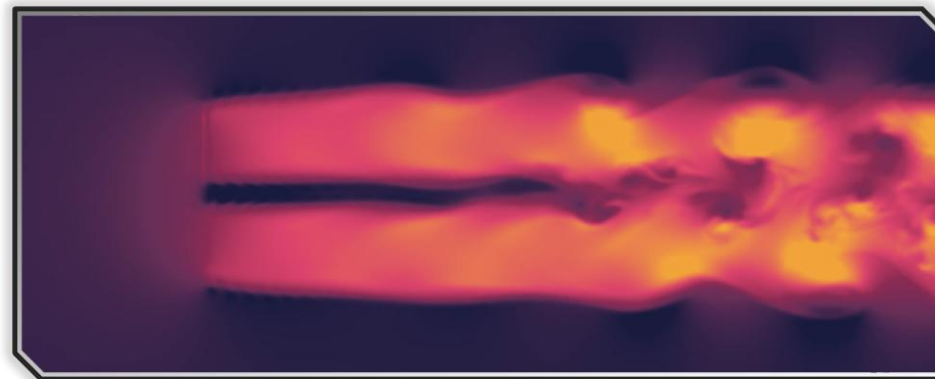
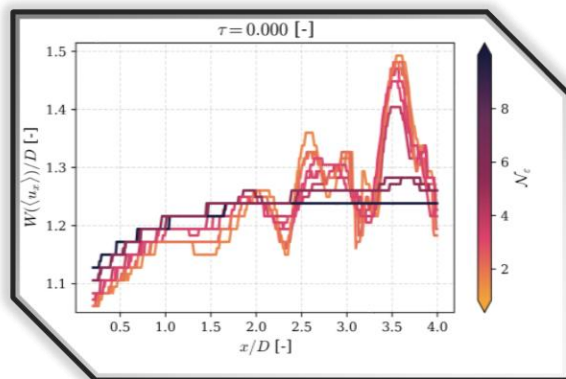


Inflow: $U_\infty = 10.59\text{ms}^{-1}$, laminar

Boundary conditions: $\partial_n \mathbf{u} = 0$

LES + Smagorinsky turbulence closure

Results:



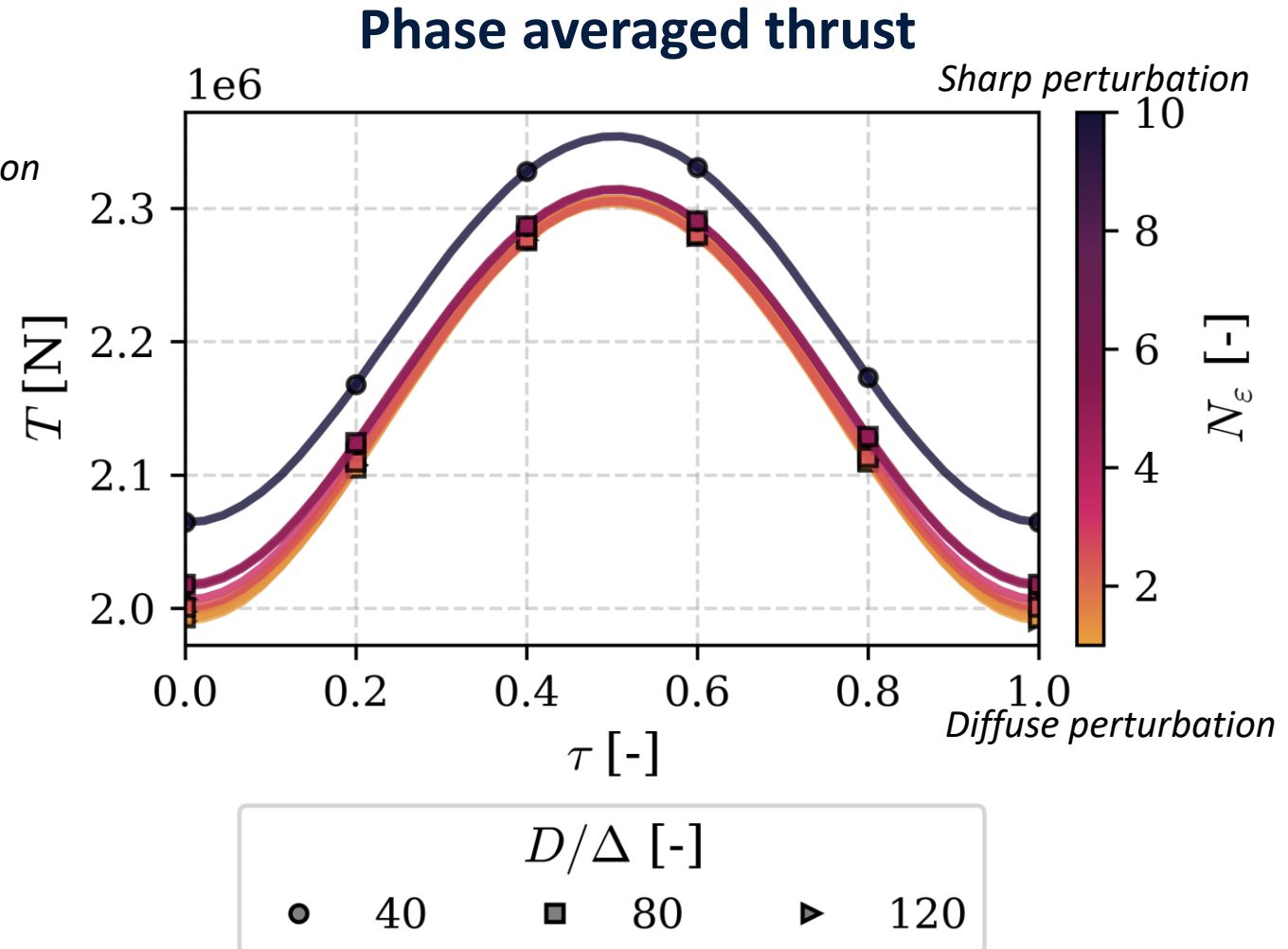
Results: Rotor Thrust



†† Rotor thrust is insensitive to N_ϵ

$$\frac{\partial T(\tau)}{\partial \tau} \gg \frac{\partial T(\tau)}{\partial N_\epsilon}$$

†† Why?



Results: Rotor Thrust

Thrust variation is caused by change in lift + drag

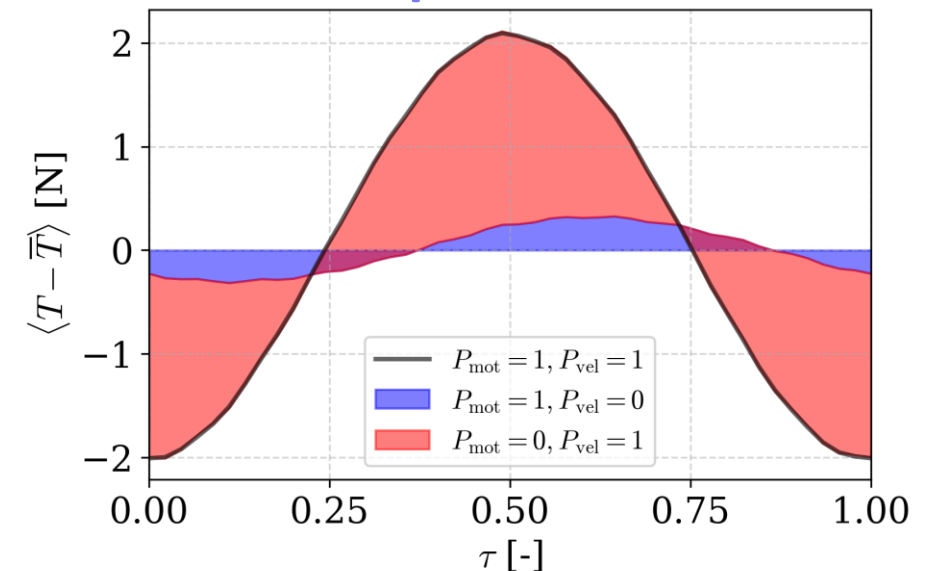
Change in lift + drag caused by a velocity variation

$$\Delta \mathbf{u} = \underbrace{\Delta \mathbf{u}_{\text{sampled}}}_{\text{changes to local flow field}} + \underbrace{\Delta \mathbf{u}_{\text{motion}}}_{\text{prescribed}} \approx \Delta \mathbf{u}_{\text{motion}}$$

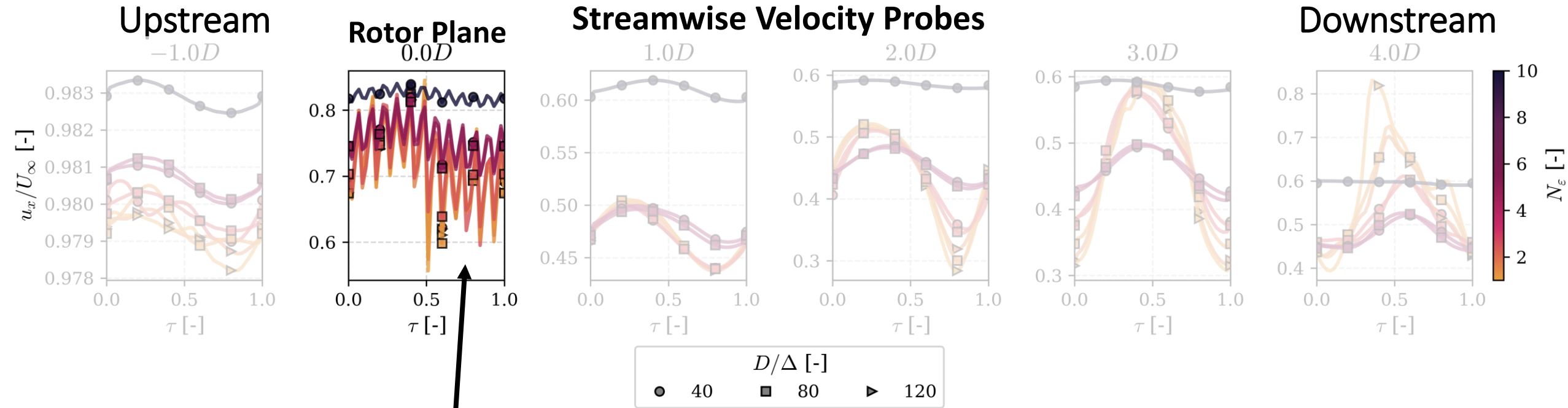
Thrust variation is not significantly affected by flow perturbation

Total Thrust
Prescribed

From perturbation



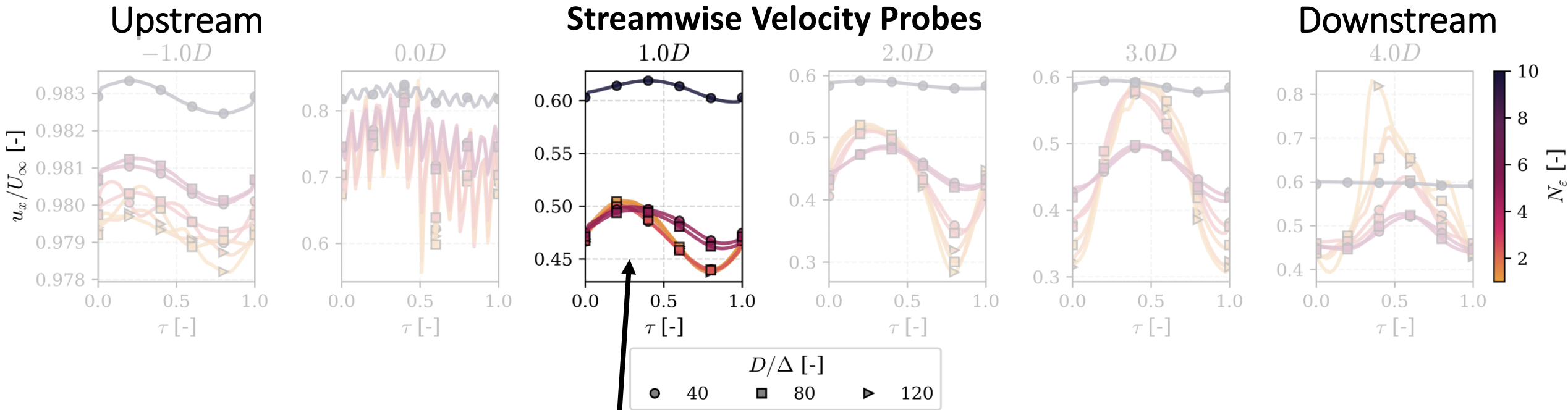
Results: Wake Velocity



Oscillations at blade passing frequency

Amplitude proportional to N_ϵ

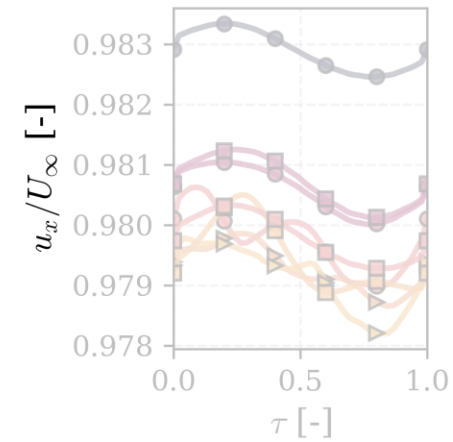
Results: Wake Velocity



Results: Wake Velocity

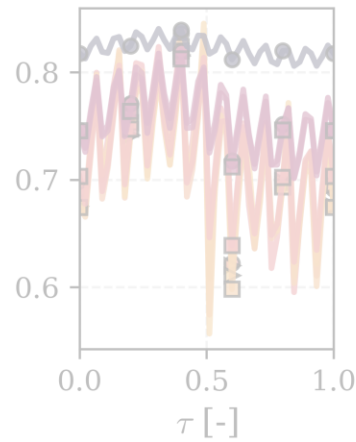
Upstream

$-1.0D$

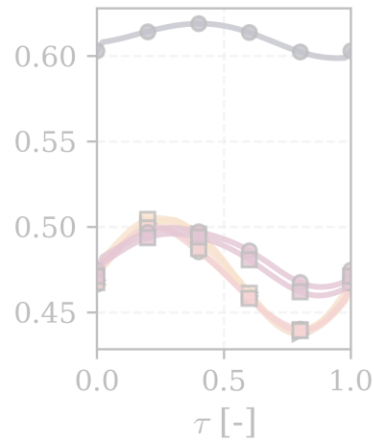


Streamwise Velocity Probes

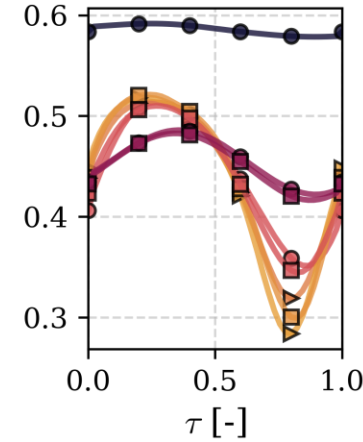
$0.0D$



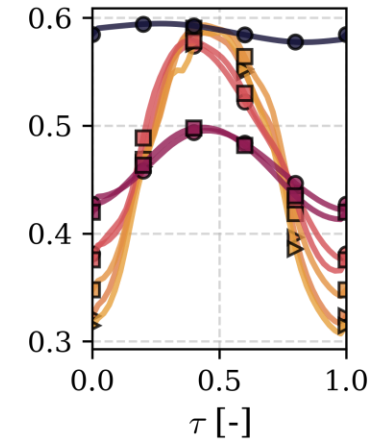
$1.0D$



$2.0D$

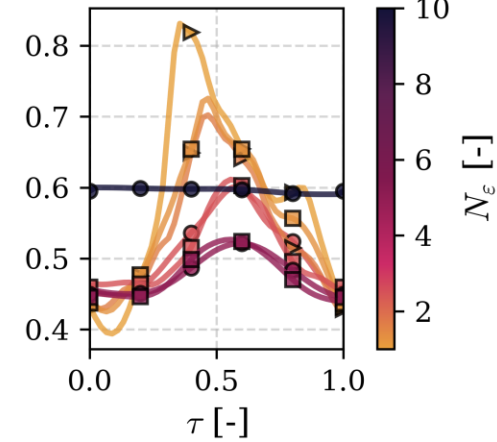


$3.0D$



Downstream

$4.0D$

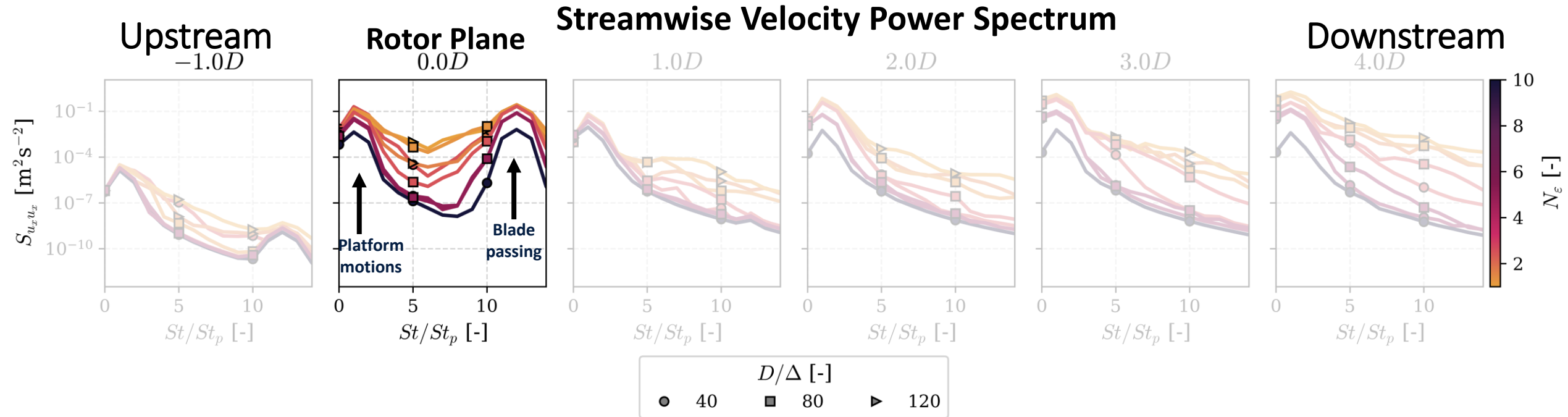


Diffuse perturbations remain stable

Sharp perturbations breakdown due to nonlinearities

Results in ordering by N_ϵ forms

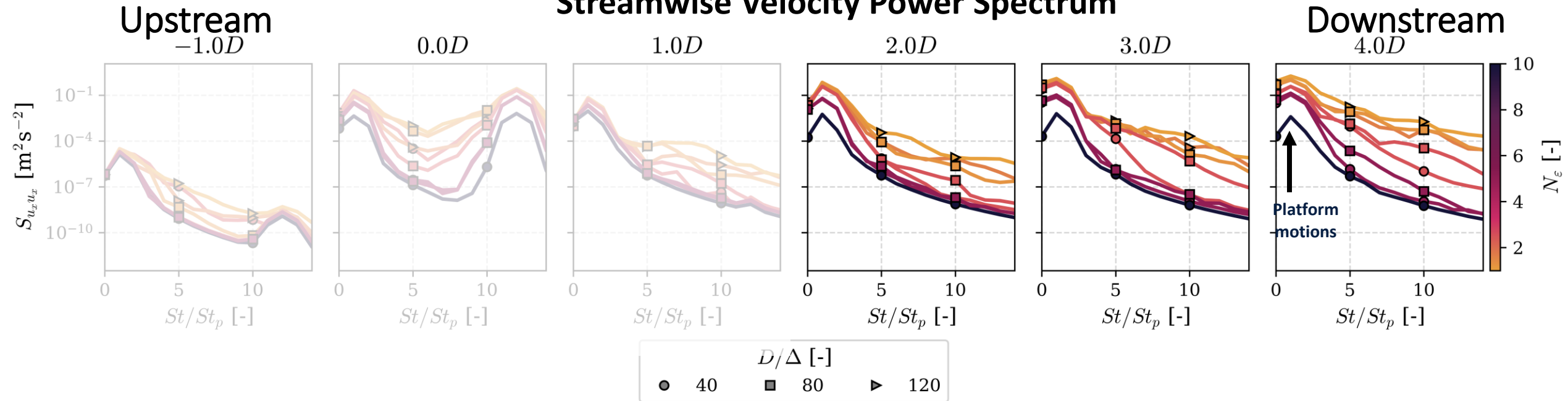
Results: Wake Velocity



Peaks at blade passing and platform (perturbation) frequency

Results: Wake Velocity

Streamwise Velocity Power Spectrum



Amplitude at platform frequency grows depending on N_ε

High frequency spectra dependent on ε and Δ

Results: Wake Recovery

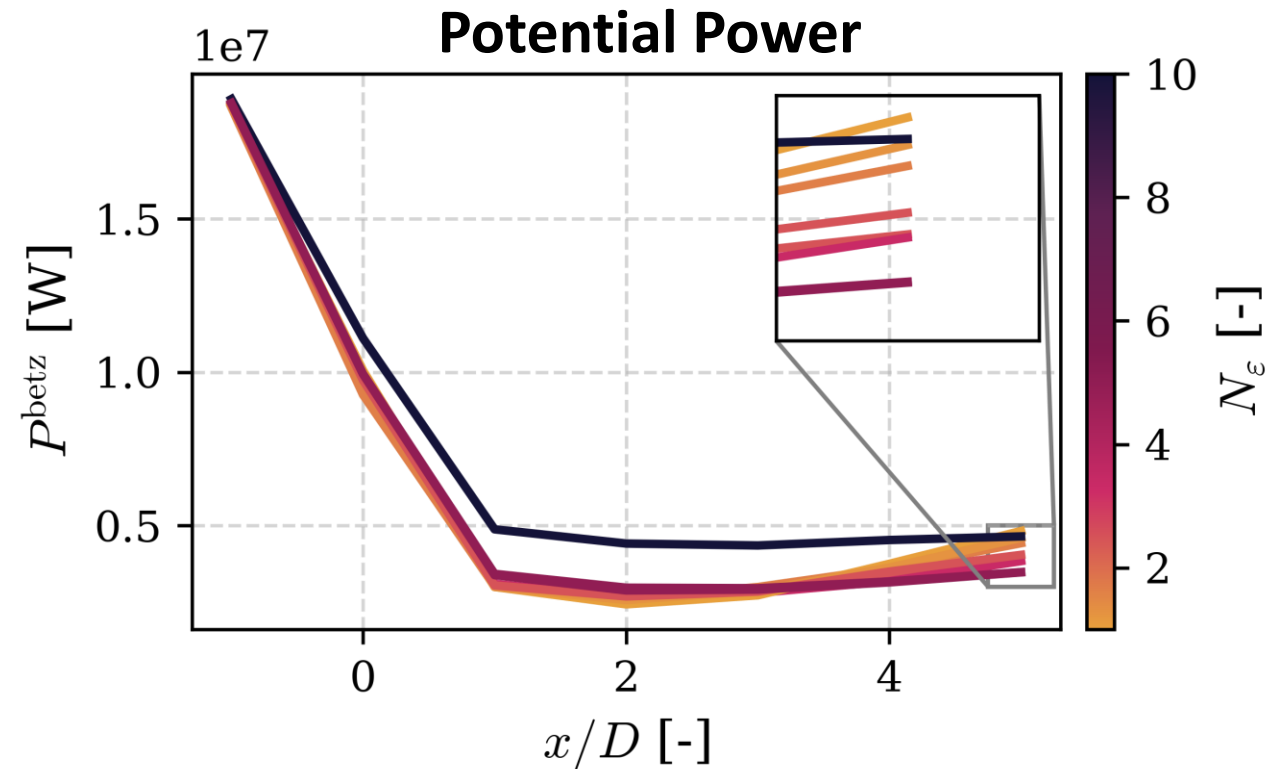
✦ Average velocity over rotor swept area

✦ Compute power of virtual Betz-rotor

$$P^{\text{betz}} = \frac{1}{2} \rho A \bar{u}^3 \cdot \frac{16}{27}$$

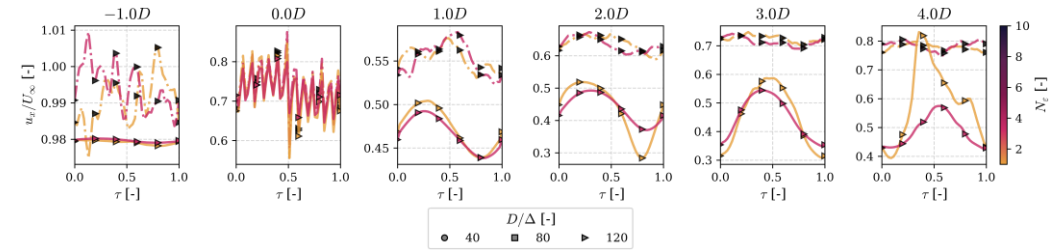
Significant differences in predicted power of downstream rotor due to N_ε

Resulting from different wake evolution processes

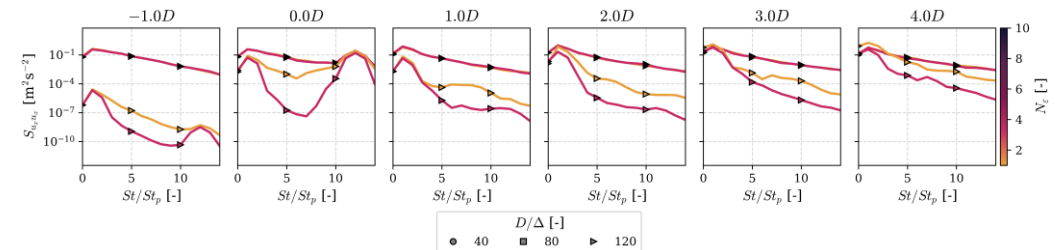


Adding Turbulence

Wake phase averaged velocity



Wake power spectrum



⚠ Inter-scale interactions cannot be ignored!

⚠ Perturbations will interact with ambient turbulence

⚠ Why are laminar simulations still useful?

1. Cost (turb sims 5-10 X more expensive)
2. Parameter space (\mathcal{L}, TI)

Results: Wake Velocity

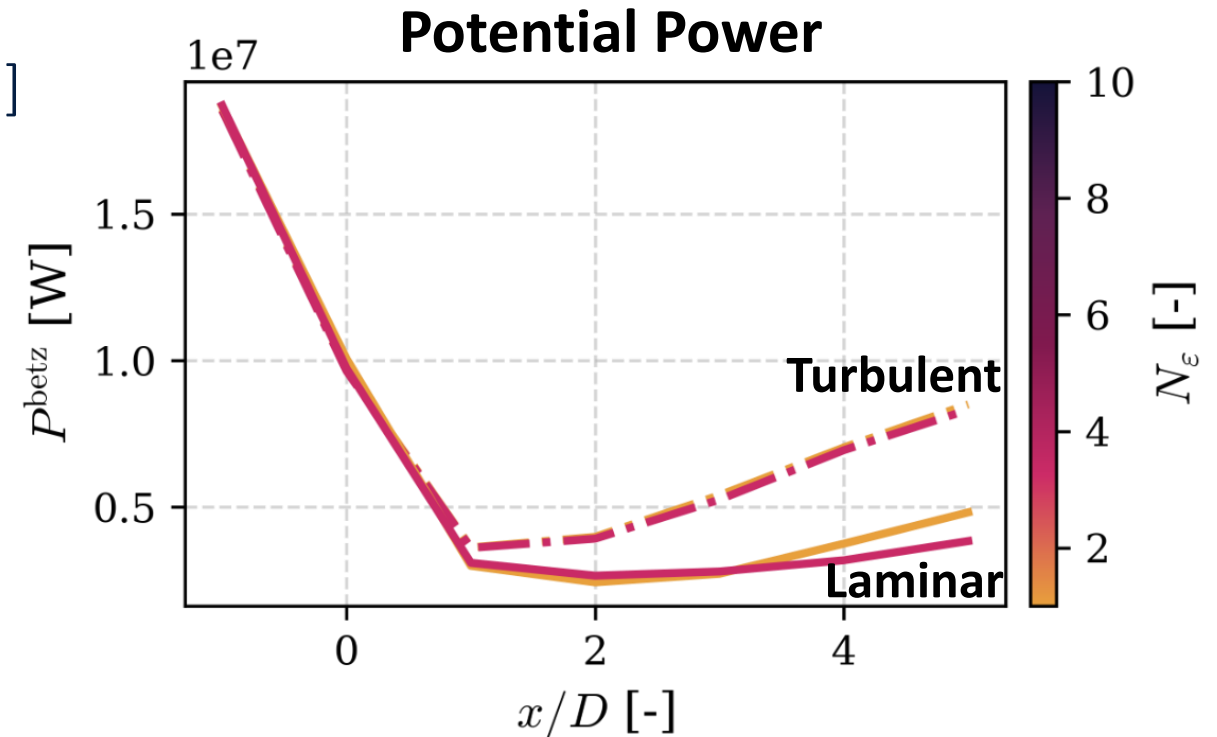
✦ Inflow turbulence produced using divergence free synthetic eddy method [1]

$$\mathcal{L} = 42 \text{ m}$$
$$TI(x = 0) = 8.5\%$$

Ambient turbulence significantly reduces sensitivity to N_ε

Turbulent fluctuations dominate over platform-induced perturbations

Preventing growth of unstable modes



Conclusions

1. Rotor **thrust is largely insensitive** to force smoothing
2. Low turbulence / laminar inflow **wakes are highly sensitive** to N_ε - Significant changes in downstream power/loading predictions
3. Laminar inflow wakes breakdown based on N_ε
4. Suggest $N_\varepsilon < 2$ for reasonable insensitivity
5. Turbulent inflow wakes experience significantly less sensitivity but are expensive!

Thanks for listening!

Contact Info:
Email: dylan.green@eng.ox.ac.uk

END

Results: Wake Coherent Structures

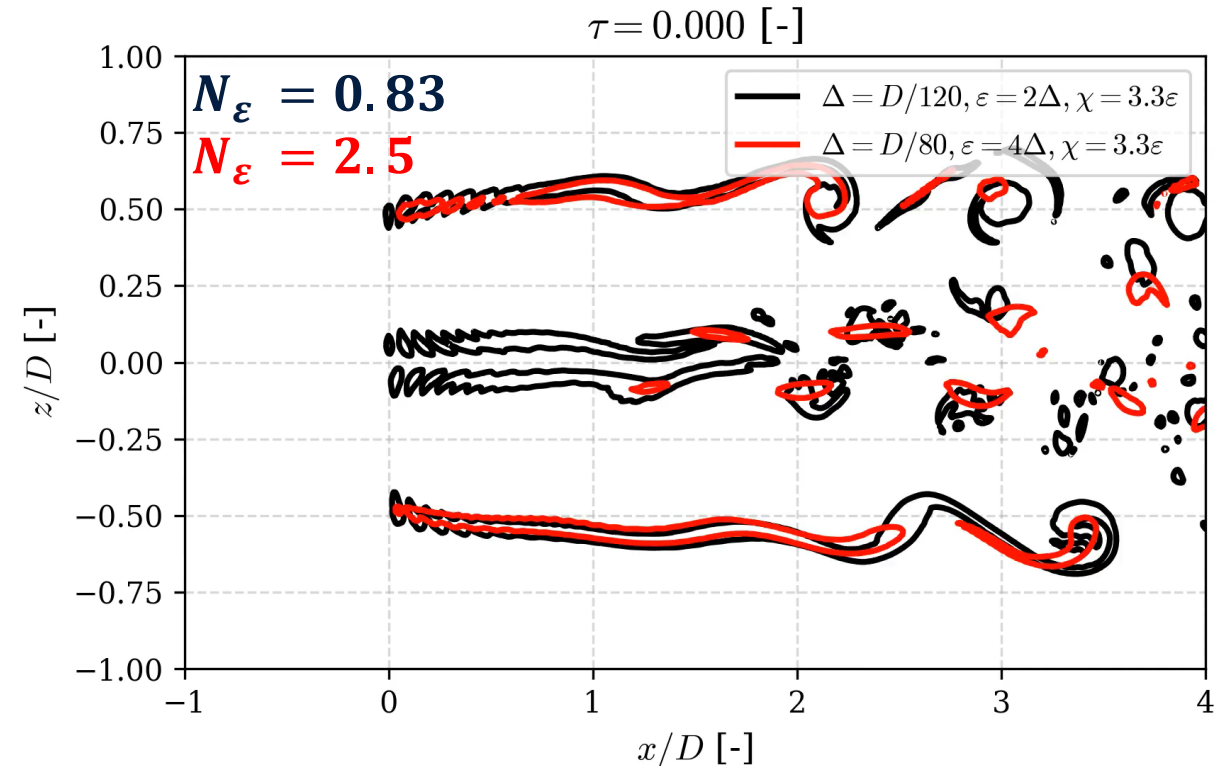
† Perturbations to wake form coherent structure

† Previously shown to be important for energy transfer between the freestream and the wake [1]

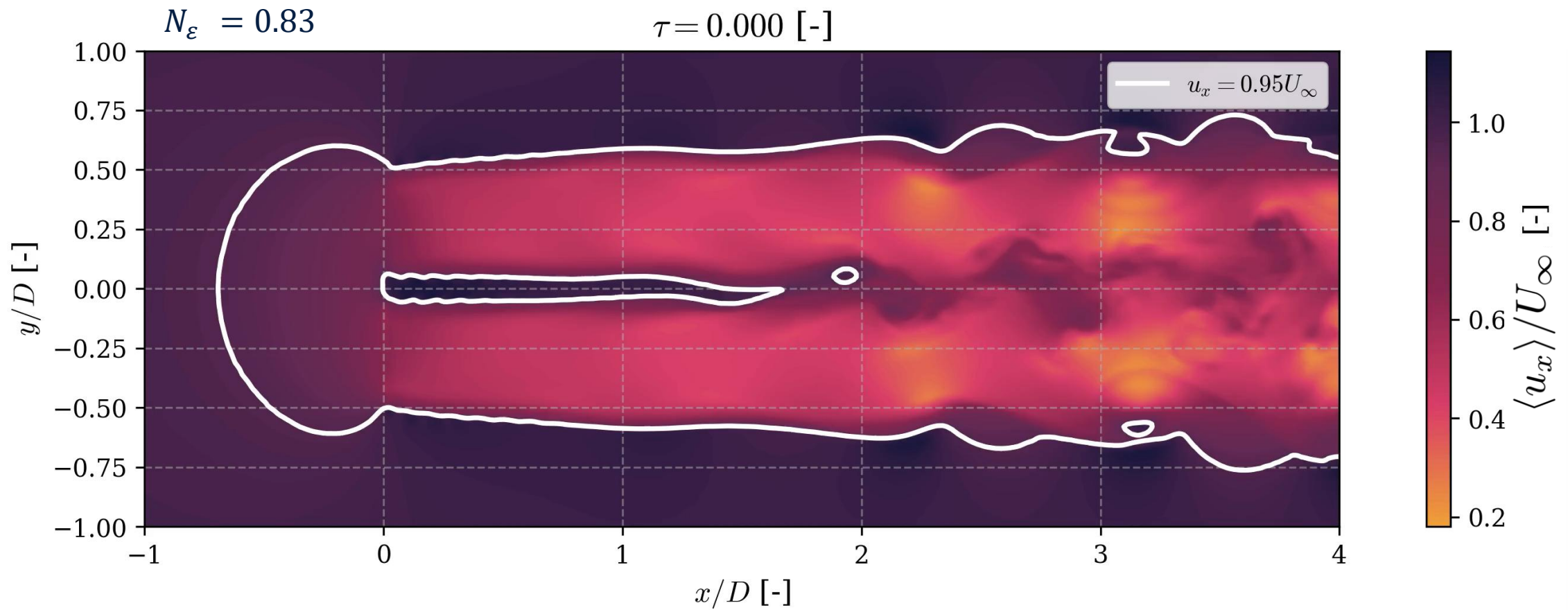
N_ε governs production and resolution of coherent structure

Therefore, N_ε is important for momentum transfer into the wake

Vorticity Iso-contours



Results: Wake Morphology



Results: Wake Morphology

✦ Wake shape related to its nonlinear evolution

✦ Measure wake width using $\langle u_x \rangle = 0.95U_\infty$ contour

Diffuse perturbations show little unsteadiness

Diffuse produce *fixed-bottom* like wake

Sharp perturbations lead to large & unsteady modulation of the wake width

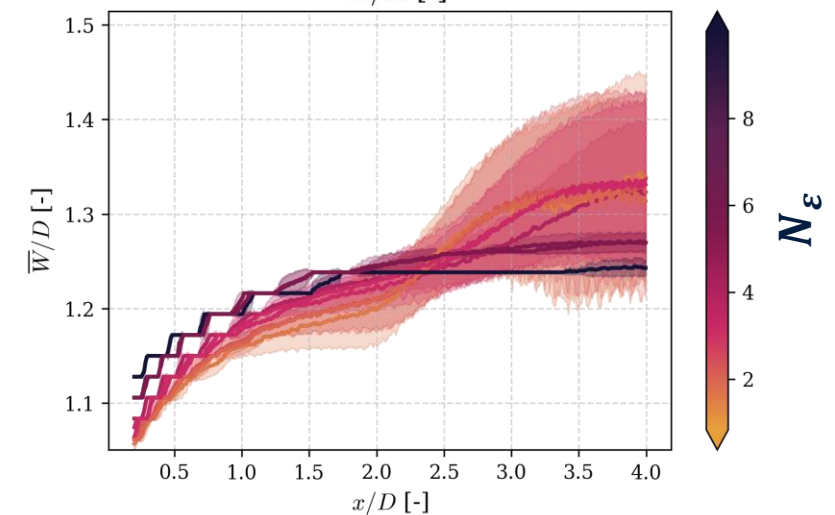
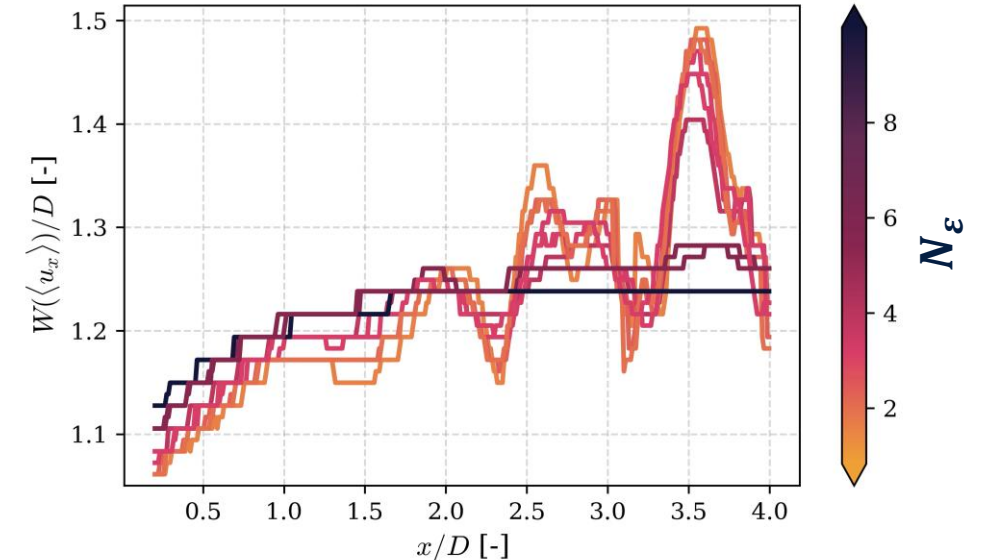


DEPARTMENT OF
ENGINEERING
SCIENCE



Wake Width

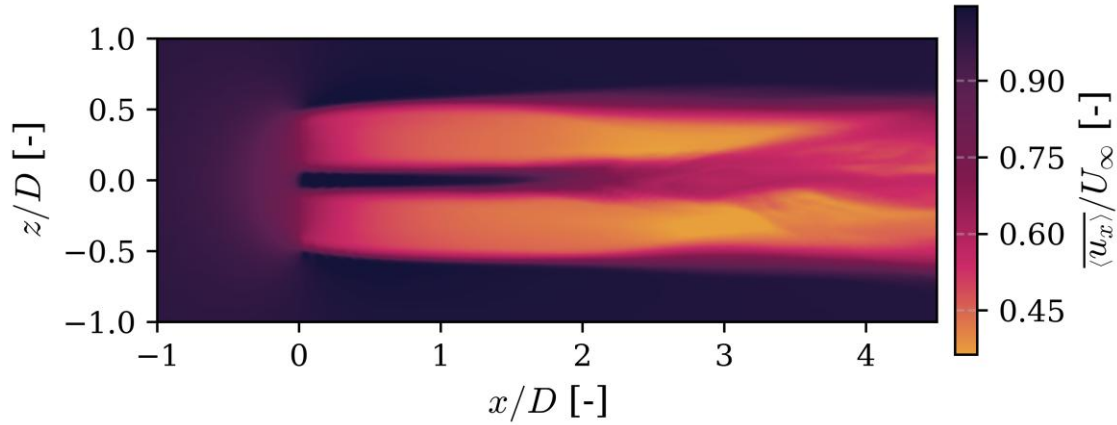
$\tau = 0.000$ [-]



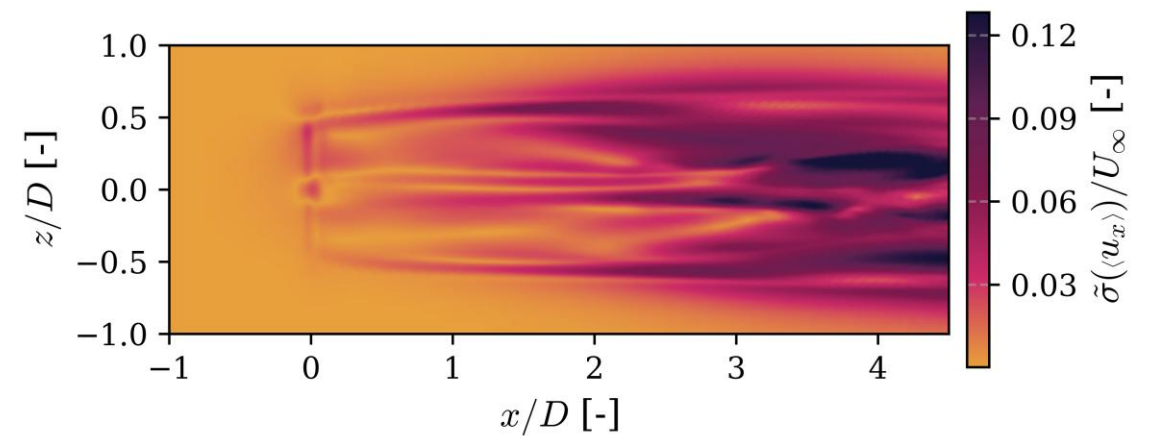
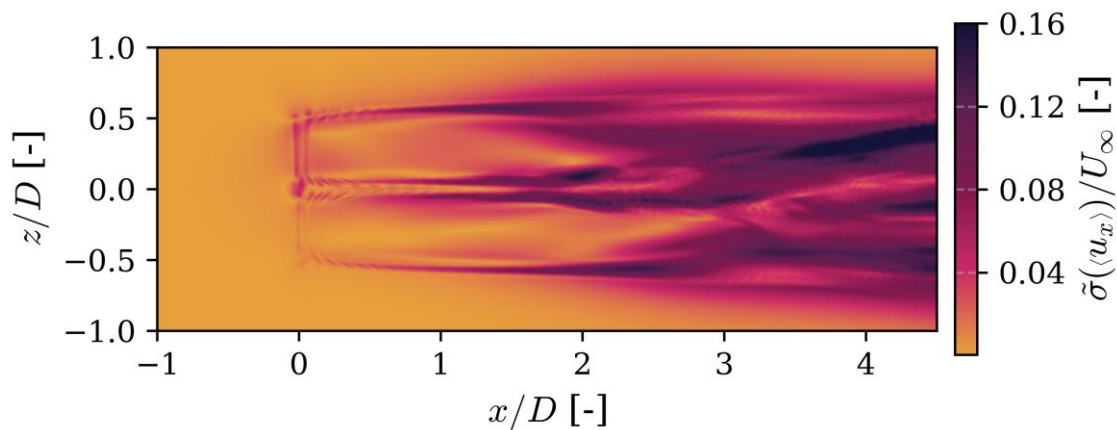
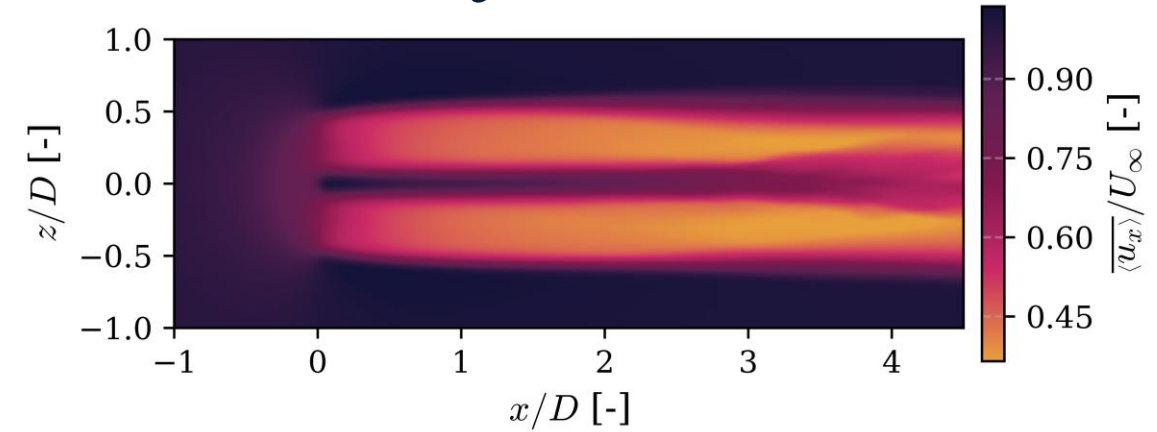
Mean and Coherent std Streamwise Velocity



$N_\varepsilon = 0.83$



$N_\varepsilon = 2.5$

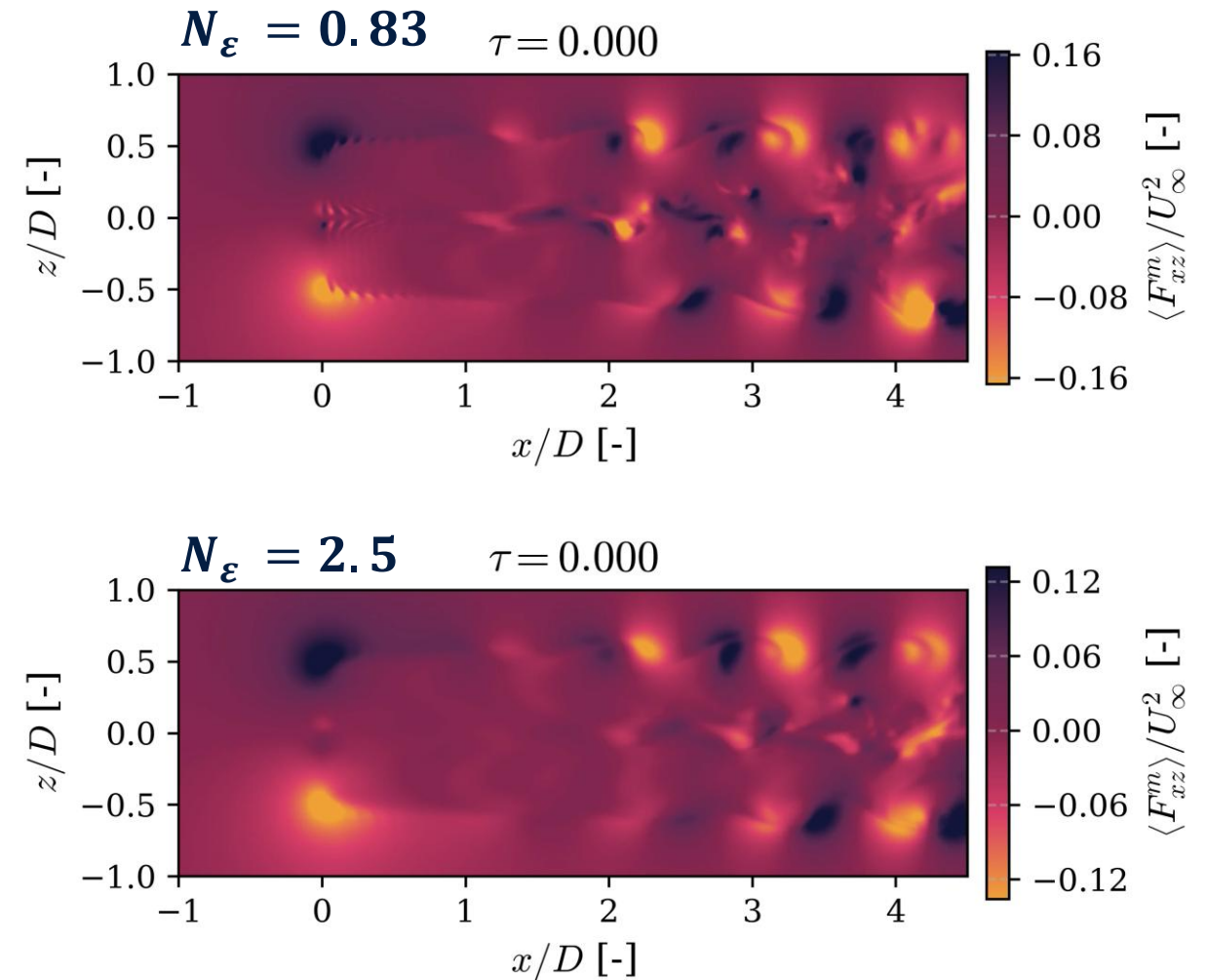


Results: Wake Entrainment

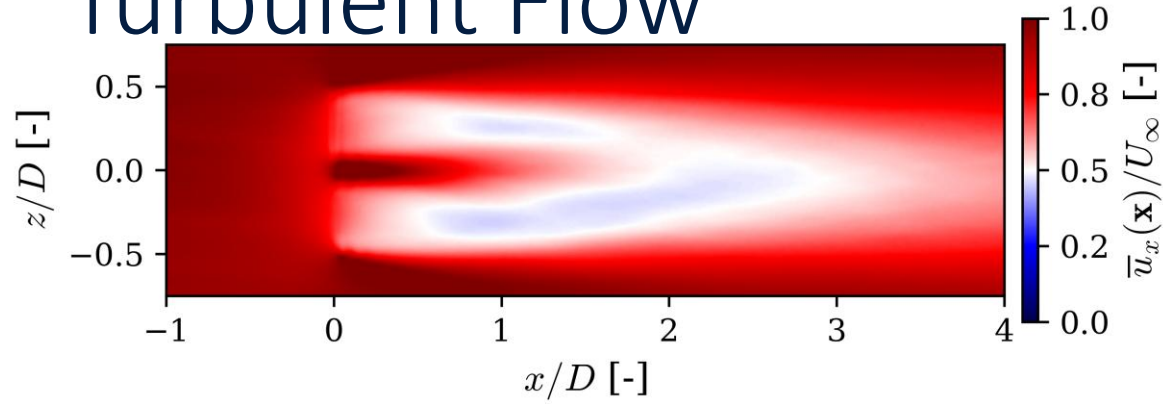
† Momentum flux:

$$\mathbf{F}_{xz}^m = \overline{u_x u_z} + \overline{u'_x u'_z} - \cancel{2\nu \overline{S}_{xz}}$$

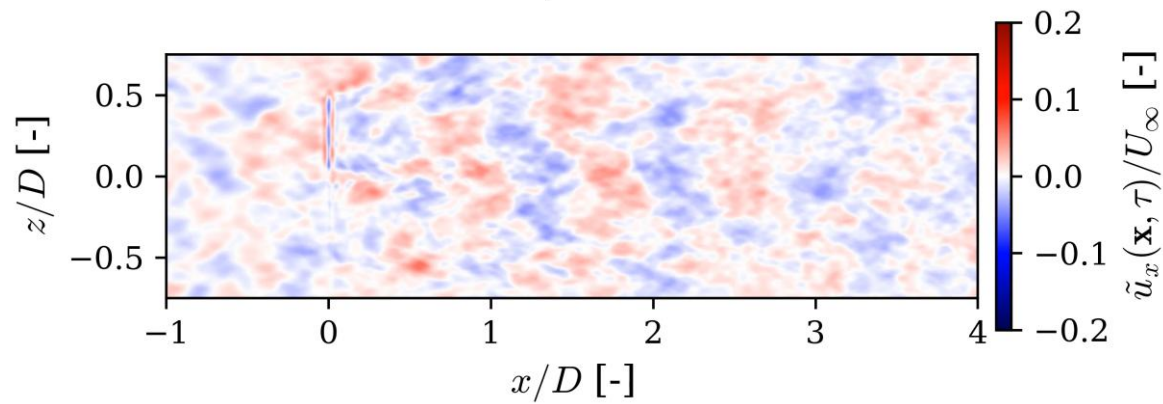
Magnitude of momentum injection into the wake sensitive to N_ε



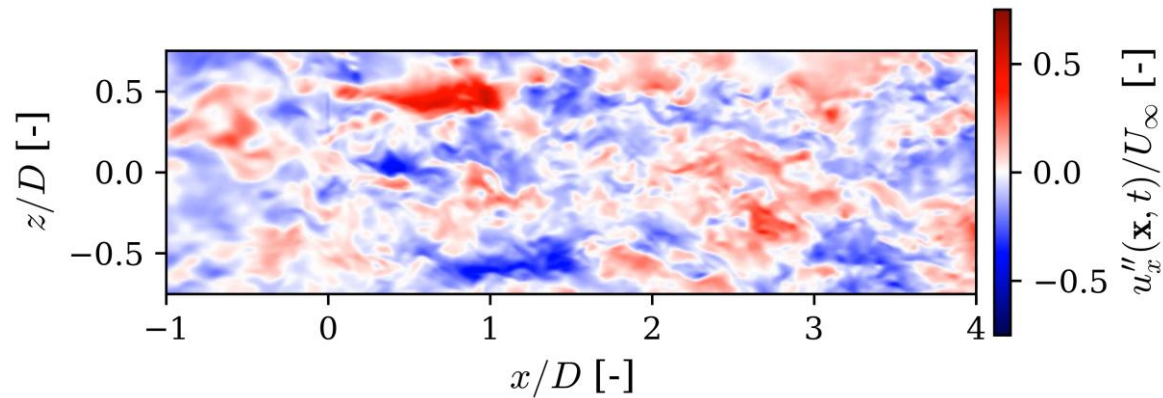
Turbulent Flow



Mean flow



Coherent flow



Fluctuating flow

Turbulent Flow

