Damping a turbulent channel flow to understand spanwise forcing for drag reduction

Marco Castelletti, Emanuele Gallorini, Maurizio Quadrio

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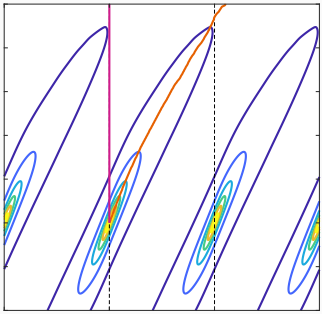
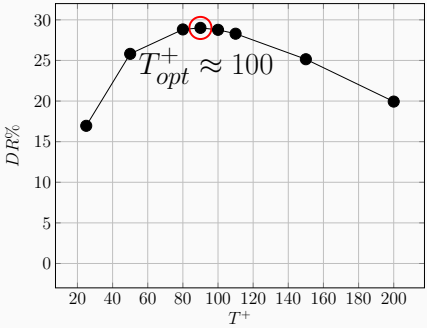


Politecnico di Milano, marco.castelletti@polimi.it

Did we really understand the Oscillating Wall?

Possible interpretations:

1. Time scale
2. Longitudinal length scale
3. Lateral displacement
4. Penetration depth length scale (δ)



A thought numerical experiment

Question

How turbulence length/life scales are involved in the working mechanism of OW?

Our strategy: Apply the OW on a turbulent flow with altered scales!

Is it possible to perform experiments on a turbulent flow with altered scales?

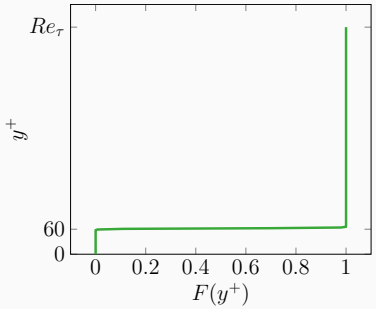
- ➤ Thanks to numerics yes!
  - e.g. Jimenez, JFM 2022: damping turbulence modifies length scales

How turbulence is damped

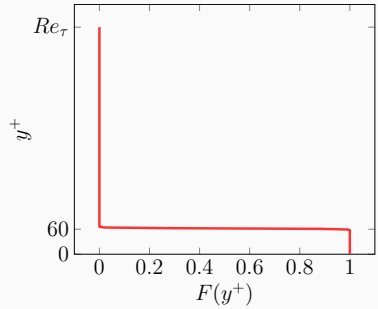
- Explicitly zeros at each time step long Fourier modes of normal vorticity ω_y
- $\omega_y(\lambda_x, y) = \omega_y(\lambda_x, y)F(y) \quad for \quad \lambda_x > \lambda_{x,f}$

Two different filters were used:

Inner filter



Outer filter



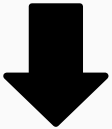
Our DNS study

- Channel flow at CFR
- Reference undamped simulation at $Re_b = 10000$ ($Re_\tau \approx 545$)
- Six damped simulation at $Re_b = 10000$: 3 with inner and 3 with outer filter

Inner filter:

	$\lambda_{x,f}/h$	$\lambda^+_{x,f}$
I2	2.09	1082
I3	1.57	782
I4	1.25	594

less damping

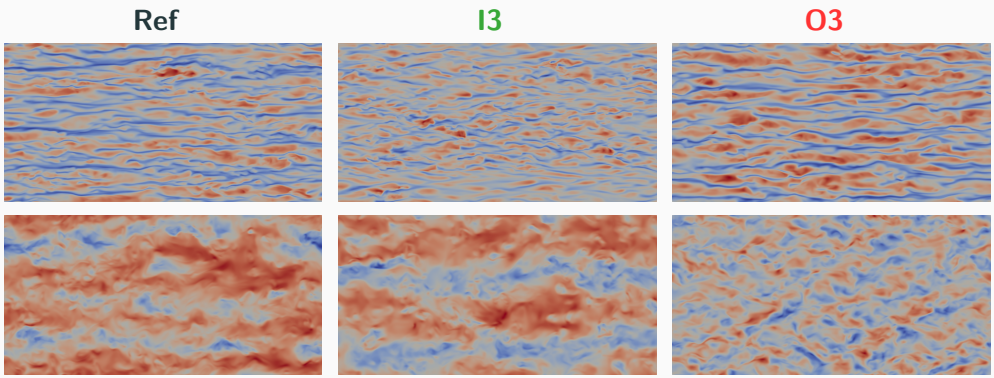


more damping

Outer filter:

	$\lambda_{x,f}/h$	$\lambda^+_{x,f}$
O2	2.09	996
O3	1.57	686
O4	1.25	482

Flow visualizations

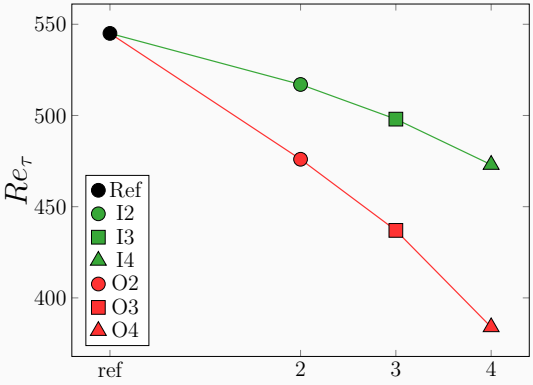


How does the damping modify near-wall turbulence?

With damping:

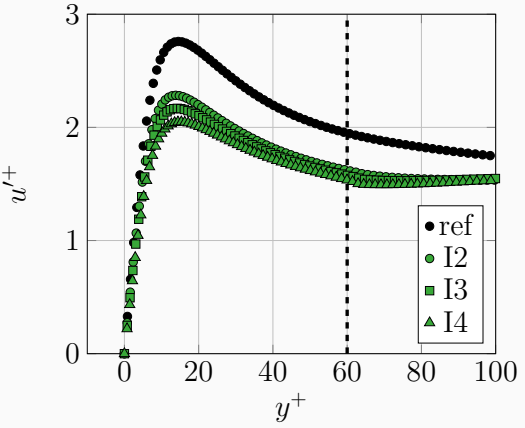
- Flow remains fully turbulent
- Re_τ of the flow is reduced

➤ Outer damping reduces more Re_τ

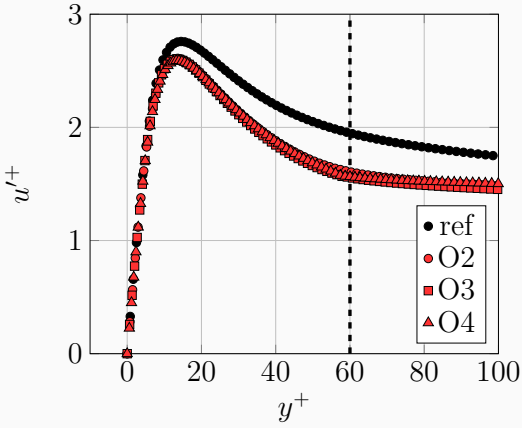


Does damped turbulence scale?

Inner filter



Outer filter



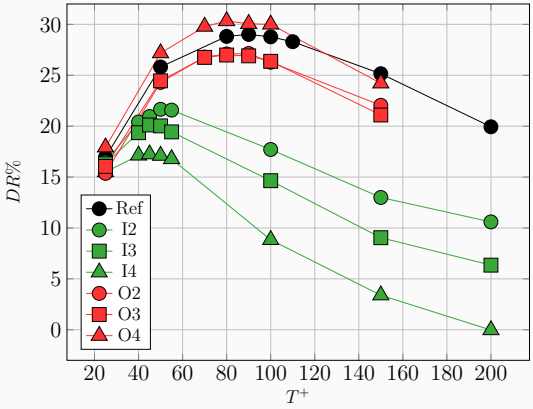
A (small) parameter study

OW applied in comparative form to the reference damped/undamped cases

- Oscillating period between $T^+ = 25$ and $T^+ = 200$
- Oscillating amplitude fixed at $A^+ = 12$

Will T^+_{opt} and DR be influenced by the damping? How?

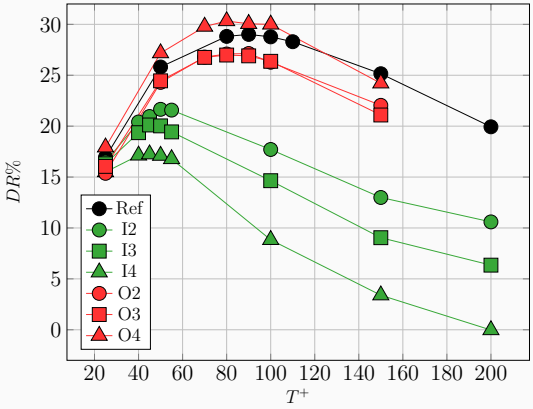
Damped turbulence with Oscillating Wall



What changes with OW + damping?

1. Maximum attainable DR

Damped turbulence with Oscillating Wall

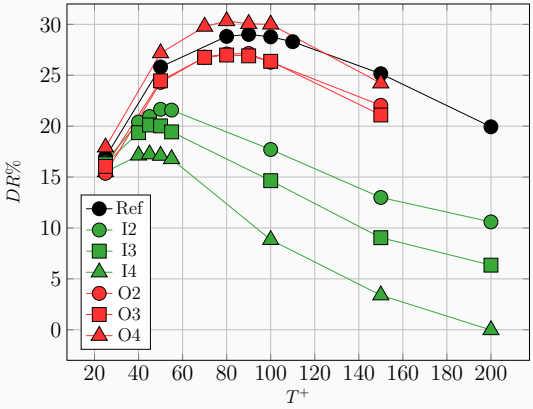


What changes with OW + damping?

1. Maximum attainable DR

Possible explanations?

Damped turbulence with Oscillating Wall



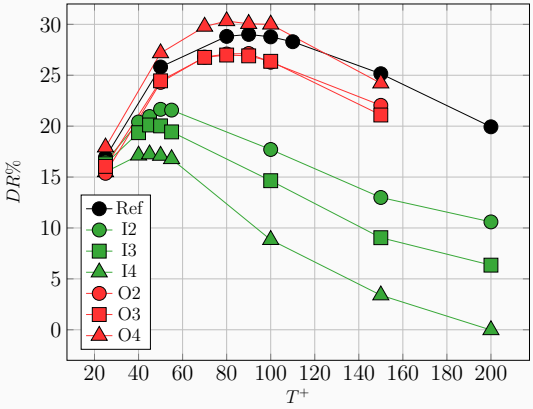
What changes with OW + damping?

1. Maximum attainable DR

Possible explanations?

1. Damping and Re_τ effects

Damped turbulence with Oscillating Wall



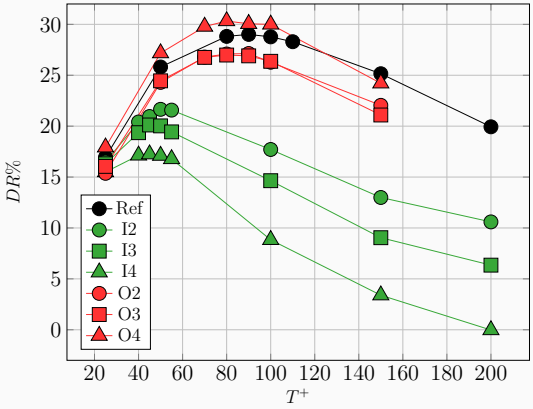
What changes with OW + damping?

1. Maximum attainable DR
2. T^+_{opt} shifts towards smaller values

Possible explanations?

1. Damping and Re_τ effects

Damped turbulence with Oscillating Wall



What changes with OW + damping?

1. Maximum attainable DR
2. T^+_{opt} shifts towards smaller values

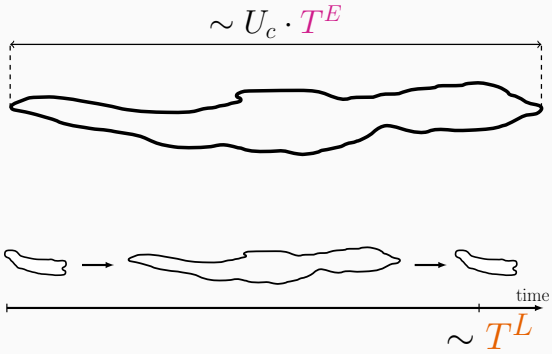
Possible explanations?

1. Damping and Re_τ effects
2. Turbulence scales?

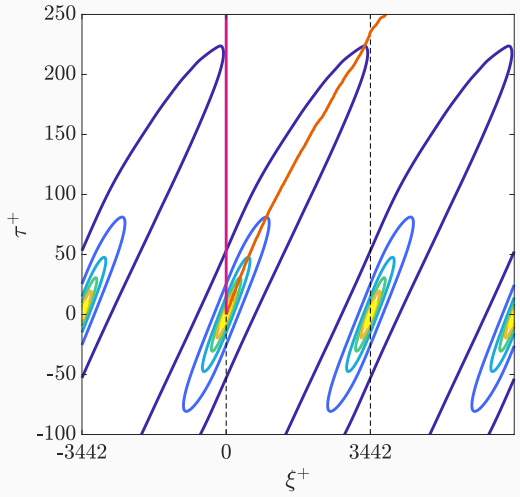
Near-wall turbulence scales

Near wall turbulence is characterized via:

- integral Eulerian time scale (T^E)
- integral Lagrangian time scale (T^L)



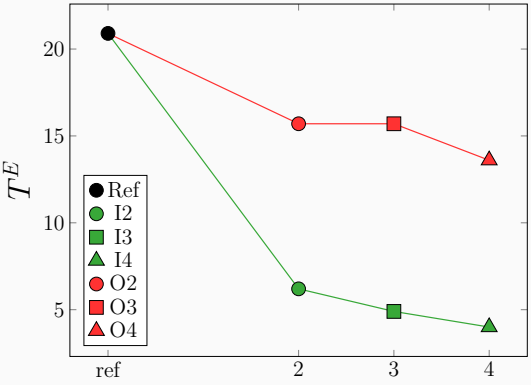
$R_{uu}(\xi^+, \tau^+)$ at $y^+ = 15$



How does the damping modify turbulence scales?

With damping:

- T^E is reduced

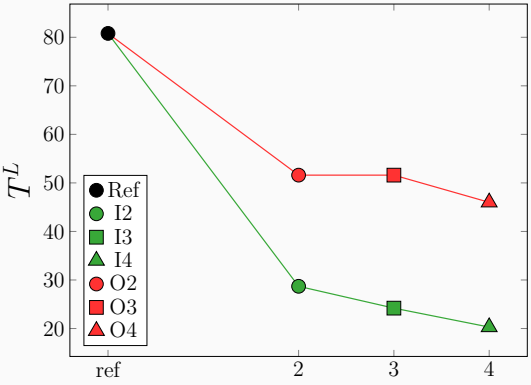


How does the damping modify turbulence scales?

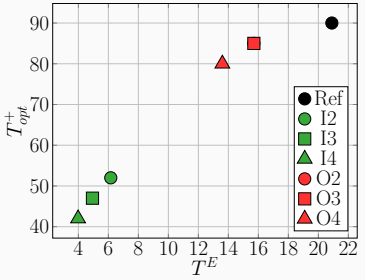
With damping:

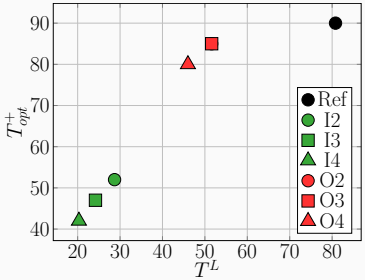
- T^E is reduced
- T^L is also reduced

➤ Inner damping reduces more T^E and T^L



Why T^+_{opt} shifts towards smaller periods?





A possible role of turbulence scales?

- T^+_{opt} decreases as T^E and T^L decrease
- Similar trend for both T^E and T^L vs T^+_{opt}

What is the meaning of these trends?

➤ Further investigation needed!

Conclusions

Altering turbulence scales modifies the response of the flow to the OW!

However:

- How turbulence scales play a role is still not clear
- Further work on the topic is needed (e.g. δ?)

Again this work confirms that:

➤ Further steps are needed to comprehend the working mechanis of the OW!

Thank you for your attention!