Drag reduction effects in a turbulent channel flow induced by spanwise wall oscillations

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THE WORK

Turbulent friction drag reduction

- Active technique
- Net energy balance: $P_{net}(\%) = DR(\%) - P_{sp}(\%)$
- Accuracy is key to calculate net balance

Spanwise forcing of near-wall turbulence

- Wall oscillation below wall turbulence - *TIME*
- Spanwise direction - *LARGE SCALE*
- W_m maximum wall velocity - T period of oscillation

$$W = W_m \sin(2\pi t/T) \qquad D_m = W_m T$$

Channel flow DNS Politecnico di Milano

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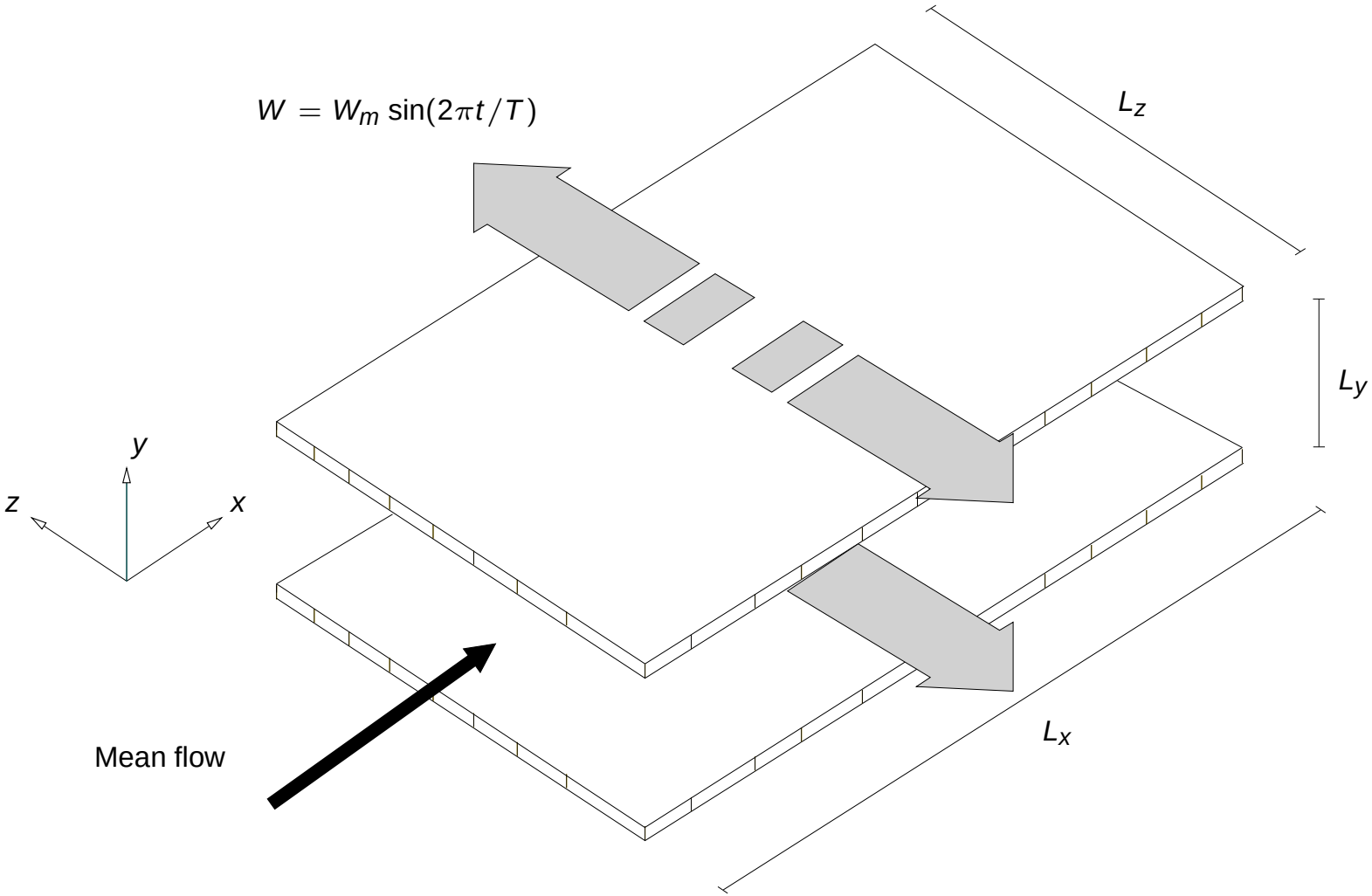
THE OSCILLATING-WALL FLOW



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OUTLINE

1. Optimum T for DR(%)

- $T^+_{opt,W} = 125$ *fixed max wall* W^+_m - *numerical approach*
- $T^+_{opt,D} = f(D^+_m)$ *fixed max wall* D^+_m - *experimental approach*

Relevant for application

2. Drag reduction & net balance

- Scaling: $DR(\%) \sim \Omega_{x,m}$ *max streamwise vorticity -* **Stokes layer**
- Maps
  - $DR(\%) = f(D^+_m, T^+)$ *drag reduction*
  - $P_{net}(\%) = f(D^+_m, T^+)$ *net energy balance*
- Minimal conditions *necessary for drag reduction*

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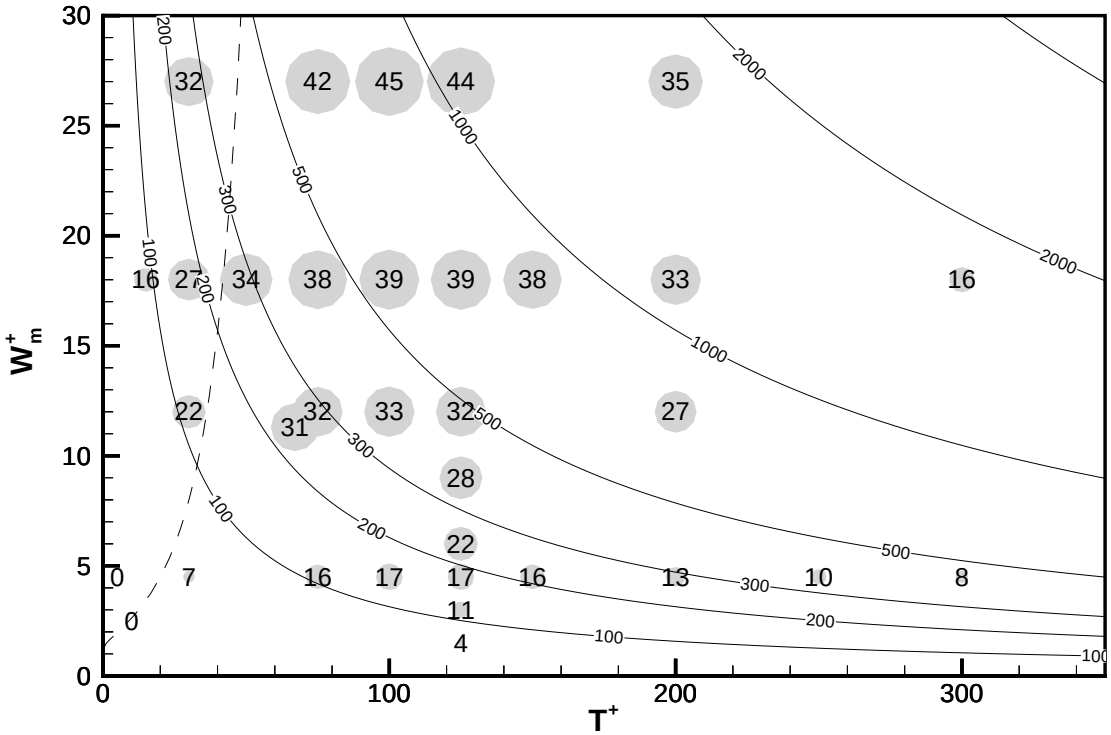
MAP OF DRAG REDUCTION

- Hyperbolae - constant D_m^+ max wall displacement
- Dashed line - Optimum $T^+_{opt,D}$



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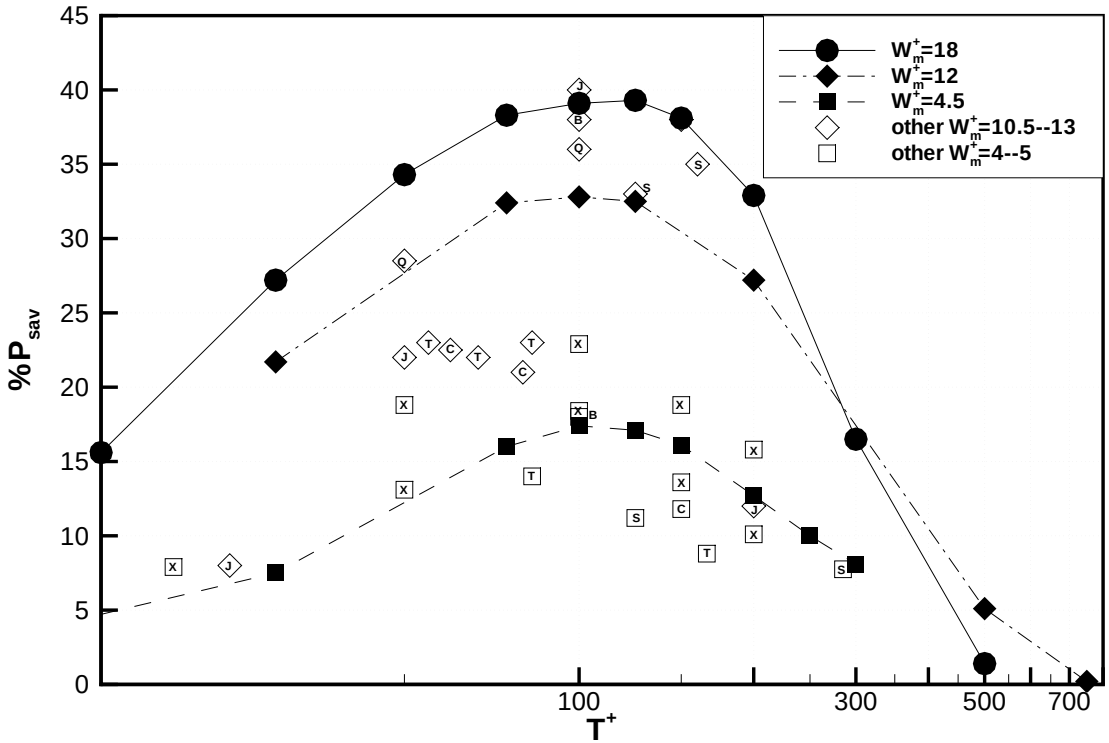
OPTIMAL PERIOD $T^+_{opt,W}$

- Optimal period at fixed W_m Max wall velocity
- It does not depend on W_m



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OPTIMAL PERIOD $T^+_{opt,D}$

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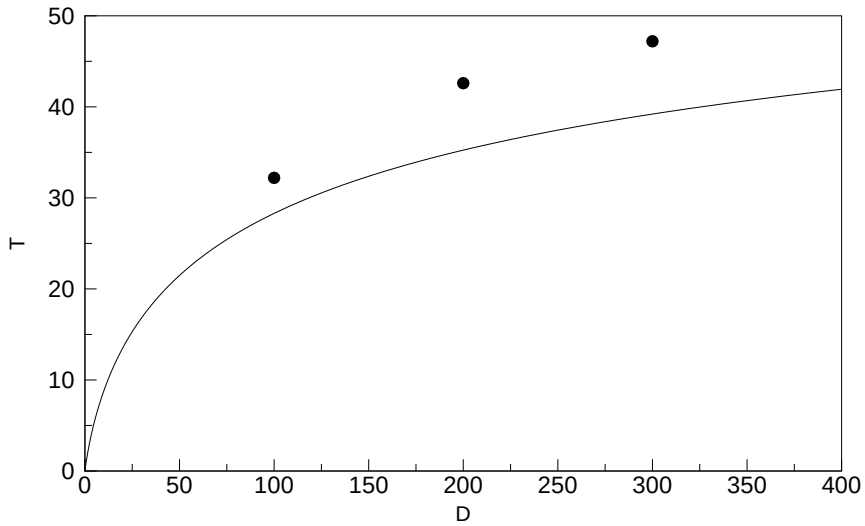
- $T^+_{opt,D} = f(D^+_m) < T^+_{opt,W}$



- Experimental: $T^+_{opt,D}$ NEVER MEASURED! $\longrightarrow$ W^+_m scaling parameter!? **;-(**
- Numerical: $T^+_{opt,W}$

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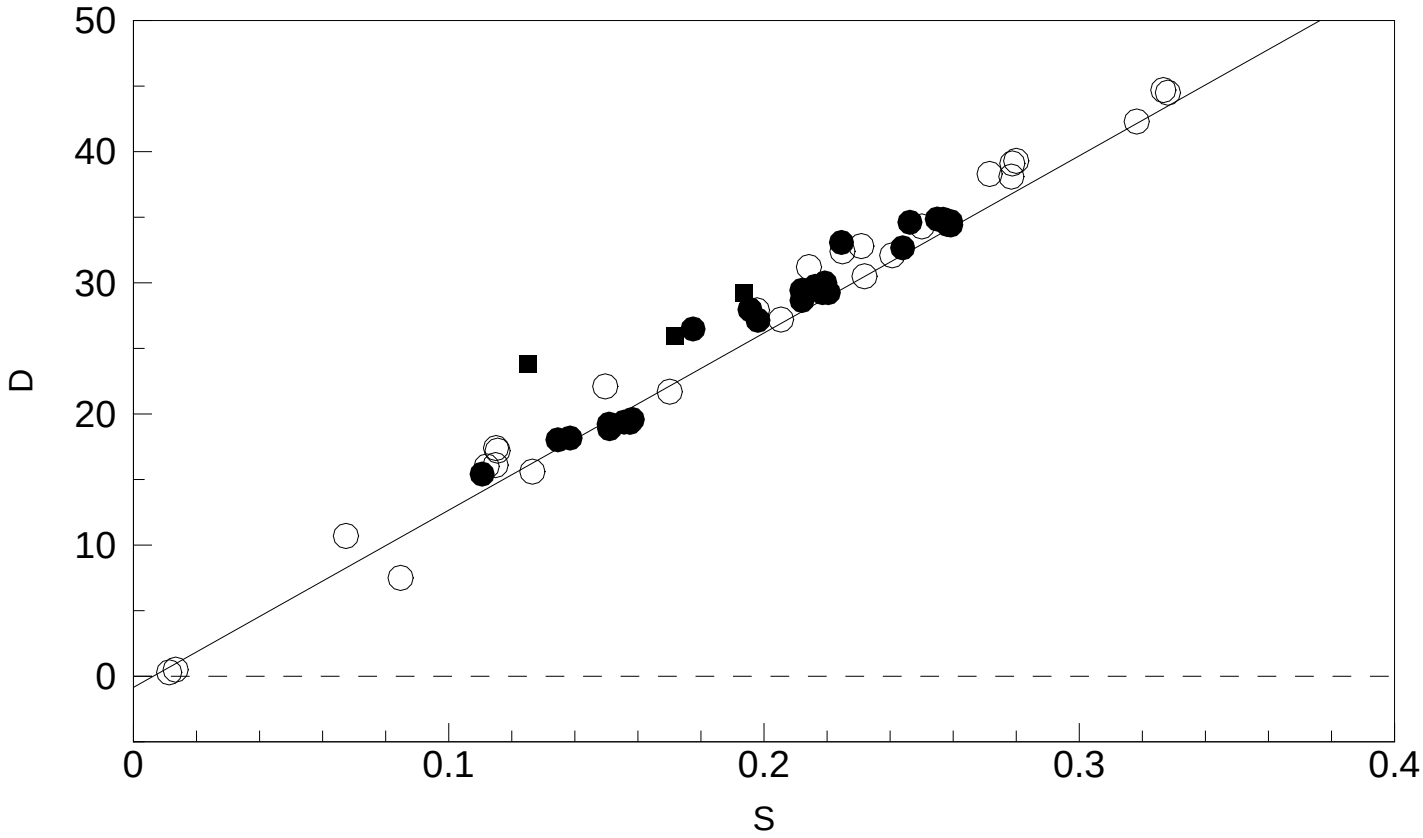
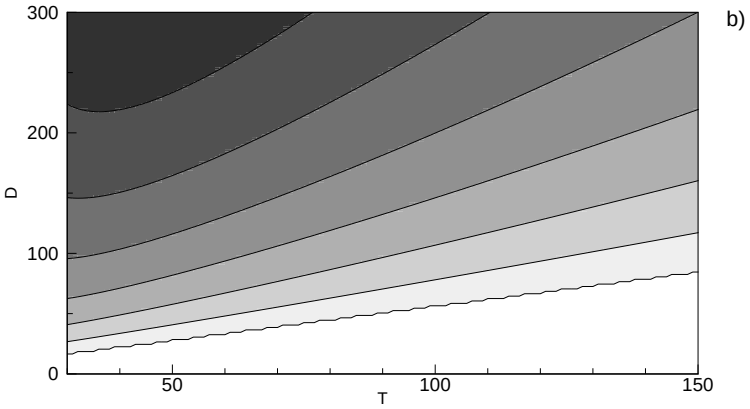
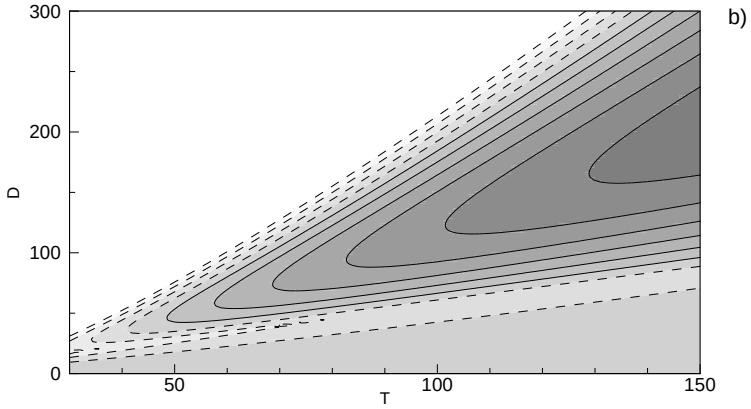
$DR(\%)$ SCALING



- Scaling: $DR(\%) \sim \Omega_{x,m}$
- Good for prediction of $DR(\%)$ and $P_{net}(\%)$

MAPS: $DR(\%)$ & $P_{net}(\%)$





- $P_{net,max} = S_1 \sqrt{\pi/T^+} \exp\left(-\ell_a^+ \sqrt{\pi/T^+}\right)\left(P_1 - \ell_a^+ \sqrt{\pi/T^+}\right) + S_2$

  maximum net energy balance
- **Minimal conditions** minimum forcing to get $DR(\%)$
- Key for applications Lorentz forcing, plasma forcing
- Minimal conditions not satisfied oscillating and sinusoidal riblets

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