Turbulence Drag Reduction by Spanwise Travelling Waves of Spanwise Velocity

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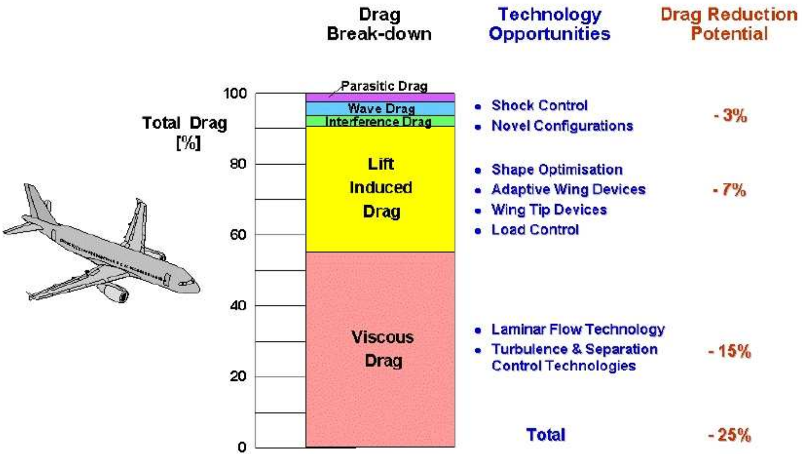
Skin-friction drag reduction: motivation

The breakdown of the drag on an aircraft



State-of-the-art

Active open-loop techniques only

Turbulent drag reduction by in-plane wall motion:

Strategy	R	S
Streamwise travelling waves (Quadrio et al JFM 2009)	large	high
Spanwise-oscillating wall (Jung et al Phys. Fluids 1992)	large	low
Spanwise travelling waves (Du et al Science 2000)	large	unknown

Spanwise travelling waves

$w = A\sin(\kappa_z z - \omega t)$

If $\kappa_z = 0$, wall oscillation

Aim and Method

Aim

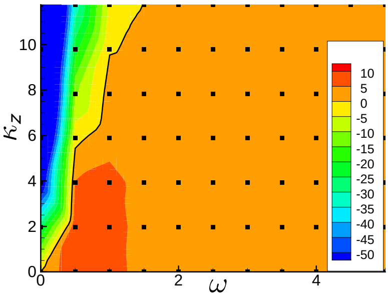
Find the optimal point in the 3d parametric space $(A - \omega - \kappa_z)$ with the best energetic performance.

Method

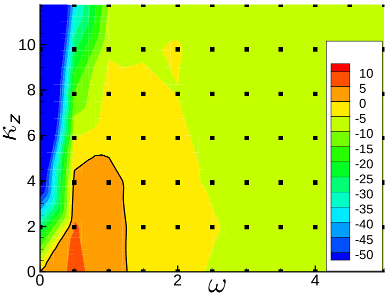
250 Direct Numerical Simulation
turbulent channel flow at $Re_\tau = 200$.

Map of Drag Reduction and Net Energy Saving

A=0.1



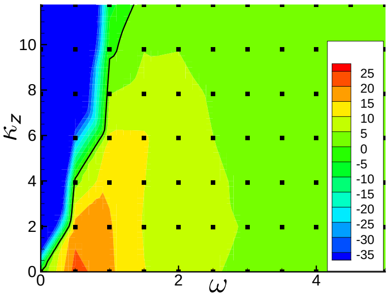
R



S

Map of Drag Reduction and Net Energy Saving (cont.)

A=0.2



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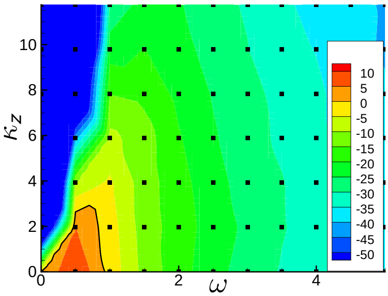
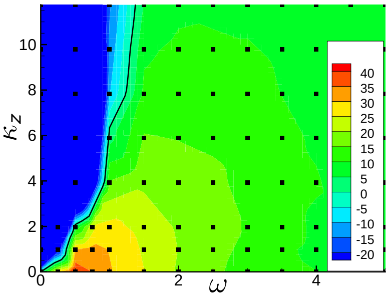


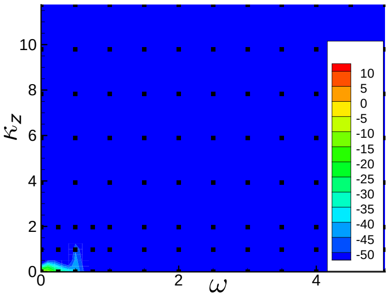
S

Map of Drag Reduction and Net Energy Saving (cont.)

A=0.5



R

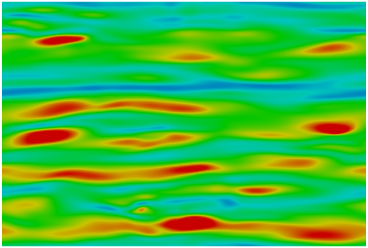


S

Modification of Near Wall Turbulence

top view

$A = 0.5, \quad \kappa_z = 4, \quad y^+ = 5$



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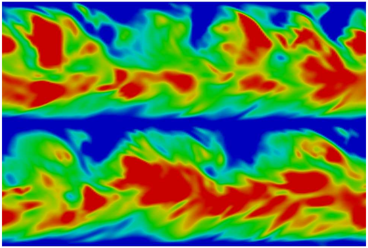
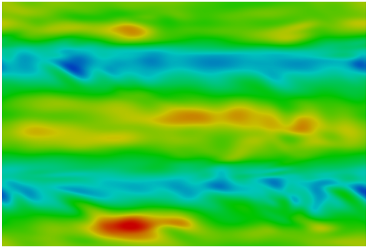


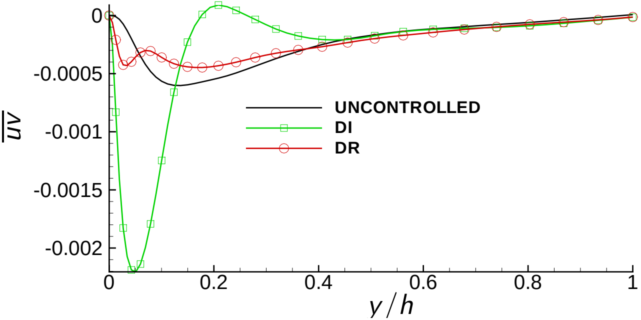
DI ($\omega = 0.5$)

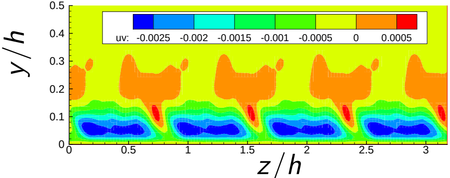


DR ($\omega = 1.0$)

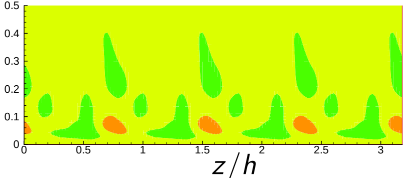
Reynolds Stress

$\overline{uv}$ of the DI and DR cases





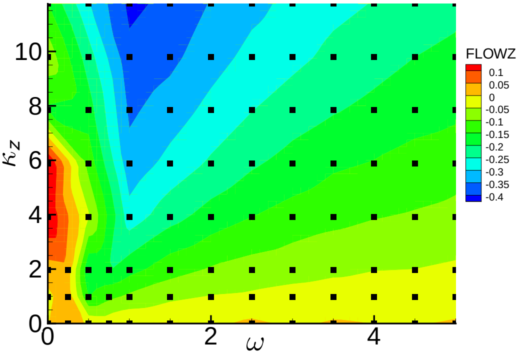
DI



DR

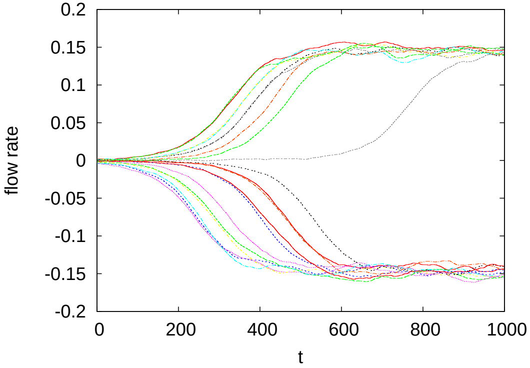
Spanwise flow rate

- $\nabla_z P = 0$ in all simulations
- spanwise flow rate arises for most of the simulations
- analogy to travelling wave of blowing and suction (Hoepffner and Fukagata JFM 2009)



In the case of standing wave

- Different initial fields lead to different sign of the flow rate. The symmetry is kept on ensemble average.



Conclusion and Future Work

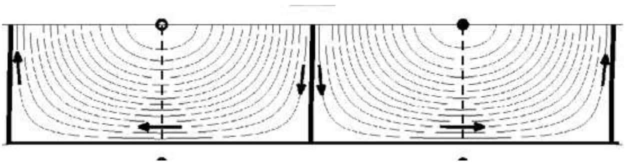
- Conclusion:
  From the global map:
  - large maximum drag reduction, but low net energy saving
  - always outperformed by the spanwise wall oscillation

  From the flow statistics:
  - near wall turbulence cycle is modified
  - creation of spanwise flow rate (could be used?)

- Future Work:
  spanwise traveling wave of body force
  (Du et al 2000 Science)

Thank you all!

"Streaming" effect from blowing/suction waves



Suppose the blowing/suction wave is travelling from left to right. We look at a particle originally at distance y_0 from the wall:

- In the first cell (the cell on the right), the particle is first pused towards the wall and then blowed back to y_0, the particle is travelling in region $y < y_0$.
- In the second cell, the particle is first blowed towards the center line and then sucked back to y_0, the particle is travelling in region $y > y_0$

(Hoepffner and Fukagata JFM 2009)