On the optimal period of spanwise forcing for turbulent drag reduction

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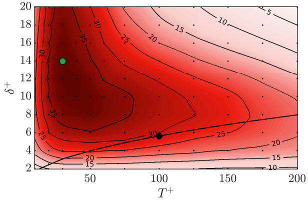

Spanwise forcing: how does it work?

It works:

- at large Reynolds number
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- with real discrete forcing devices

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How does it work?

- to get insight of the working mechanism
- to design more performing actuators

Spanwise forcing: What we know

Oscillating wall (Jung et al., PoF 1992)

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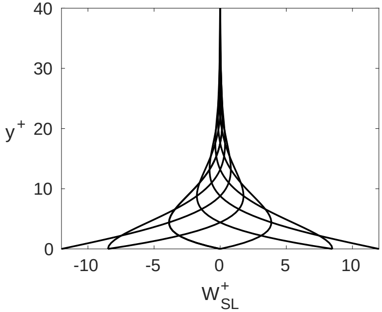

It creates a spanwise Stokes layer (SL)

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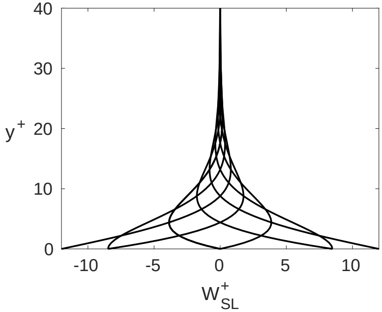

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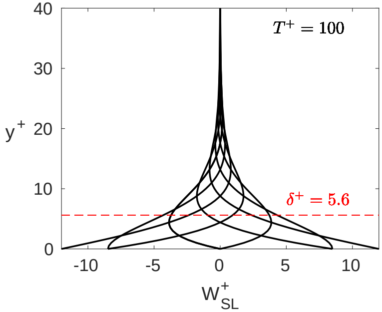

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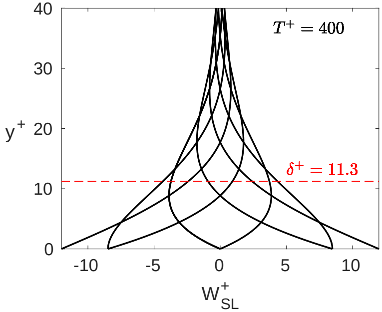

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- Time scale
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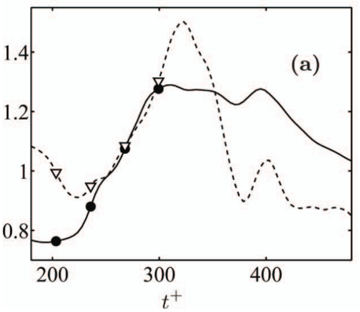

Jimenez, PoF 2013

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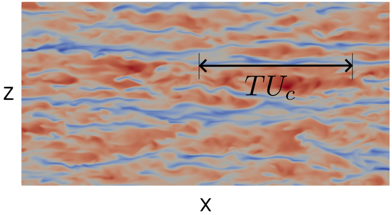

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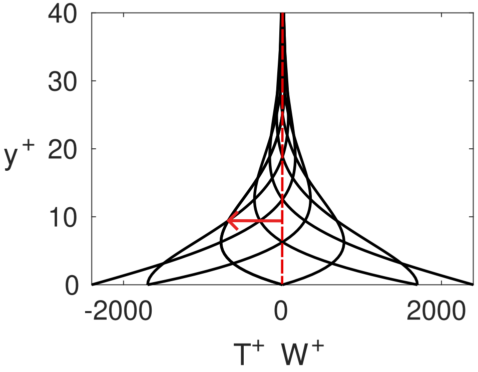

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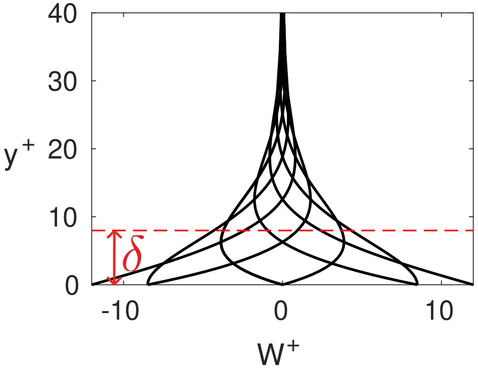

Thought experiment manipulating the control

✗ Oscillation of the wall

✓ Directly imposition of the desired spanwise velocity profile W_{ESL} at each time step

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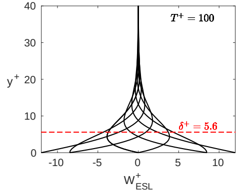
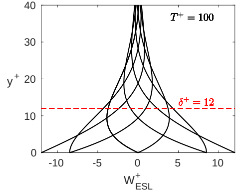
We decouple T and δ:

$$W_{ESL} = Ae^{y/\delta} sin\left(\frac{2\pi}{T}t - \frac{y}{\delta}\right)$$

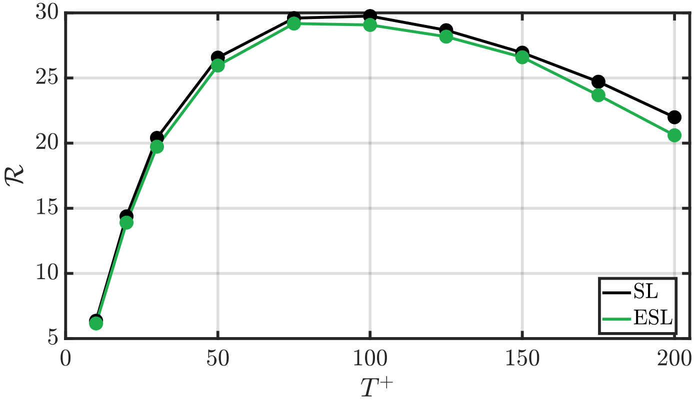
$$\delta \neq \sqrt{\frac{\nu T}{\pi}}$$



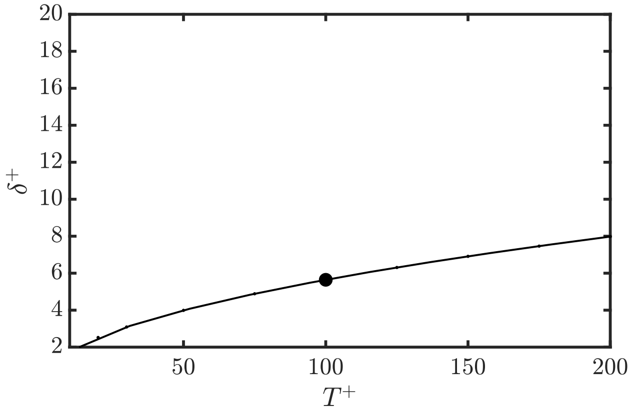


Validation

- Channel flow
- $A^+ = 12$
- $Re_\tau = 400$



Drag reduction map



● $T^+_{opt} = 100$, $\delta^+_{opt} \approx 6$
$\rightarrow \mathcal{R} \approx$ 30%

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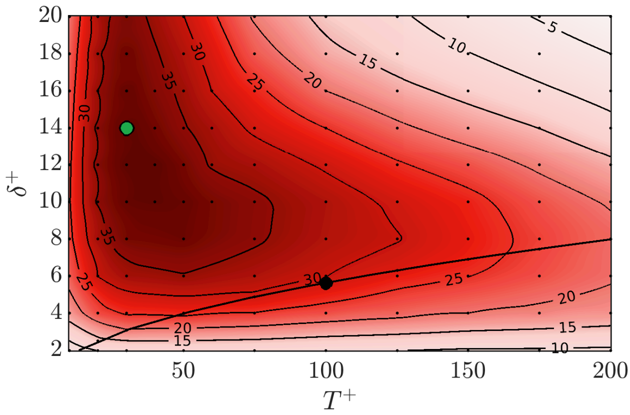

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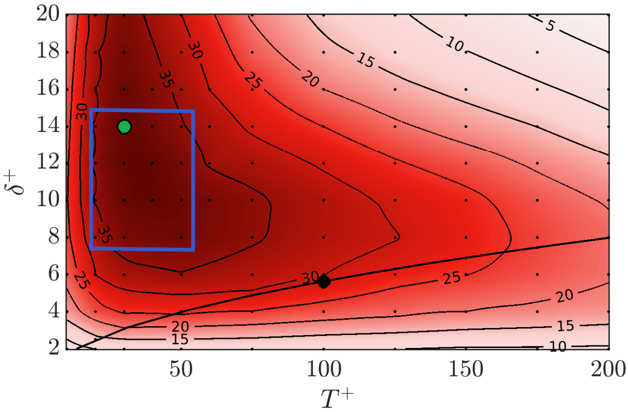
● $T^+_{opt} = 30, \delta^+_{opt} = 14$
$\rightarrow \mathcal{R} \approx 40\%$

Drag reduction map



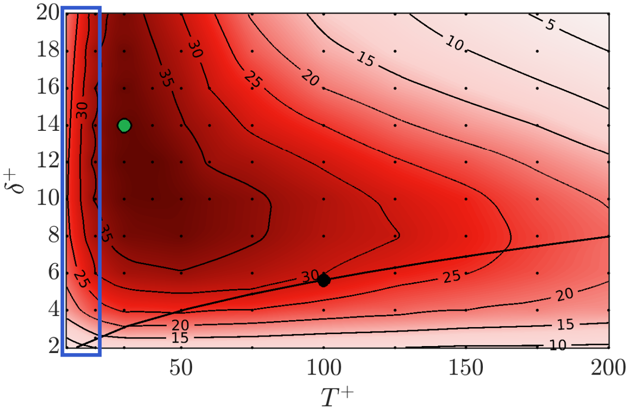
The area of the maximum $\mathcal{R}$

- $20 \leq T^+ \leq 50$
- $8 \leq \delta^+ \leq 14$

corresponds to

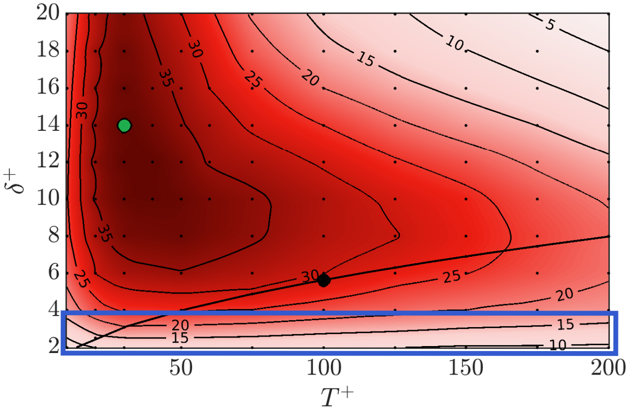
- the regeneration time-scale of the streaks
- the position of buffer layer

Drag reduction map



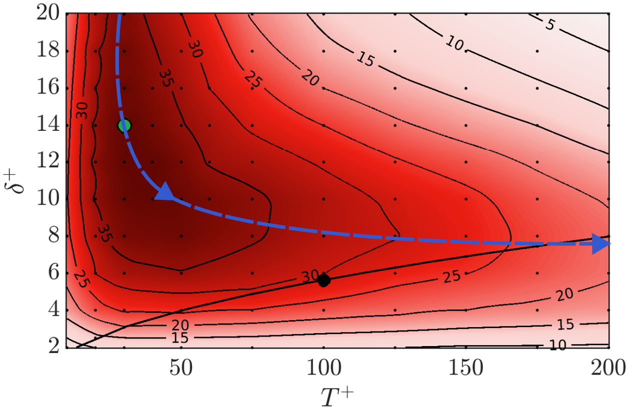
- $T^+ \leq 20$
- $\mathcal{R}$ small and almost constant with δ
- T is too small compared to the flow time scales

Drag reduction map



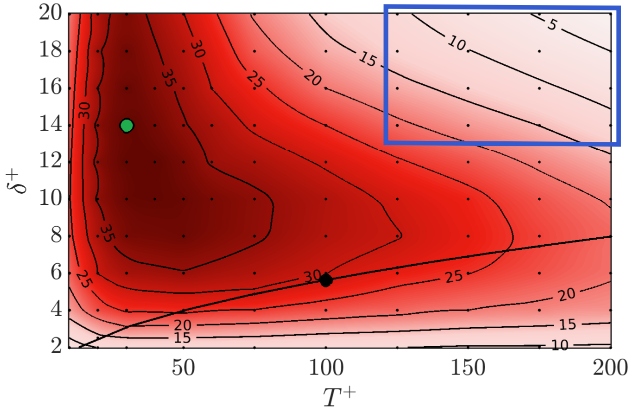
- $\delta^+ \leq 4$
- $\mathcal{R}$ small and almost constant with T
- The spanwise motion is confined in the viscous sublayer

Drag reduction map

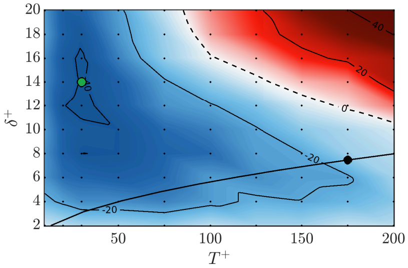


- For large T, the control is more effective if confined close to the wall

Drag reduction map



- Large spanwise fluctuations induced by the control erode $\mathcal{R}$
- $\Delta W^{rms} = 100 \frac{\langle W^{rms}_{ESL} \rangle - \langle W^{rms}_{ref} \rangle}{\langle W^{rms}_{ref} \rangle}$



Conclusions

- Successfully decoupling the effect of T and δ
- $T^+_{opt} \approx 100$ and $\delta^+_{opt} \approx 6$ do not possess a special physical meaning
- Way paved for the design of alternative control strategies (actuation $\neq$ control)
- Ongoing: computation of the net power saving

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Thank you for the attention