Spanwise forcing for turbulent drag reduction: the optimal oscillation period

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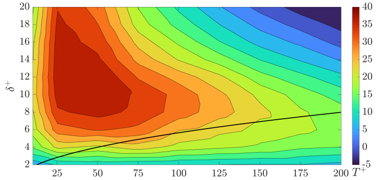
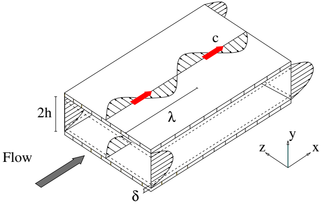
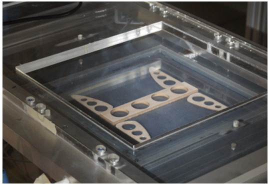
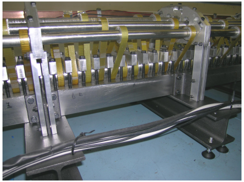
ETC18, Valencia, Sept 5, 2023

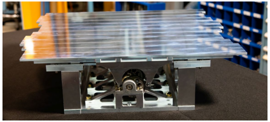


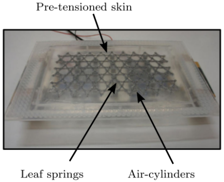
Actuators for spanwise forcing




Gatti Exp.Fluids 2015


Auteri Phys.Fluids 2010

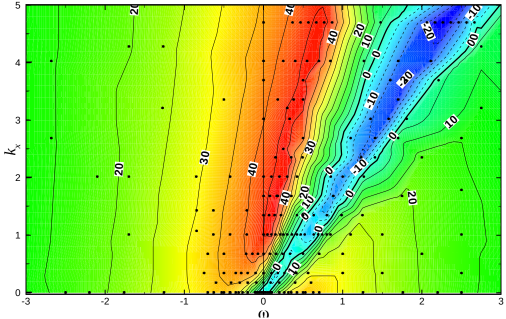

Marusic Nat.Comm 2021



Bird FTaC 2018

We have answers to several questions, but . . .

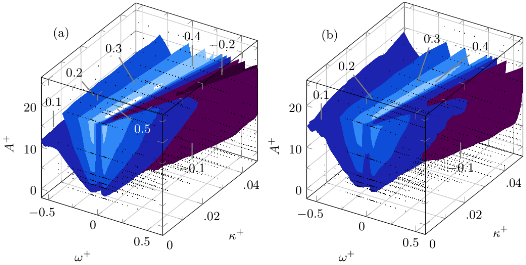
- Performance



Quadrio et al JFM09

We have answers to several questions, but . . .

- Performance
- Reynolds number



Quadrio & Gatti JFM16

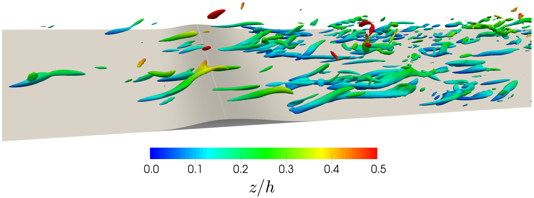
We have answers to several questions, but ...

- Performance
- Reynolds number
- Compressibility

Talk by F.Gattere, session "Control", room S04 today at 15:30

We have answers to several questions, but . . .

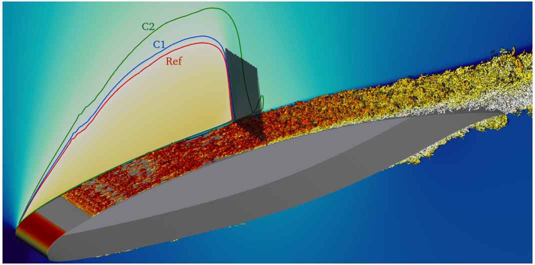
- Performance
- Reynolds number
- Compressibility
- Complex geometries



Banchetti et al JFM20

We have answers to several questions, but . . .

- Performance
- Reynolds number
- Compressibility
- Complex geometries
- Transonic airfoil (airplane)



Quadrio et al JFM22

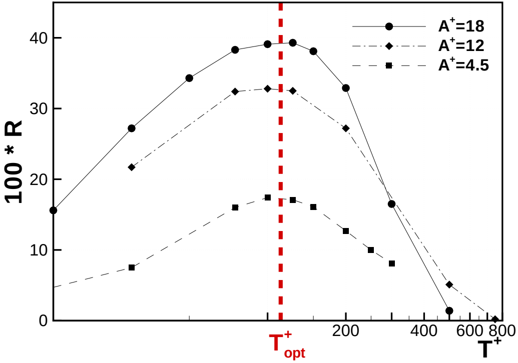
We have answers to several questions, but ...

- Performance
- Reynolds number
- Compressibility
- Complex geometries
- Transonic airfoil (airplane)
- How does it work?

- Several studies and reviews
- Statistics are either unchanged or consequence of drag reduction
- No convincing explanation for the drag reduction mechanism
- The mechanism should be known before searching for an actuator

Focus on spanwise wall oscillation

$$\boxed{w(x, y = 0, z, t) = A \sin\left(\frac{2\pi}{T} t\right)}$$



- An optimal oscillation period exists
- Its value is $T^{+}_{opt} \approx 100$

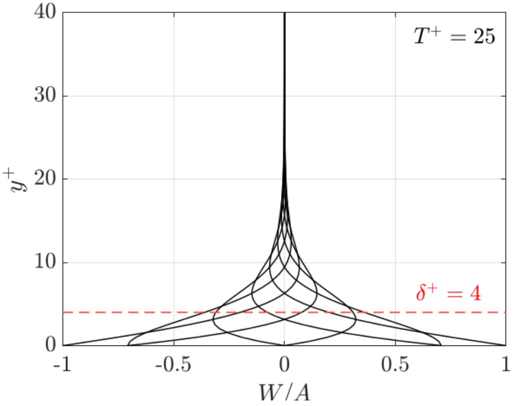
The transversal Stokes layer

It is well described by the laminar solution:

$$W_{SL}(y,t) = A \exp\left(\frac{-y}{\delta}\right) \sin\left(\frac{2\pi}{T} t - \frac{y}{\delta}\right)$$

with

$$\delta(T) = \sqrt{\frac{\nu T}{\pi}}$$



Possible interpretations of T_{opt}

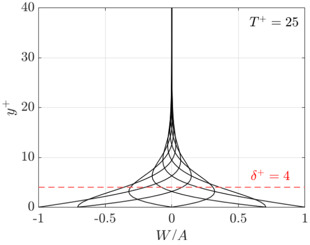
- a wall-normal length scale (thickness of the Stokes layer)?
- a time scale of turbulence (lifetime of wall structures)?
- a streamwise length scale (a convection distance)?
- a streamwise length (the length of low-speed streaks)?
- none of the above?

A thought experiment

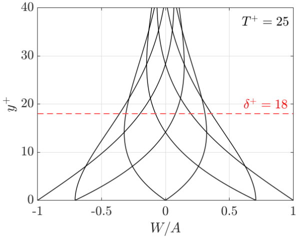
In a DNS, an artificial Stokes layer can be prescribed: T and δ can be decoupled!

The profile $W_{SL}(y,t)$ is enforced, instead of computed

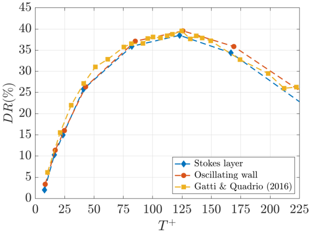
True W_{SL}:



Artificial W_{SL}:



Check:



Parameter study of $DR = DR(\delta, T)$

Channel flow DNS at $Re_\tau = 200$

Domain size $4\pi h \times 2\pi h$

$A^+ = 12$ is fixed

≈ 100 DNS are carried out by varying T and δ independently

Parameter study of $DR = DR(\delta, T)$

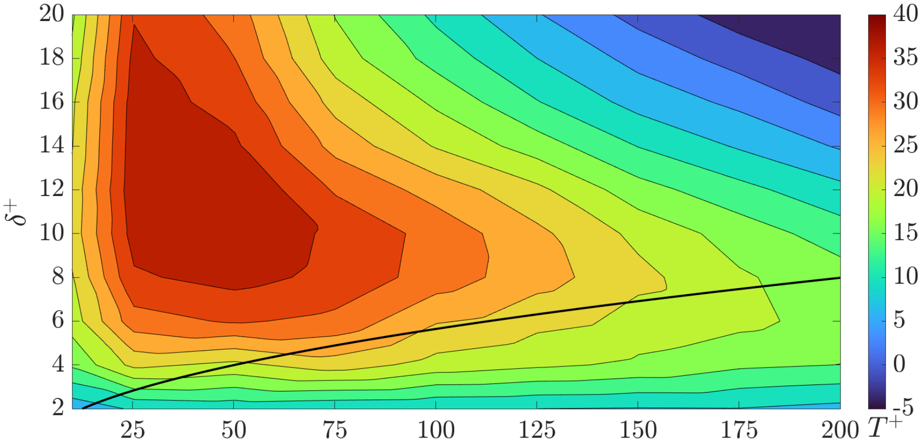
Channel flow DNS at $Re_\tau = 400$

Domain size $4\pi h \times 2\pi h$

$A^+ = 12$ is fixed

≈ 100 DNS are carried out by varying T and δ independently

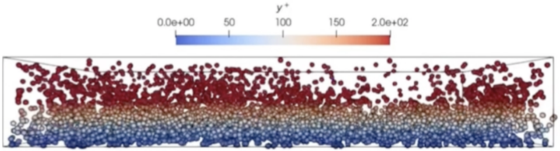
Drag reduction map at $Re_\tau = 400$



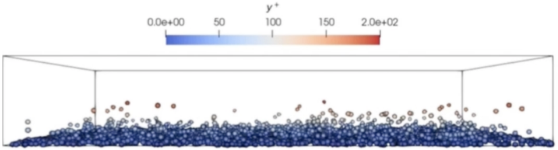
Conclusions

- The ‘magic’ value $T^+_{opt} = 100$ carries no special meaning
- Ongoing work towards understanding of spanwise forcing

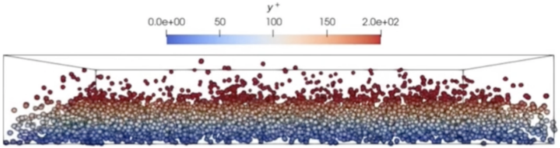
Lagrangian particles



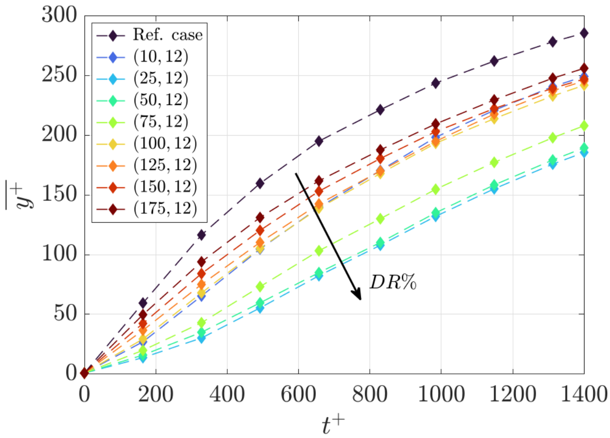
Reference case



$(T^+_{opt}, \delta^+_{opt}) = (50, 12)$
$\Longrightarrow$ DR=39.4%



$(T^+, \delta^+_{opt}) = (175, 12)$
$\Longrightarrow$ DR=13.8%



300
250
200
150
100
50
0
$\overline{y^+}$
0
200
400
600
800
1000
1200
1400
t^+
Ref. case
(10, 12)
(25, 12)
(50, 12)
(75, 12)
(100, 12)
(125, 12)
(150, 12)
(175, 12)
DR%

DR map in * units