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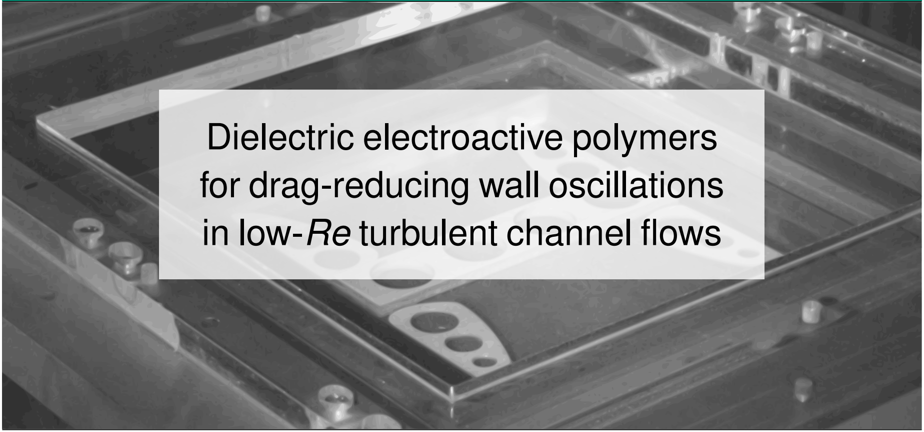
EFMC10, Copenhagen, 14-18 September 2014



Dielectric electroactive polymers for drag-reducing wall oscillations in low-*Re* turbulent channel flows

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Wall oscillations in practice

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- Many bulky, energetically inefficient proof-of-principle experiments
  - Significant modification of the wind-tunnel test section
- Few modular and smart solutions
- Practical realization insurmountable challenge
  - Small space- and timescales of wall motion
  - Large areas to be displaced uniformly
- A recent attempt by Gouder (EXIF2013) with dielectric electroactive polymers
  - Technology dropped as unripe for flow control application

Motivation for a laboratory experiment

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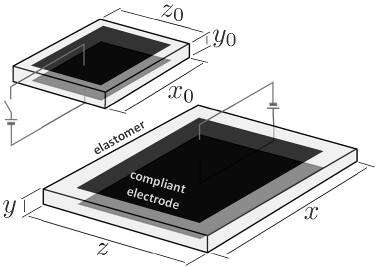
Experimentally test oscillating surfaces made of dielectric electroactive polymers (DEAPs) in a channel flow geometry.

The goals are:

- Fabricate reliable DEAP-based actuators
- Test the potential of DEAPs
- Investigate the effects of non-ideal wall-forcing

Dielectric electroactive polymers (DEAP)



incompressible dielectric $x_0 y_0 z_0 = xyz$

active Maxwell stress $p = \epsilon_0 \epsilon_r \left(\frac{\Phi}{z}\right)^2$

Pros:

- simple
- inexpensive
- efficient

Cons:

- high-voltage
- developing technology
- fragile

DEAP actuator in action

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f = 80 Hz

Φ = 3000 V

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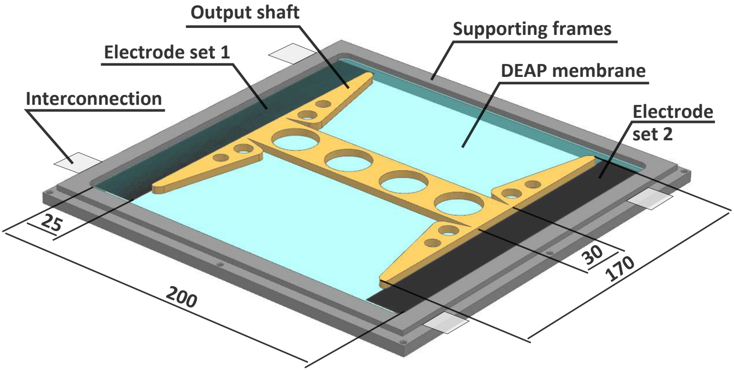
The DEAP actuator

driver module



The DEAP actuator (cont'd)

complete module

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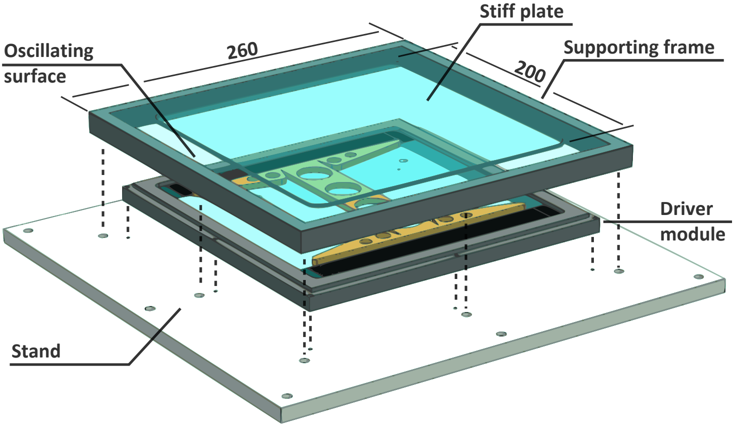

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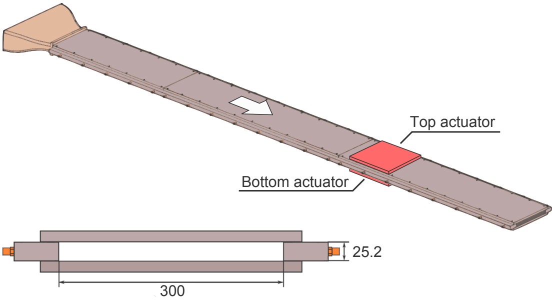
Flow parameters

Blower wind-tunnel with channel flow geometry (Güttler EFMC10)



Working fluid is air

$$
\begin{array}{rcl l}
2h = & 25.2 & & \text{mm} \\
w = & 300 & & \text{mm} \\
2.7 \leq & U_B & \leq 9.1 & \text{m/s} \\
4500 \leq & Re_B & \leq 15000 & \\
150 \leq & Re_\tau & \leq 450 & \\
0.6 \leq & \Delta p & \leq 6 & \text{Pa!!!}
\end{array}
$$

Active test section

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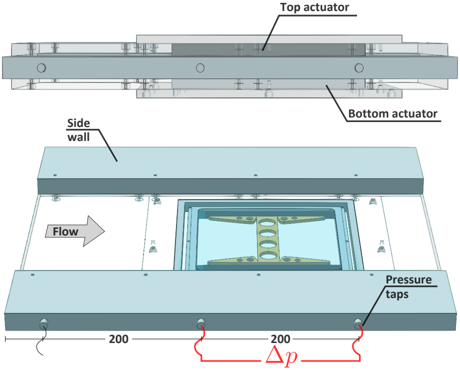
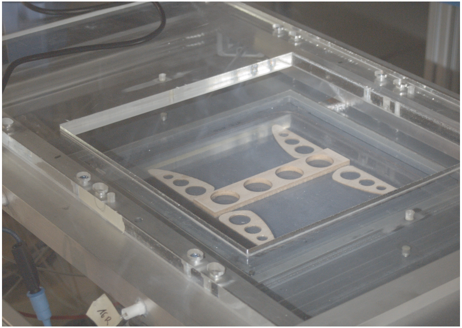
Control parameters: $T = 1/65\,\mathrm{s}$ $A = 820\,\mathrm{mm/s}$





Drag Reduction

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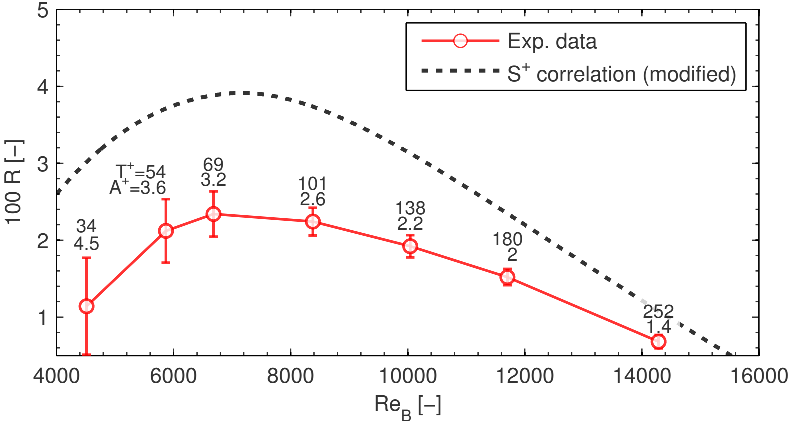

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Drag Reduction (cont'd)

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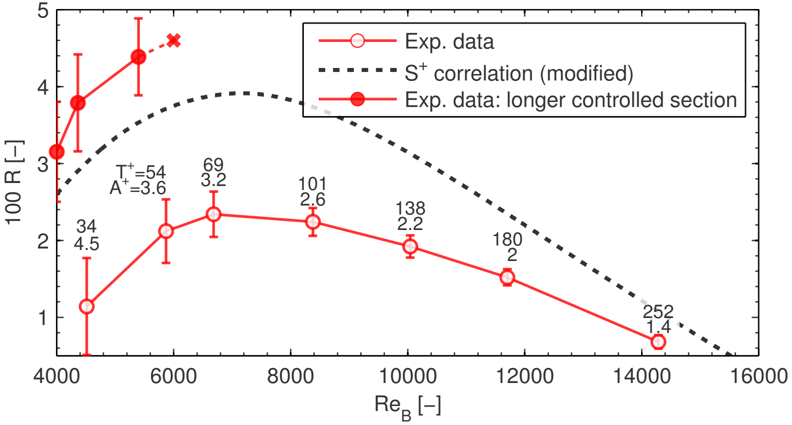

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Power balance

below S=0, yet promising!

We measured $$S = R - \frac{P_{in}}{P_0}$$

- P_{in} = 1 W/actuator
- P_0 ranges between 13 and 300 mW !!!
- $S_{\max} = -4.9$ at $Re_B = 15000$
  (Auteri *et al.*, PoF2010 estimated $S = -13000$!!!)
- $G_{\max} = \frac{P_0 - P}{P_{in}} = 0.002$ at $Re_B = 13500$

Conclusions and outlook

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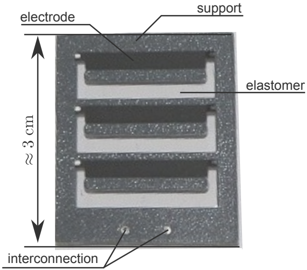
- DEAPs tool for experimental active flow control
  - Efficiency and simplicity
  - Compliancy and fragility
- Interest for higher-*Re* experiments
  - Need to increase resonance frequency
- Array of miniaturized actuators
  - Rises resonant frequency
  - Improves reliability
  - Increases stiffness



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THANKS
for the kind attention!

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Finite-size actuation (DNS)

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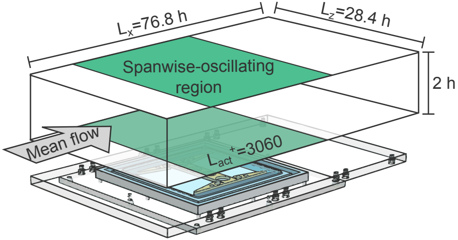
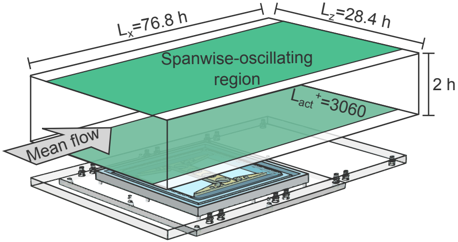
DNS of turbulent channel flow with inhomogeneous actuation:

- $Re_\tau = 200$
- $A^+ = 3.6$
- $T^+ = 54$

Limited-length actuation



Limited-width actuation



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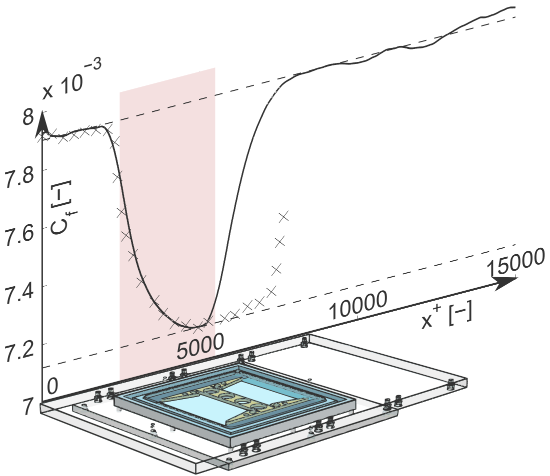
Finite-size actuation (DNS) (cont'd)

limited-lenght



- Homogeneous:
  $100R = 9.93 \pm 0.13$
- Limited-length:
  $100R = 8.3$

Finite-size actuation (DNS) (cont'd)

limited-width

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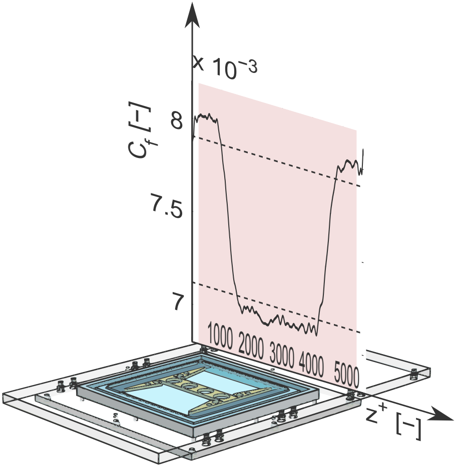

- Homogeneous:
  $100R = 9.93 \pm 0.13$
- Limited-length:
  $100R = 8.3$
- Limited-width:
  $100R = 6.3$

- DNS (tot): $100R = 5.3$
- Experiment $100R = 2.3$!!

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