Inner-outer layer interaction in drag-reduced turbulent channels

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Background

active wall-based turbulent skin-friction drag reduction: is it possible at large values of $Re$?

**YES** sizeable amount of drag reduction can be achieved at high $Re$ (Gatti & Quadrio, JFM 2016)

$$\Delta B = \frac{2}{\sqrt{C_{f,0}}} \left[ (1 - R)^{0.5} - 1 \right] - \frac{1}{2\kappa} \ln(1 - R)$$
Background

active wall-based turbulent skin-friction drag reduction: is it possible at large values of $Re$?

**YES** sizeable amount of drag reduction can be achieved at high $Re$
(Gatti & Quadrio, JFM 2016)

**NO** turbulent large-scale structures
- carry large amount of Reynolds shear stress
- can not be affected by wall-based control
Goal

turbulent drag reduction as mean to assess

How do large scale structures interact with the near-wall turbulence?

today’s actual goal

Is a particular realization of large-scale structures affected by wall-based flow control?

in particular: is the near-wall “footprint” affected by the control?
Model control strategy

Streamwise-travelling wave of spanwise wall velocity

\[ w_w = A \sin(\omega t - \kappa x x) \]

Constant Pressure Gradient

\[ Re_\tau = 1000 \]
\[ \frac{U_b}{U_{b,ref}} = 1.17 \]
\[ R = 1 - \frac{C_f}{C_{f,ref}} = 26.4\% \pm 0.6\% \]

Quadrio, Ricco & Viotti, JFM 2009
Large scales?

Today’s definition:

long meandering streamwise velocity fluctuations,
very long compared to the underlying small-scale fluctuations,
as observed in wall-parallel planes.

adapted from Hutchins & Marusic, JFM, 2007

- not Galilean invariant, thus…
- Reynolds decomposition to be used with care
  in structural analysis
  Kwon, Hutchins, Monty, JFM, 2016

Eduction strategy:

two-dimensional Huang-Hilbert Empirical Mode Decomposition

Agostini & Leschziner, PoF, 2014

- no filter lengthscales to be defined a priori
- “structures” do not necessarily have compact support
  in Fourier space
\( u(x, z) = \sum_{i=1}^{n} IMF_i + res_n \)

\( u(x, z) = u_{SS} + u_{LS} \)

\( u_{LS} = \langle u \rangle + u'_{LS} \)

**IMF** are Intrinsic Mode Functions

- \( \overline{IMF_i} = 0 \)
- function shape not known a priori
Eduction results (1)

streamwise-velocity at $y^+ = 15$ (wall-parallel planes)
Eduction results (2)
Eduction results (3)
Three dimensional structure

isosurface at

$$u'_{LS} = \pm \max(u'_{rms})/4$$
Footprint onto skin-friction

correlation between $\tau_{LS}$ and $u'_{LS}$ at different channel heights
Footprint onto skin-friction

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Conclusions

- Two dimensional Empirical Mode Decomposition
  arbitrary yet useful method to separate large scales
  can be applied to three-dimensional flow data

- Three dimensional topology of large scales
  long regions of positive and negative fluctuations
  alternates in the spanwise direction with spacing $\lambda_z \approx 1000$

- Wall-based drag reduction and large-scale structures
  the correlation between large scale streamwise velocity
  and wall shear fluctuations is modified beyond
  the buffer layer
Outlook

Streamwise velocity fluctuation are one (not Galilean invariant) symptom of large scale structures. Other exists:

- connected regions of $-uv$, vortex packets

Give the structure a dynamics

- spatio-temporal correlation
- track temporal evolution of large scales

Deepen the description of the present qualitative observation

- what causes the two-point correlation to change?
THANKS
for your kind attention!

for questions, complaints, ideas:
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Eduction results (3)