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

- Parasitic Drag
- Wave Drag
- Interference Drag
- Lift Induced Drag
- Viscous Drag

Drag Break-down

Technology Opportunities
- Shock Control
- Novel Configurations
- Shape Optimisation
- Adaptive Wing Devices
- Wing Tip Devices
- Load Control
- Laminar Flow Technology
- Turbulence & Separation Control Technologies

Drag Reduction Potential
- 3%
- 7%
- 15%
- 25%

Total
State-of-the-art
Active open-loop techniques only

Turbulent drag reduction by in-plane wall motion:

<table>
<thead>
<tr>
<th>Strategy</th>
<th>R</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streamwise travelling waves (Quadrio et al JFM 2009)</td>
<td>large</td>
<td>high</td>
</tr>
<tr>
<td>Spanwise-oscillating wall (Jung et al Phys. Fluids 1992)</td>
<td>large</td>
<td>low</td>
</tr>
<tr>
<td>Spanwise travelling waves (Du et al Science 2000)</td>
<td>large</td>
<td>unknown</td>
</tr>
</tbody>
</table>
Spanwise travelling waves

\[ \omega = A \sin(\kappa_z z - \omega t) \]

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 \(Re_T = 200\).
Map of Drag Reduction and Net Energy Saving

$A=0.1$
Map of Drag Reduction and Net Energy Saving (cont.)

A=0.2

R

S
Map of Drag Reduction and Net Energy Saving (cont.)
A=0.5
Modification of Near Wall Turbulence

top view

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

UNCONTROLLED

DI ($\omega = 0.5$)

DR ($\omega = 1.0$)
Reynolds Stress

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

\begin{align*}
\text{DI} & : \text{UNCONTROLLED} \\
\text{DR} & : \text{DI}
\end{align*}
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 pushed 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)