On the forcing term in the DNS of a turbulent channel flow

Maurizio Quadrio\textsuperscript{1}, Bettina Frohnapfel\textsuperscript{2}, Yosuke Hasegawa\textsuperscript{3}

\textsuperscript{1}Politecnico di Milano
\textsuperscript{2}Karlsruhe Institute of Technology
\textsuperscript{3}University of Tokyo

Rome, Sept 20, 2014
My best wishes to P.O.!
The need for a forcing term in DNS

- NS equations alone cannot push fluid through the duct
- Forcing term must be added to mimic pump / gravity / etc
Forcing term is "arbitrary"

- Popular choices are constant flow rate (CFR) and constant pressure gradient (CPG)
- Often equivalent on physical grounds
- Known difference on practical grounds
- Different realizations, statistics are the same
Important when comparing two different flows

Example: turbulent drag reduction by spanwise oscillating walls

"Turbulence intensity is destroyed"
Important when comparing two different flows

Example: turbulent drag reduction by spanwise oscillating walls

"Turbulence intensity is destroyed"
Important when comparing two different flows

Example: turbulent drag reduction by spanwise oscillating walls

"Turbulence intensity is destroyed"
Important when comparing two different flows

Example: turbulent drag reduction by spanwise oscillating walls

"Turbulence intensity is destroyed"
CFR or CPG?

*Pre-determines the global energy budget for drag reduction*

- Potential source of confusion
- Concerns both DNS and experiments
- CFR: pumping power is *reduced* with drag reduction
- CPG: pumping power is *increased* with drag reduction
A further option: CPI
The Money-vs-Time plane (JFM 2012, 2014)

\[ E_p = \frac{\tau_w V}{A} = \frac{M U_b^2 C_f}{2A} \]

Turbulent (uncontrolled)
\[ E_p \propto \left( U_b \right)^{7/4} \]

CPI line
(Constant Power Input)

CPG line

laminar (uncontrolled)
\[ E_p \propto U_b \]

CFR line

\[ U_b^{-1} \]

\[ C_f \propto U_b^{-1} : \text{laminar} \]
\[ C_f \propto U_b^{-1/4} : \text{turbulent} \]
Does the choice of the forcing term affect the statistics of the same flow?
Finding the answer

- Large spatio-temporal DNS channel databases for CFR, CPG, CPI
- DNS code: mixed-discretization solver
- Channel flow at $Re_\tau \approx 200$
- $L_x \times L_y \times L_z = 4\pi h \times 2h \times 2\pi h$
- $\Delta x^+ = 9.6 \ \Delta z^+ = 4.8 \ \Delta y^+ = 0.8 - 4.9$
- Sample size: $T^+ = 100,000$ at $\Delta t^+ = 1$
No obvious changes (obviously!)

<table>
<thead>
<tr>
<th>forcing term</th>
<th>flow driven with</th>
<th>measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFR</td>
<td>$Re_b = 3173$</td>
<td>$Re_\tau = 199.01$</td>
</tr>
<tr>
<td>CPG</td>
<td>$Re_\tau = 200$</td>
<td>$Re_\tau = 199.89$</td>
</tr>
<tr>
<td>CPI</td>
<td>$Re_\Pi = 6500$</td>
<td>$Re_\tau = 199.49$</td>
</tr>
</tbody>
</table>

![Graphs showing \( y^+ \) vs. \( y \) for different flow conditions.](image-url)
Focus on wall friction
Comparison with Lenaers et al, PoF 2012
An in-depth look
Space-time autocorrelation of wall friction

Red: CFR; black: CPG; green: CPI
Differences appear in Lagrangian frame only!
One-dimensional space or time correlations are mostly unaffected
Statistical significance?
Link to vortical structures?

Integral timescale of "lagrangian" correlation: lifetime of near-wall structures
Conclusions

- Choice of forcing term does leave a statistical footprint
- Most evident (so far) in lagrangian frame
- Relevance?
A 18-years-old pair of skies
Gratefully remembering my first workshop in Aussois (1997), organized by P.O.