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

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My best wishes to P.O.!

The need for a forcing term in DNS

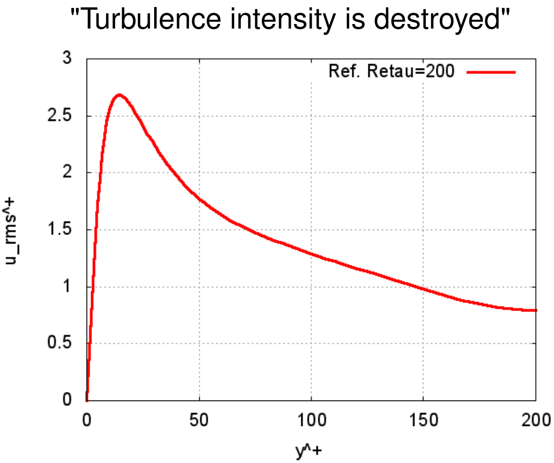
- NS equations alone cannot push fluid through the duct
- Forcing term must be added to mimick pump / gravity / etc

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



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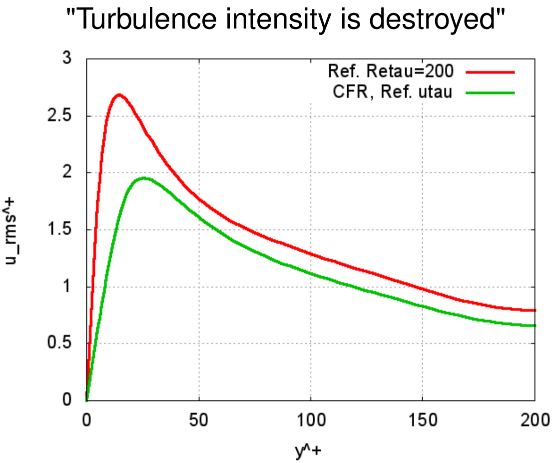

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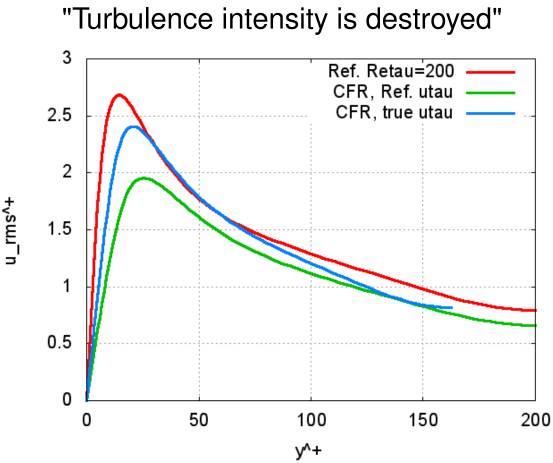

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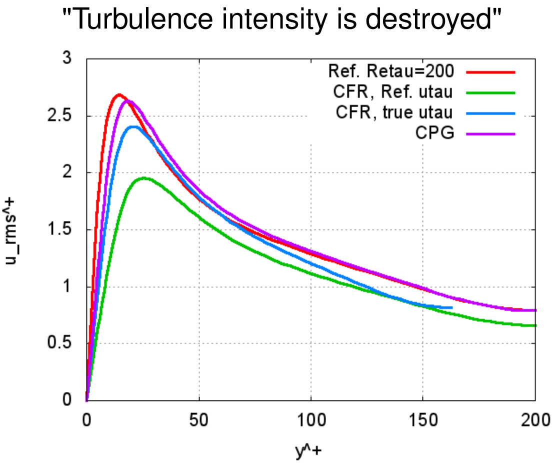


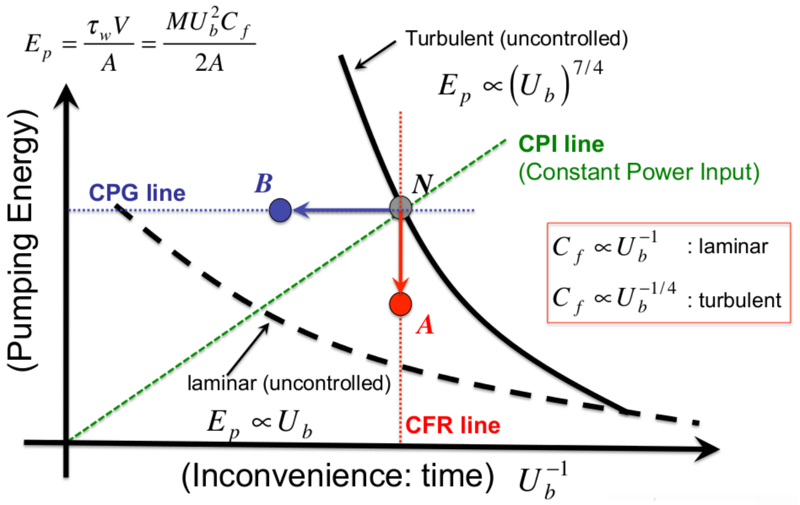
CFR or CPG?

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)



Question

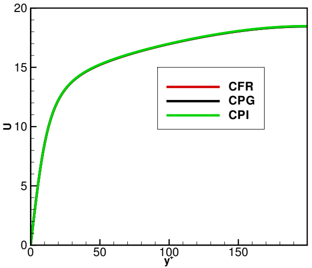
Does the choice of the forcing term
affect the statistics
of the same flow?

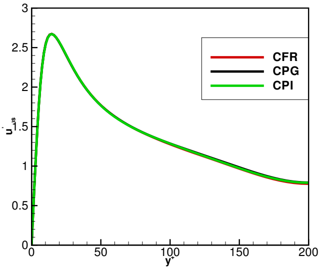
Finding the answer

- 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!)

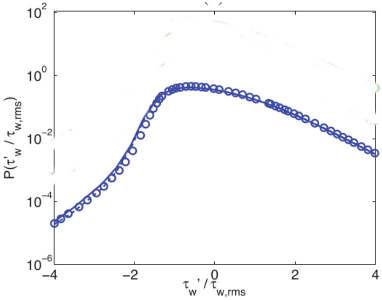
forcing term	flow driven with	measured
CFR	$Re_b = 3173$	$Re_\tau = 199.01$
CPG	$Re_\tau = 200$	$Re_\tau = 199.89$
CPI	$Re_\Pi = 6500$	$Re_\tau = 199.49$

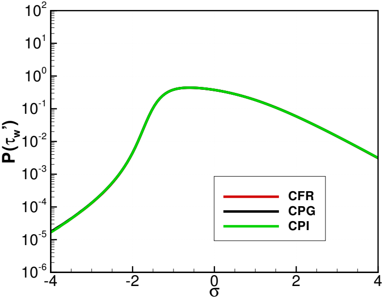




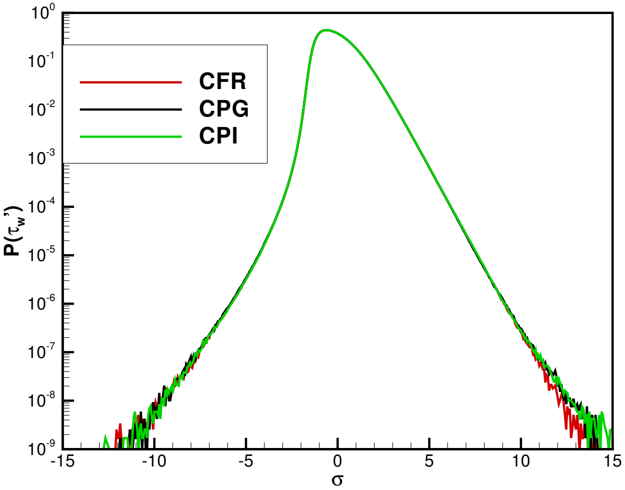
Focus on wall friction

Comparison with Lenaers et al, PoF 2012



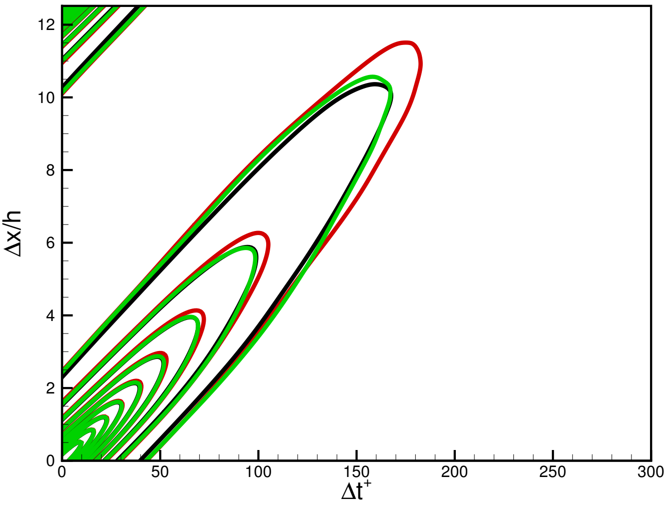


An in-depth look



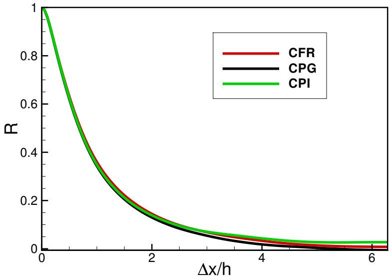
Space-time autocorrelation of wall friction

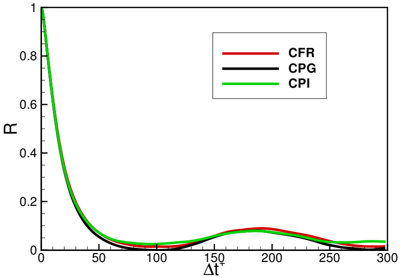
Red: CFR; black: CPG; green: CPI



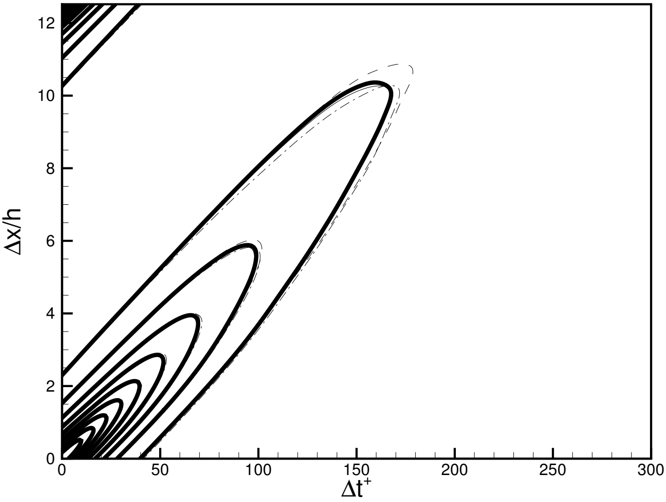
Differences appear in Lagrangian frame only!

One-dimensional space or time correlations are mostly unaffected



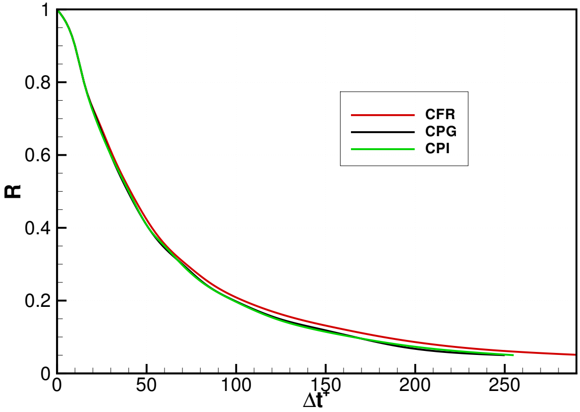


Statistical significance?



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.