COMPARING DRAG REDUCTION TECHNIQUES IN THE "MONEY-VS-TIME" FRAMEWORK

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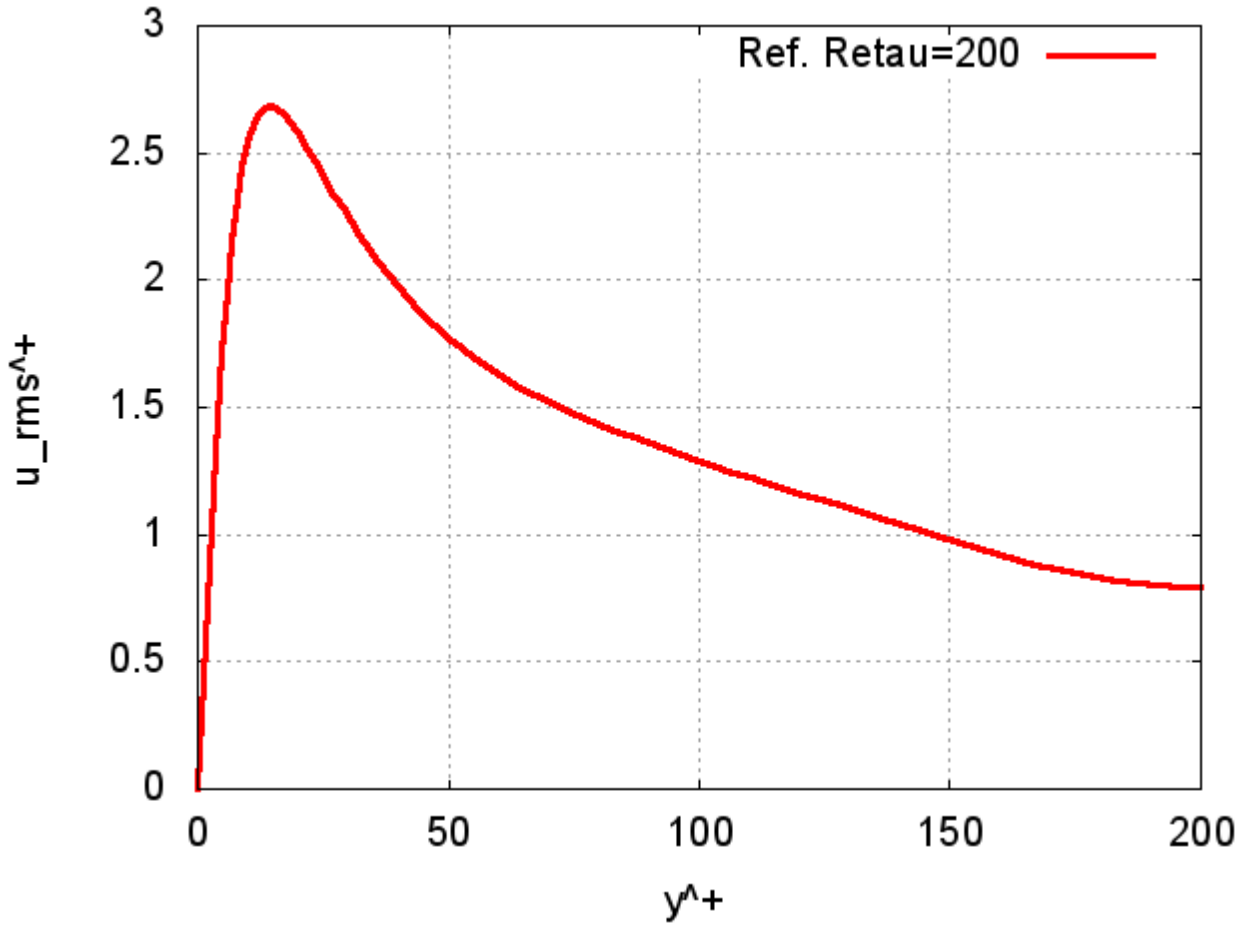
Outline

Background

- Turbulent skin-friction drag reduction
- Open-loop spanwise forcing (oscillating wall, travelling waves)

MOTIVATION
BETTER UNDERSTANDING OF THE PHYSICS

SOW: "Turbulence intensity is destroyed"



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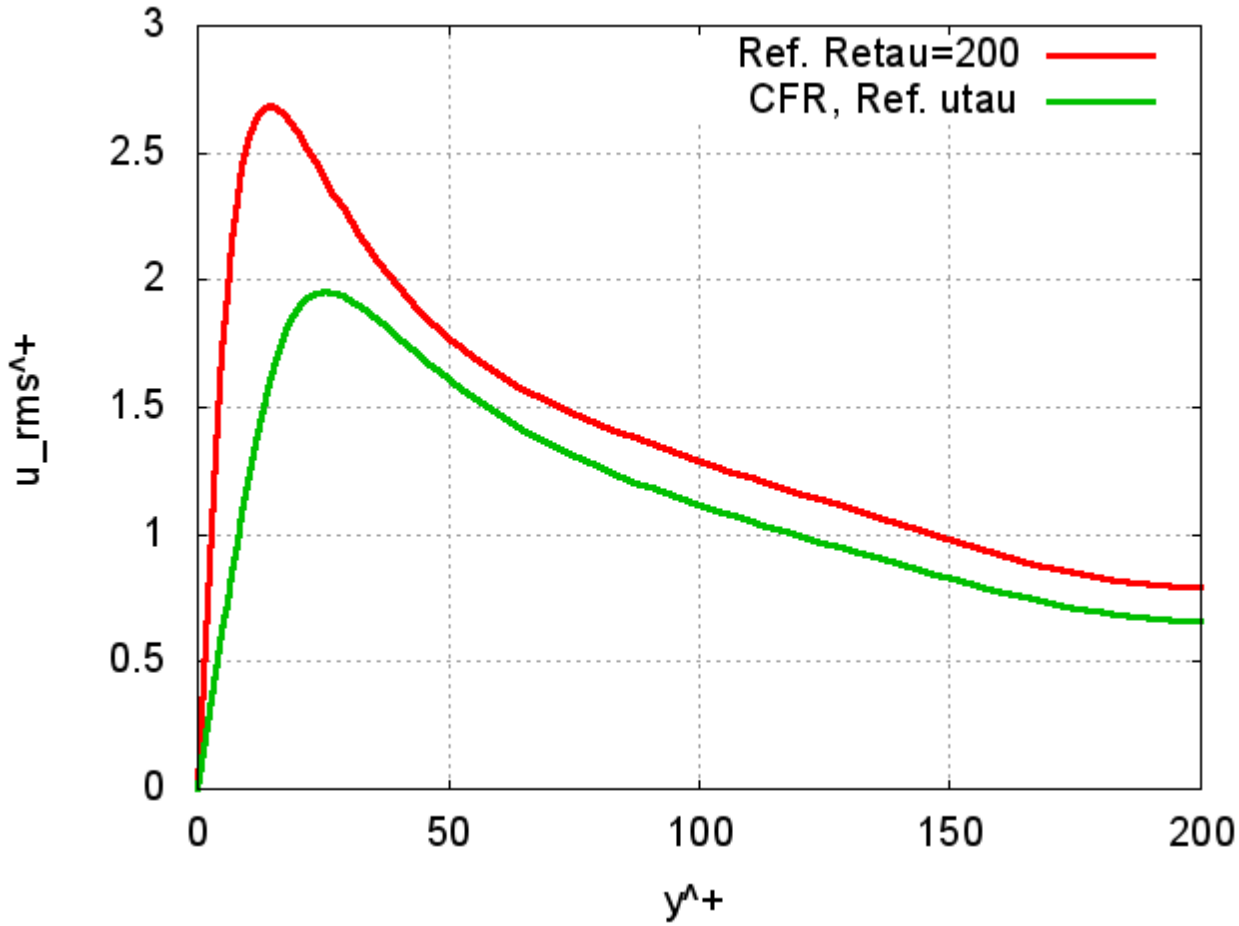

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Better understanding of the physics

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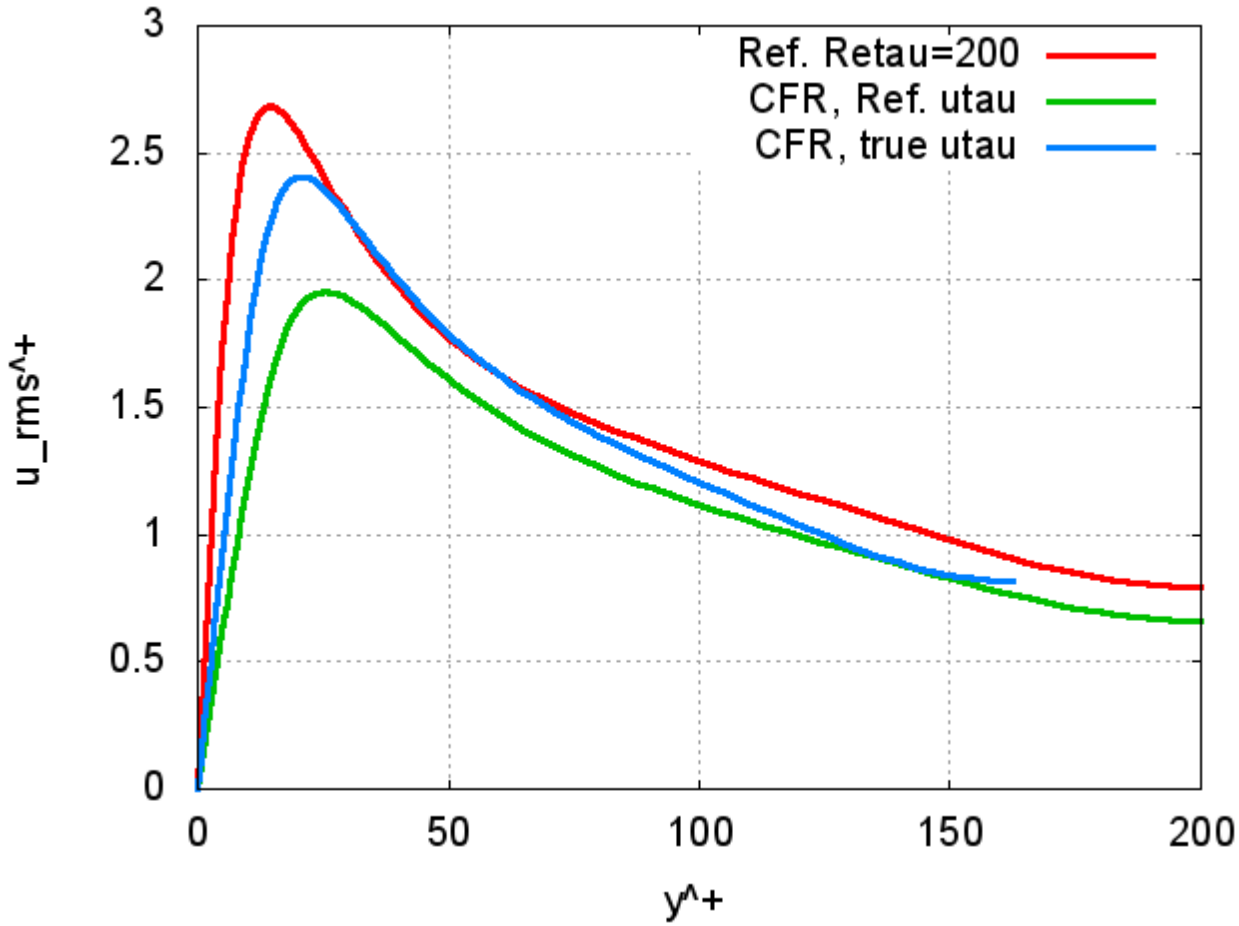

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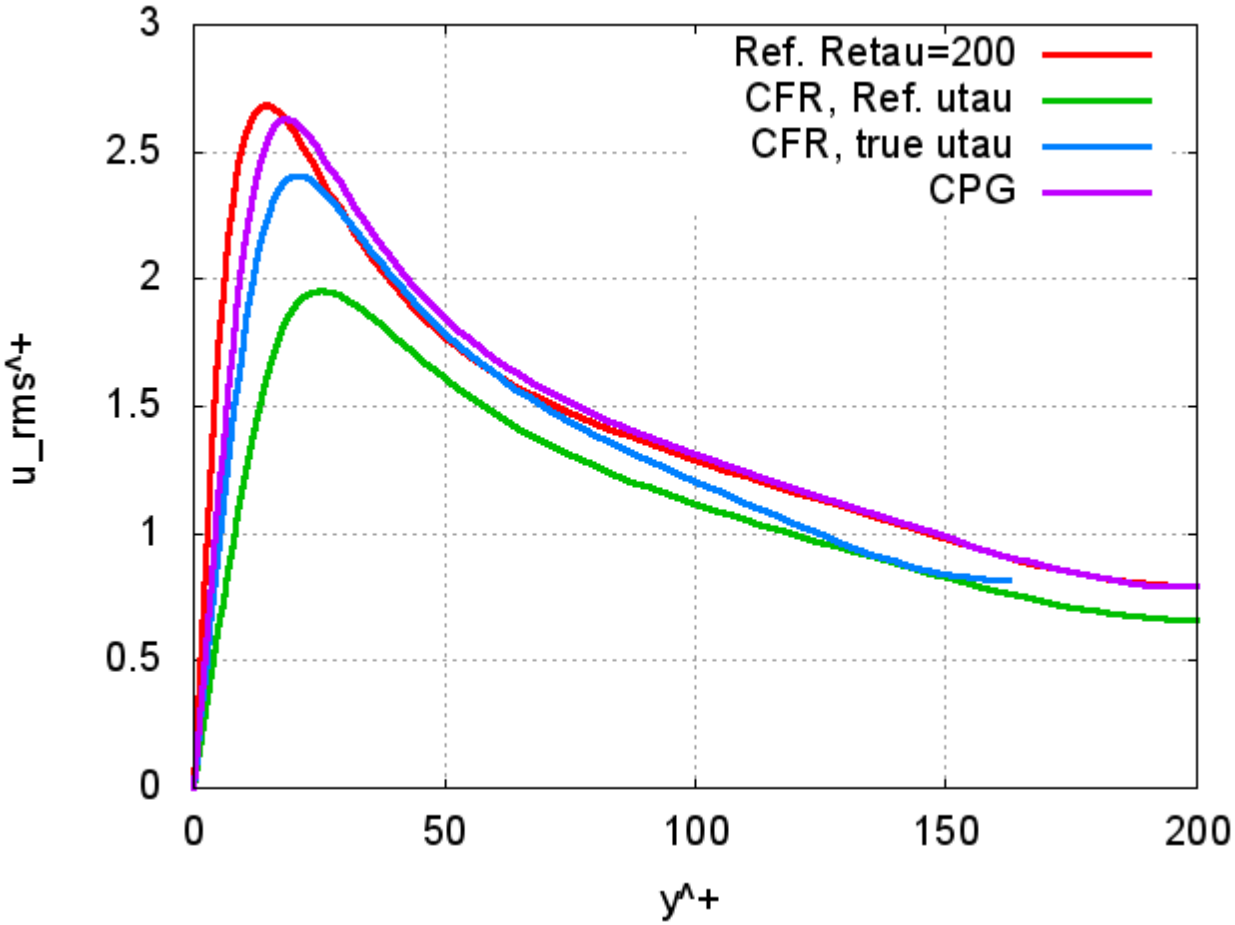
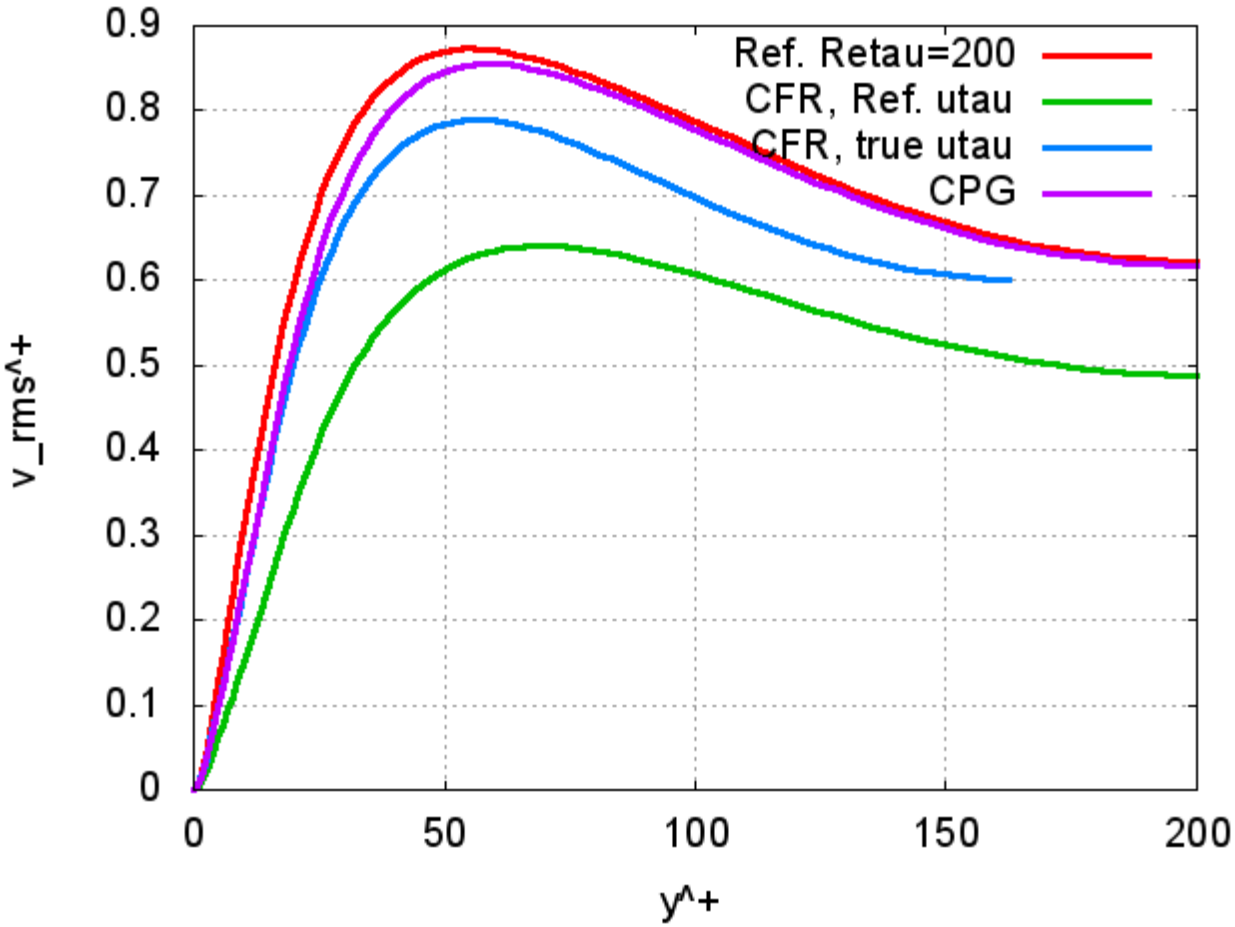


Motivation

Other components and/or different scaling



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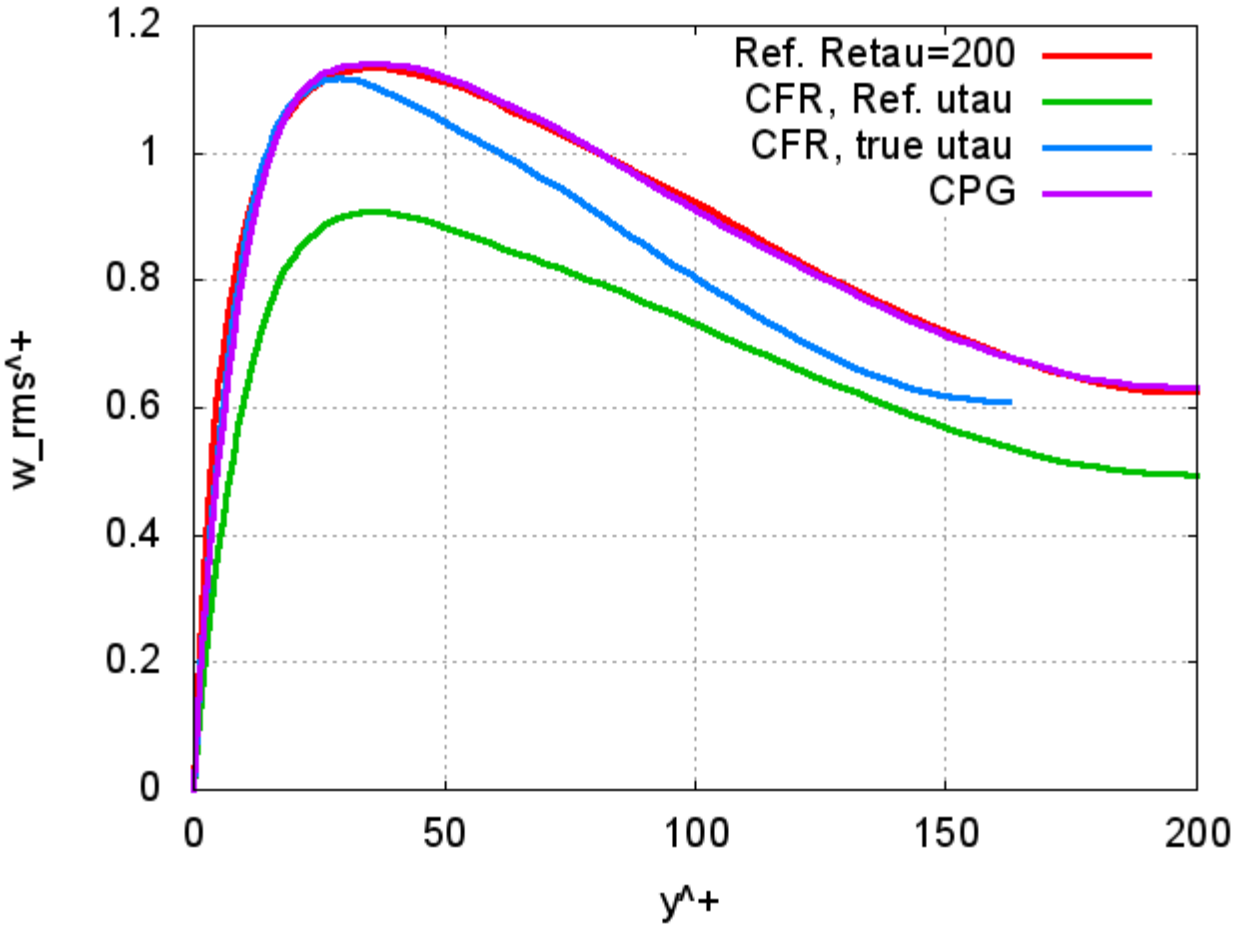

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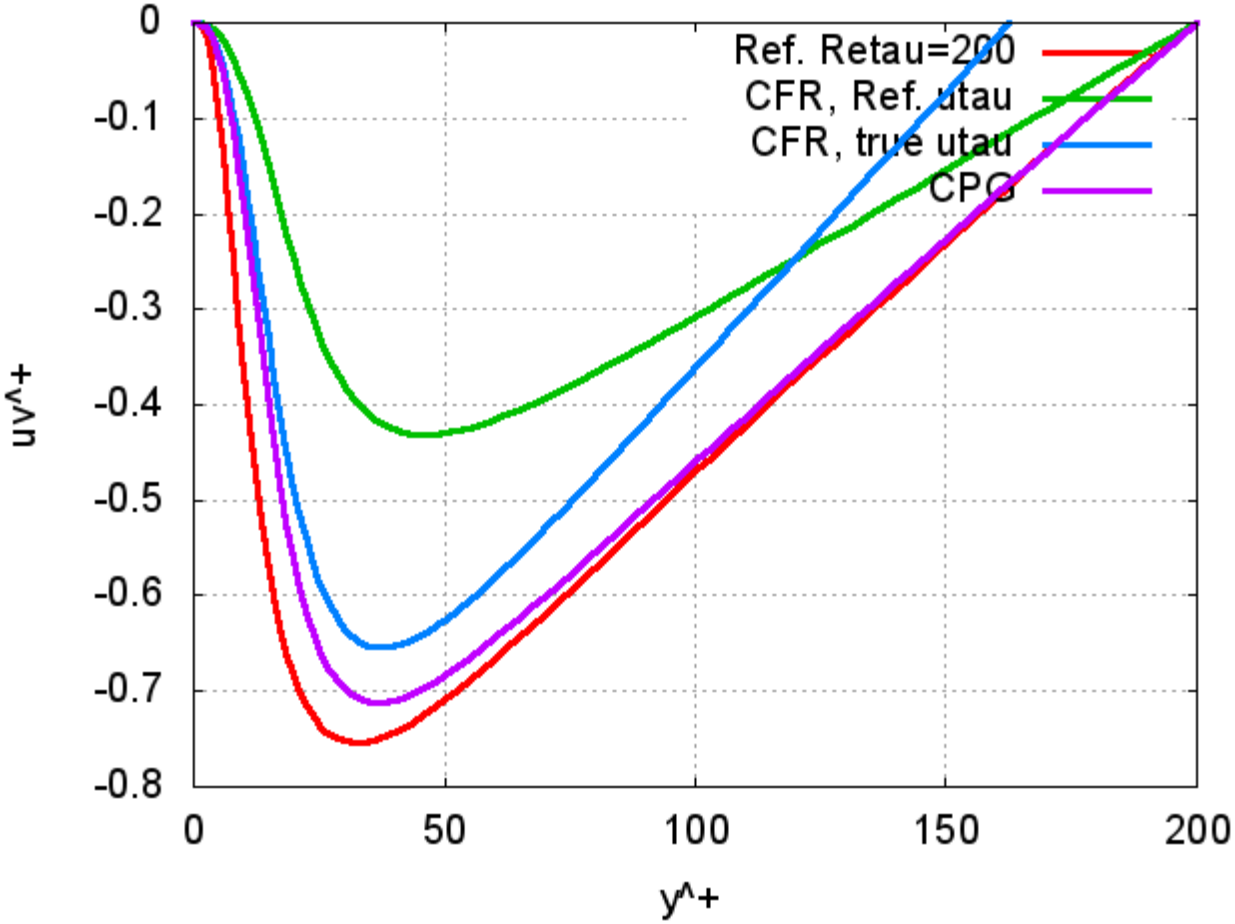


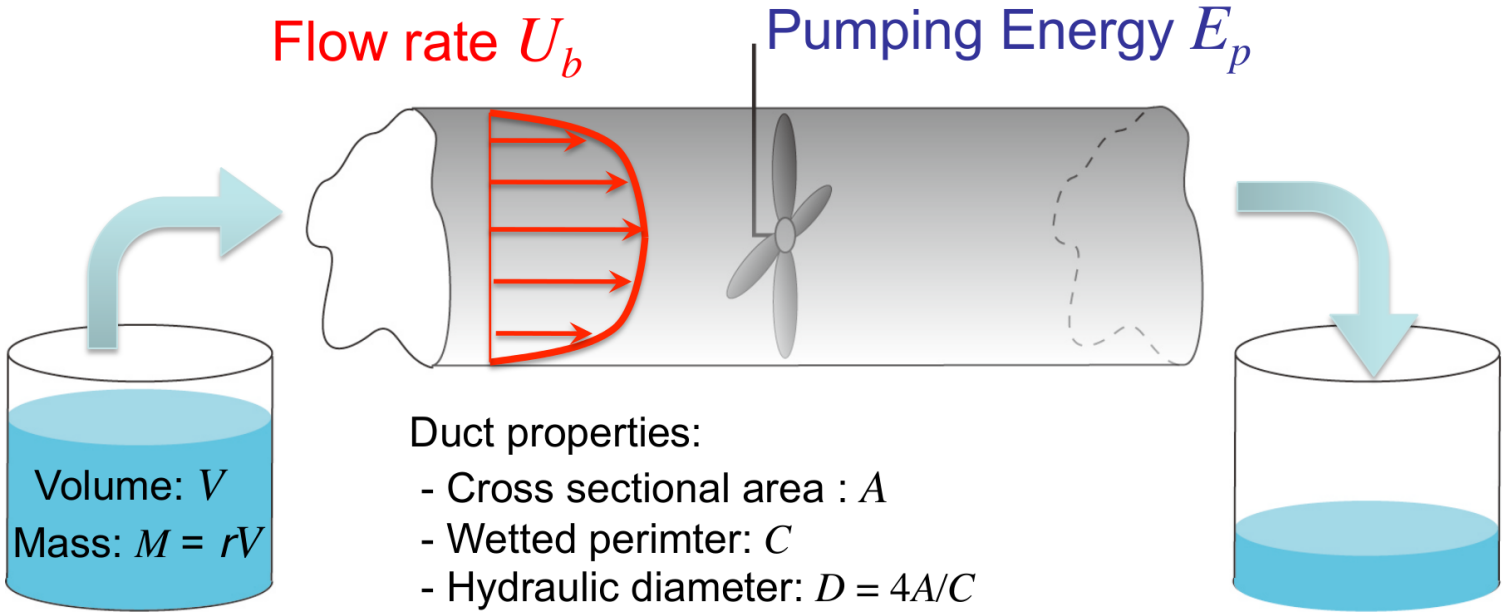
Constant Flow Rate or Constant Pressure Gradient?

- One potential source of confusion
- Concerns both DNS and experiments
- CFR: pumping power is reduced
- CPG: pumping power is increased

Outline

RE-STATE THE PROBLEM

Problem setup (dimensional) for duct flows



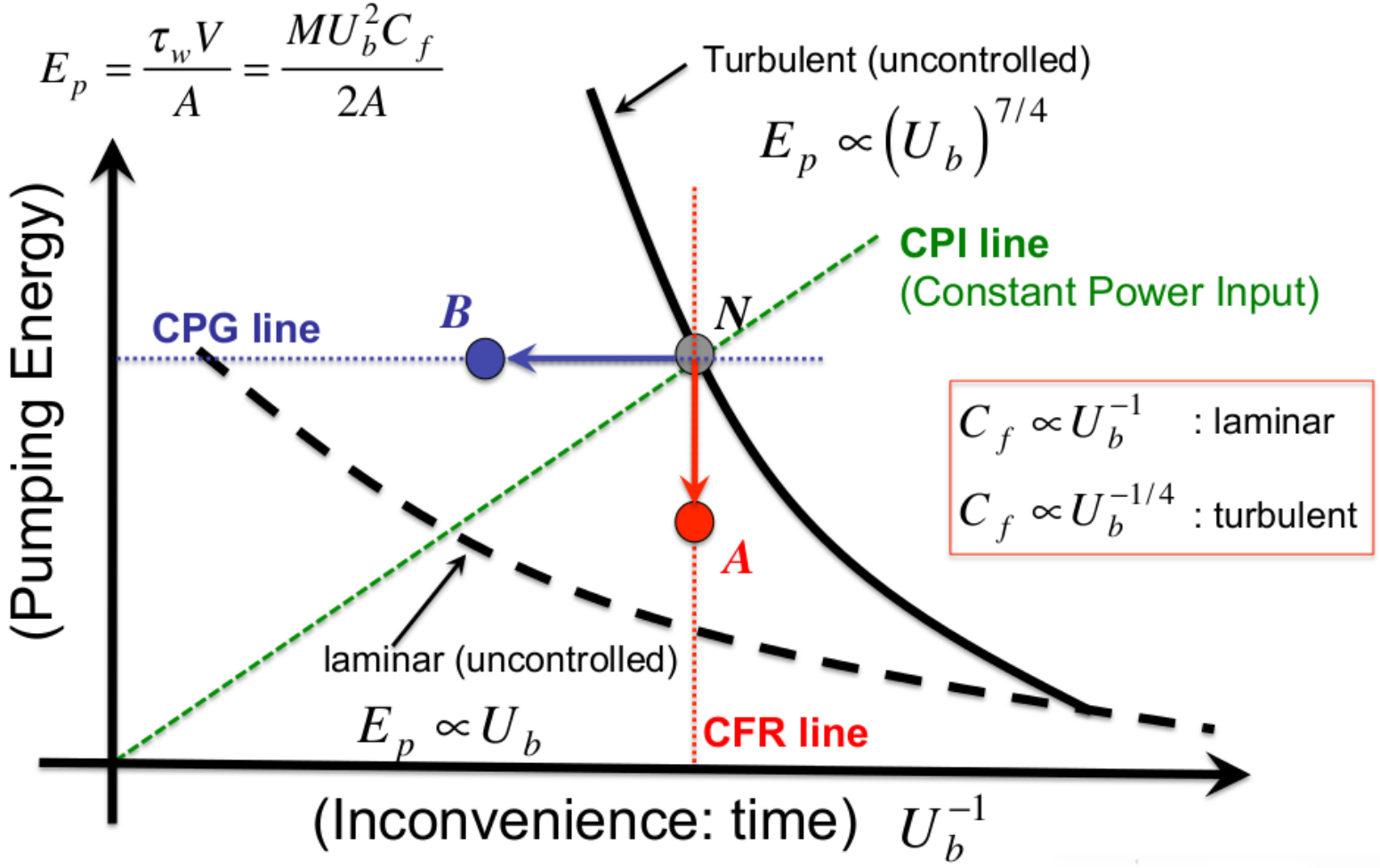
- ✓ Fluid travel time per unit length: $1/U_b$
- ✓ Pumping energy per unit wetted area:

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

Friction coefficient

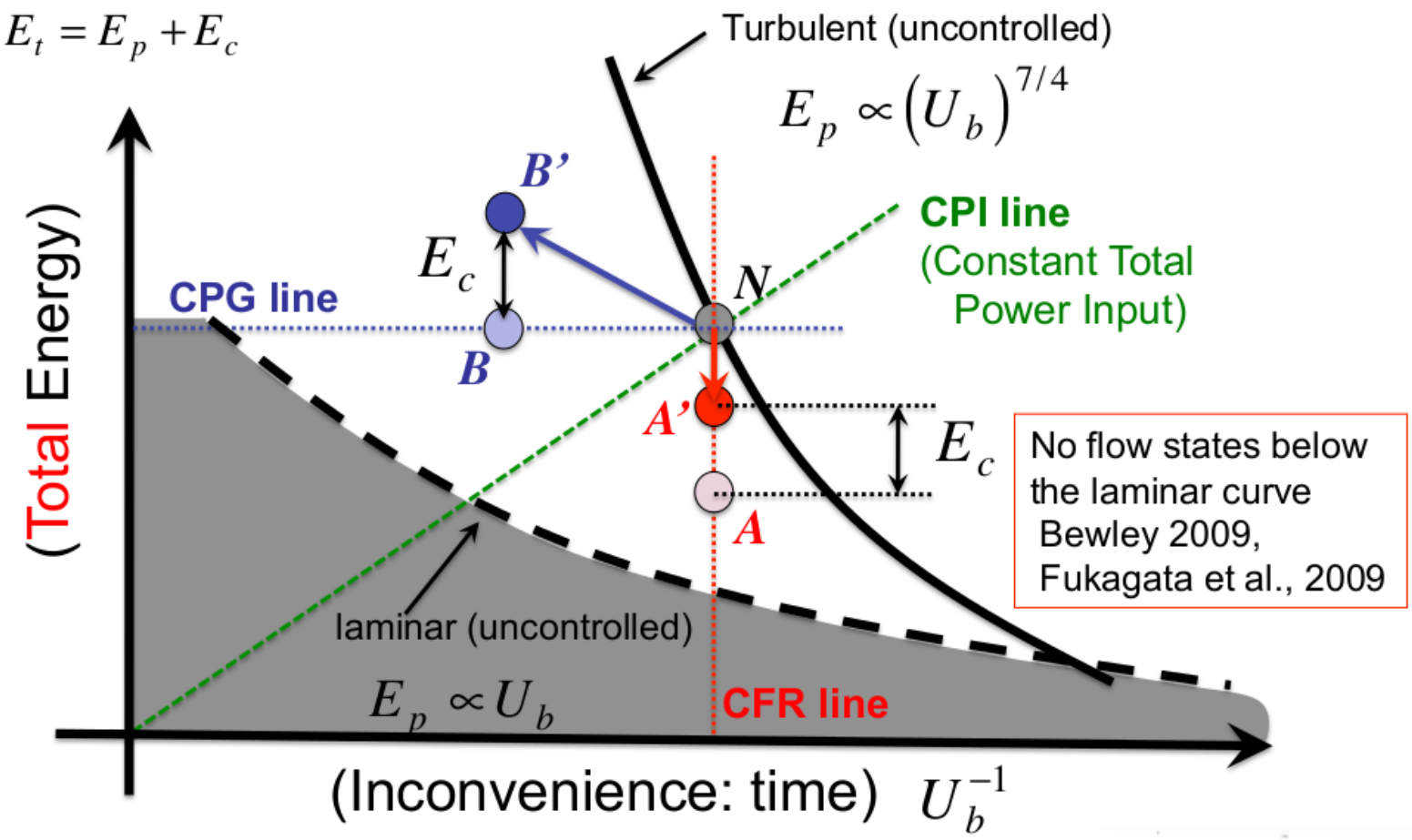
$$C_f = \frac{\tau_w}{\frac{1}{2}\rho U_b^2}$$

Energy vs Convenience

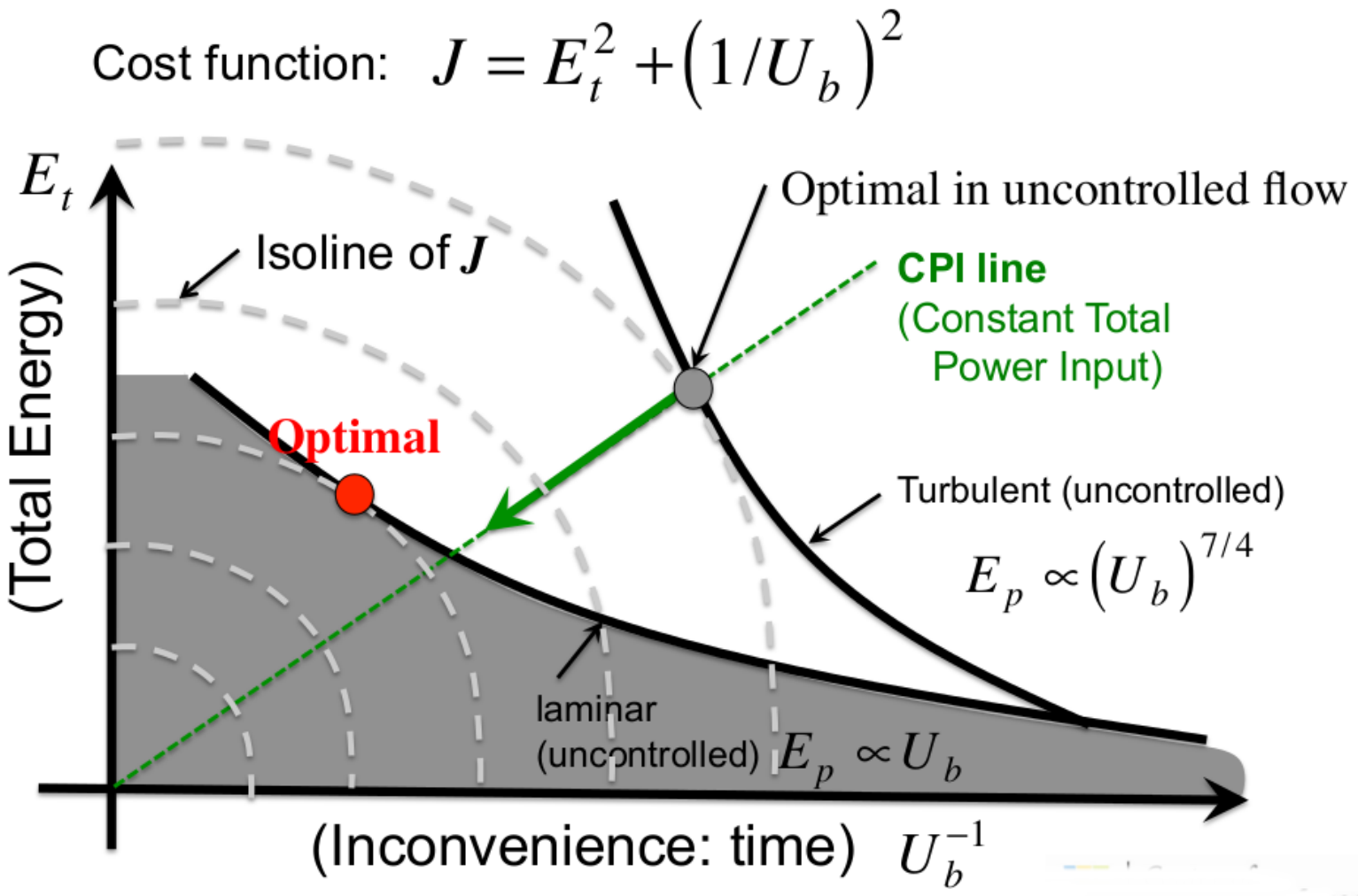


EMPHASIS ON TOTAL ENERGY BUDGET

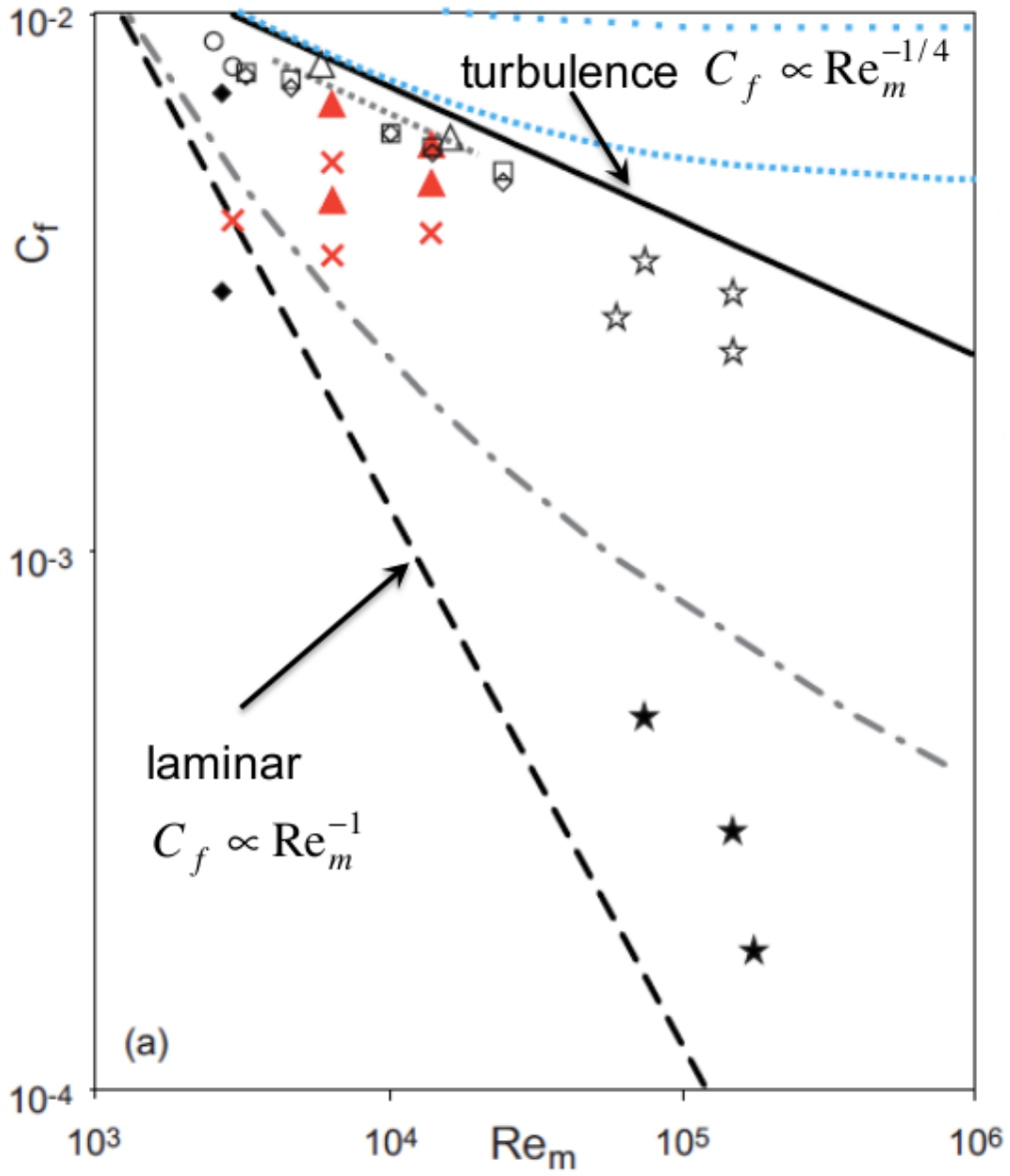
ADDING CONTROL ENERGY E_c TO THE PICTURE



COST FUNCTION

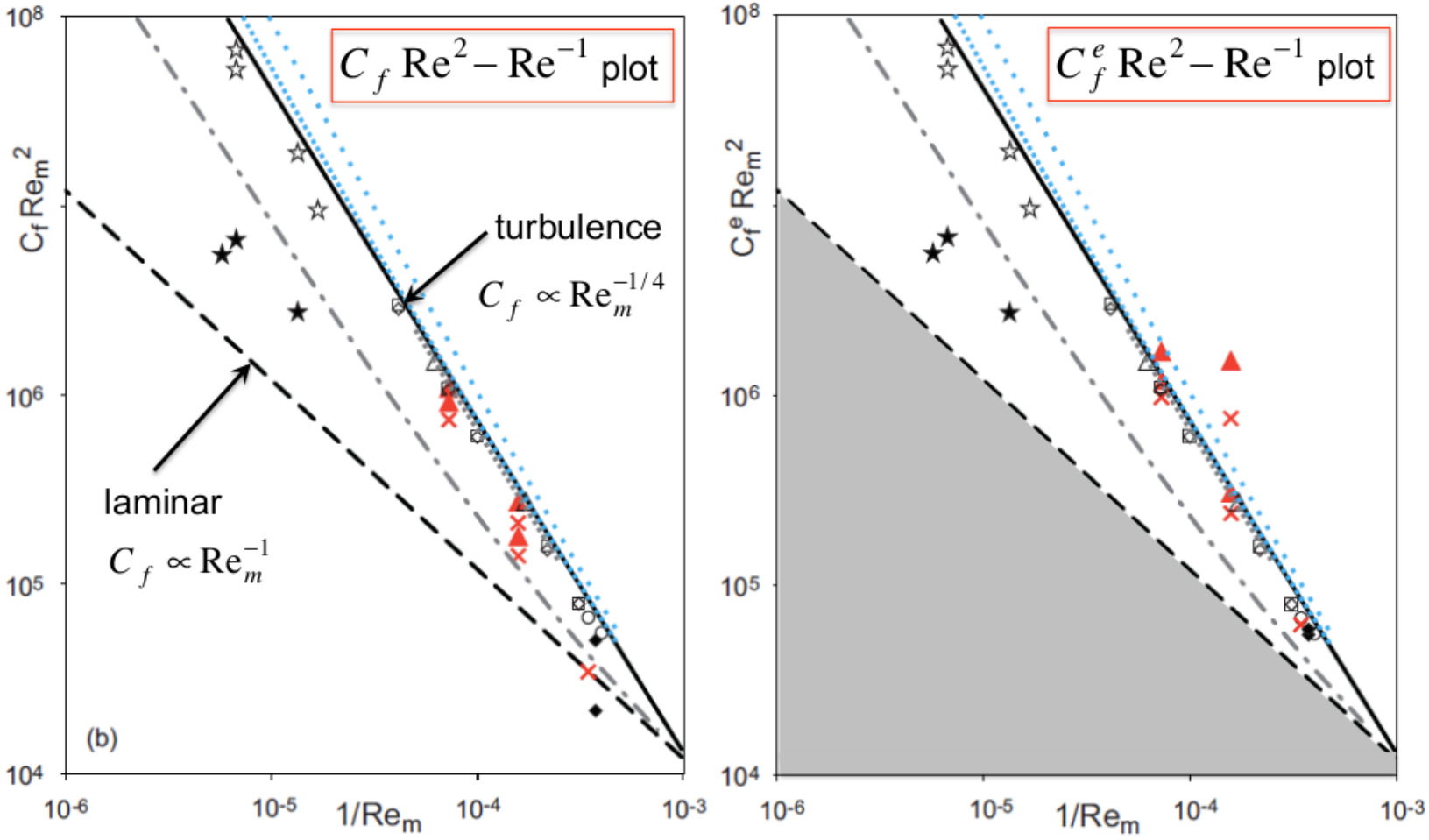


THE CONVENTIONAL $C_f - Re$ MAP



- The value of C_f does not represent energy consumption
- Comparison of C_f at different Re is not meaningful

THE "MONEY-VS-TIME" DIMENSIONLESS MAP

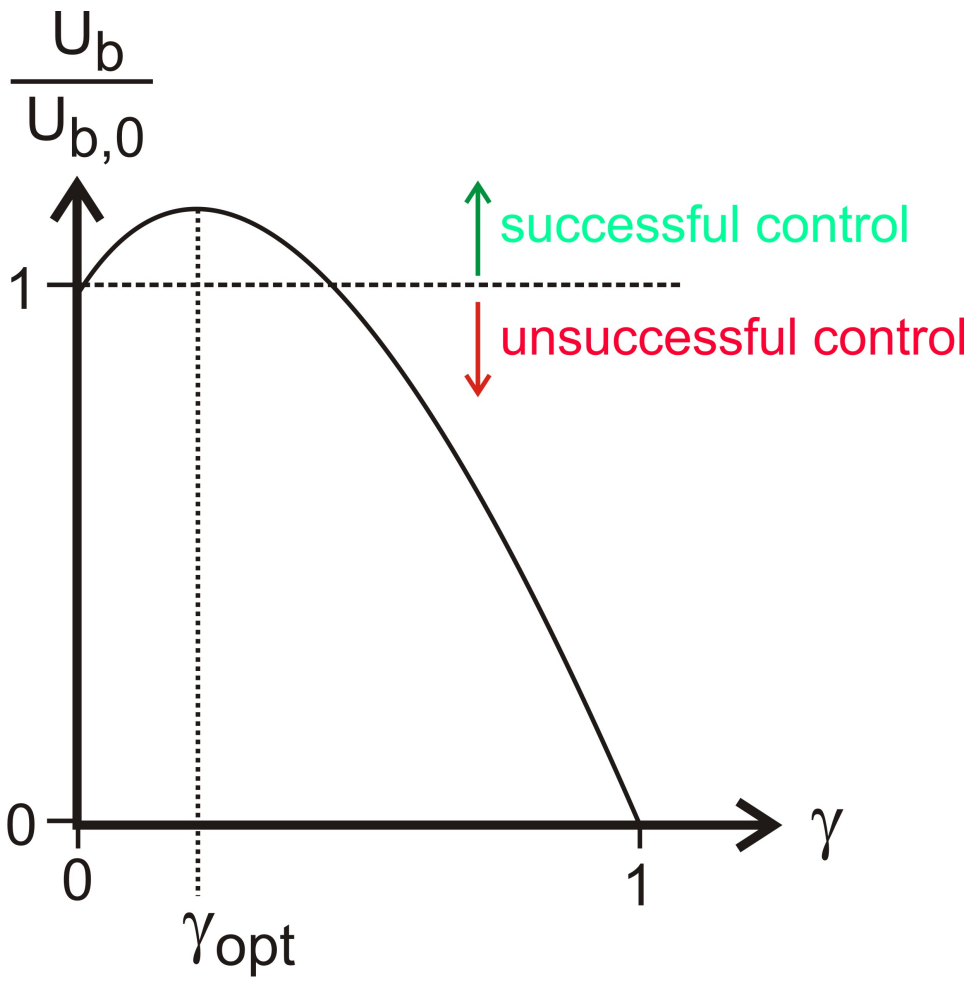


Outline

CPI: A USEFUL ALTERNATIVE?
A NATURAL STRATEGY IN THE MONEY-VS-TIME PLANE

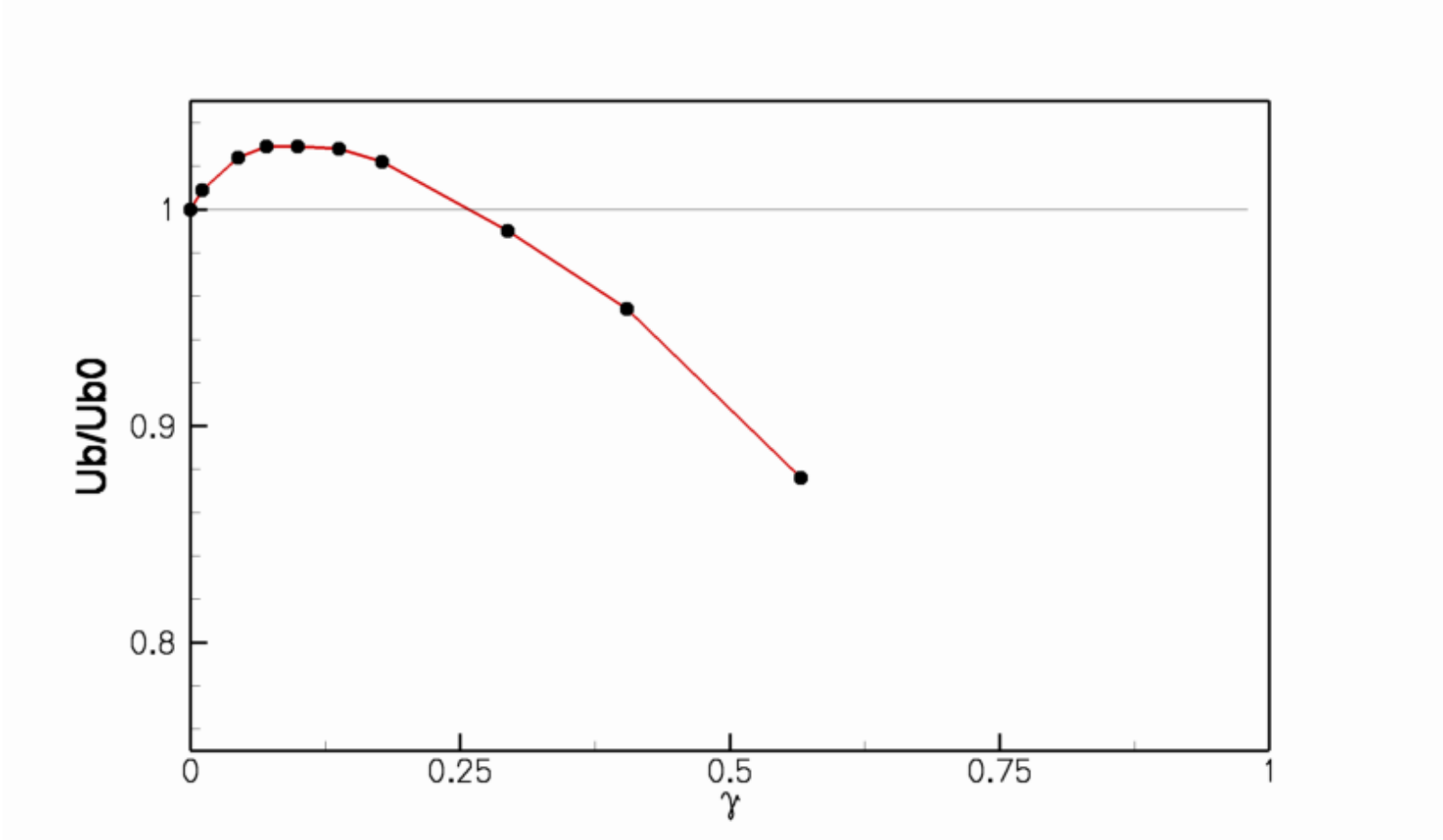
- Total power input is kept constant
- Energy (money) is reduced while flow rate (time) is increased at the same time
- Not "better" (it's application-dependent!)
- May help understanding how turbulence is affected

What does flow control do in CPI?

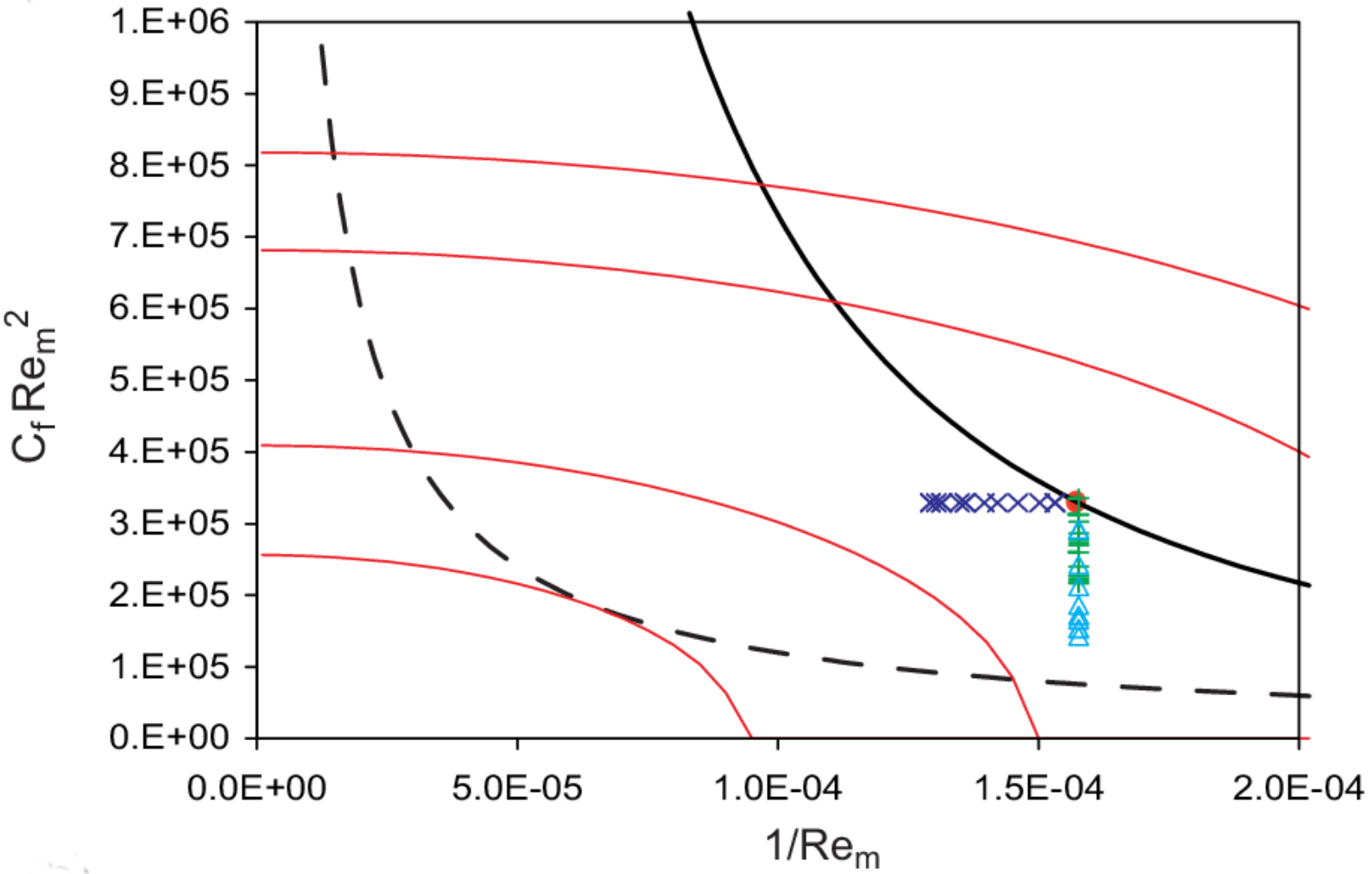


- $P_t =$ total power
- $\gamma P_t =$ control power
- $(1-\gamma)P_t =$ pumping power

Example results
sow



FURTHER RESULTS
SOW + STTW



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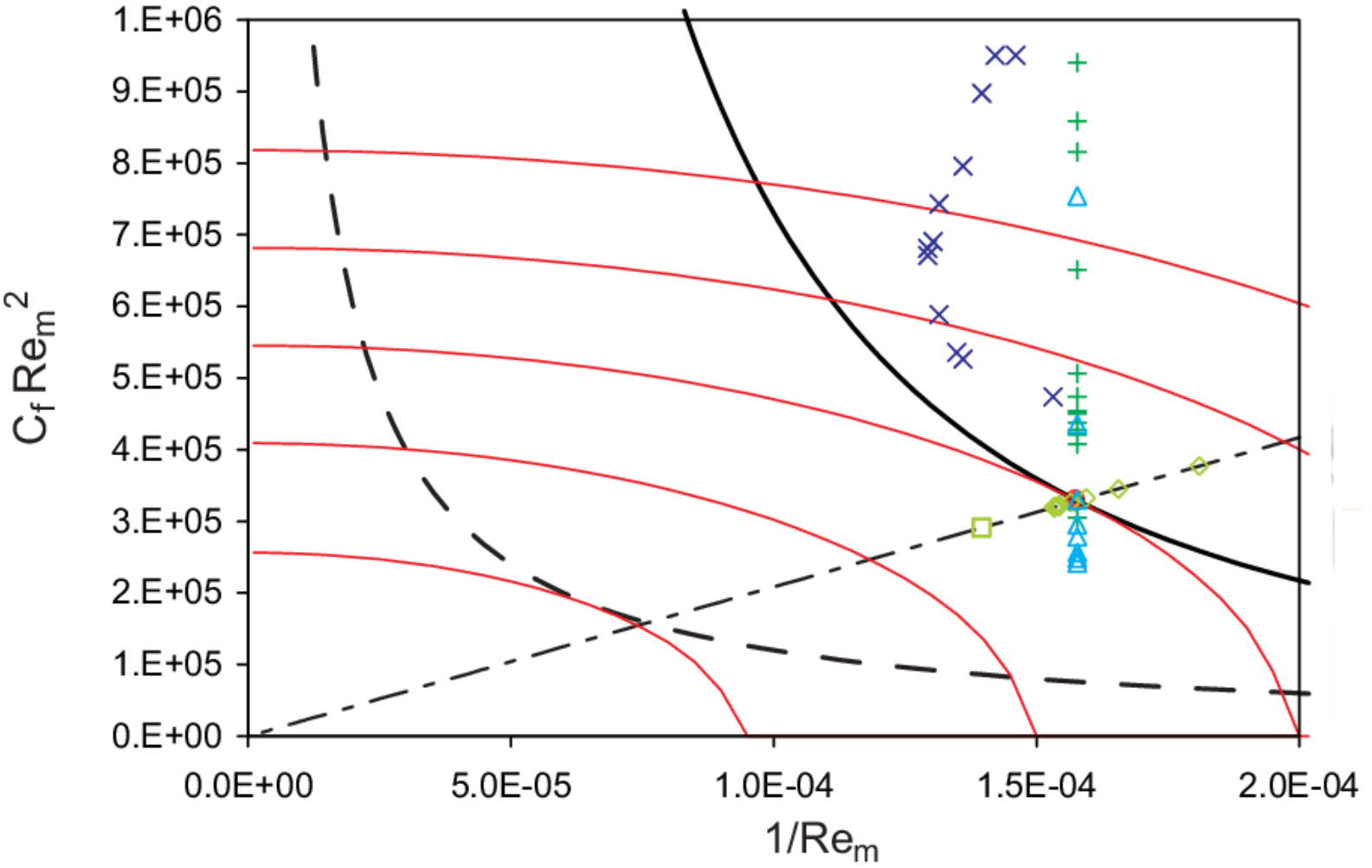

Conclusions

- Need to compromise between Money and Time
- Cost function is application-dependent
- CPI might be a useful alternative to CFR and CPG
- Our "application" is understanding physics

Reference: Frohnapfel, Hasegawa & Quadrio, "Money versus Time", JFM **700**, pp.406–418, 2012