Modification of Turbulent Flow using Distributed Suction

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INTRODUCTION

Use of wall-normal blowing/suction is very effective for turbulence control.

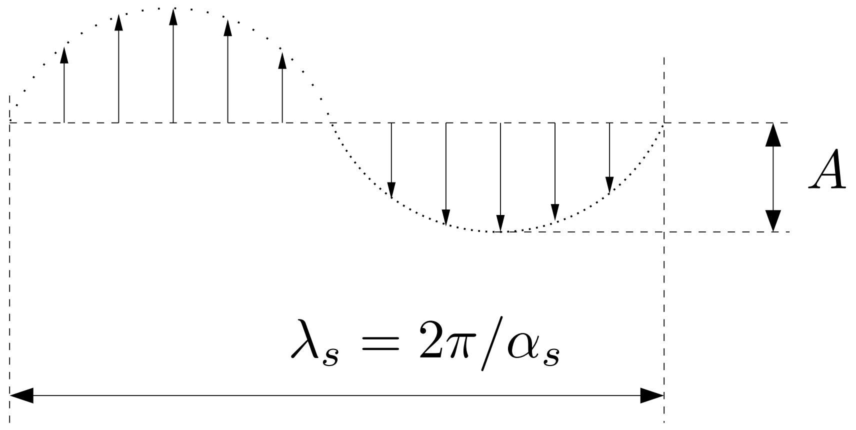
Sumitani & Kasagi, AIAA J. 1995: constant blowing (suction) is known to affect significantly the friction drag and the heat transfer.

Choi *et al.* JFM 1994: use of time- and space-dependent blowing/suction (difficult to implement in practice!) is known to allow 25% turbulence drag reduction.

Jiménez *et al* JFM 2001: active/passive porous walls, increase in drag.

MOTIVATION I

Study the effect of a steady, longitudinal distribution of suction at the wall, with low amplitude and zero net mass flux.

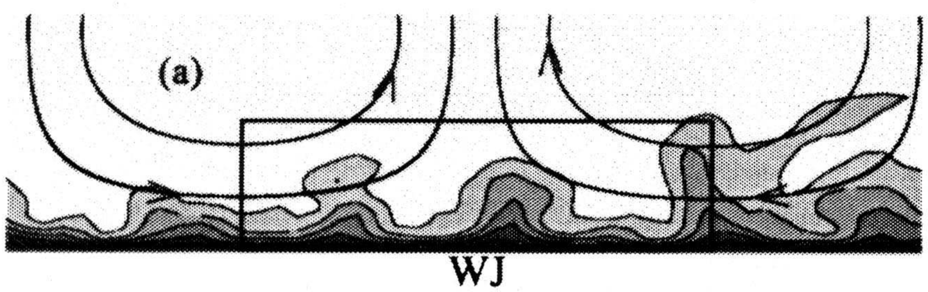


Tool: DNS of the turbulent plane channel flow.

$$v(x, y = \pm h, z, t) = A \sin(\alpha_s x)$$

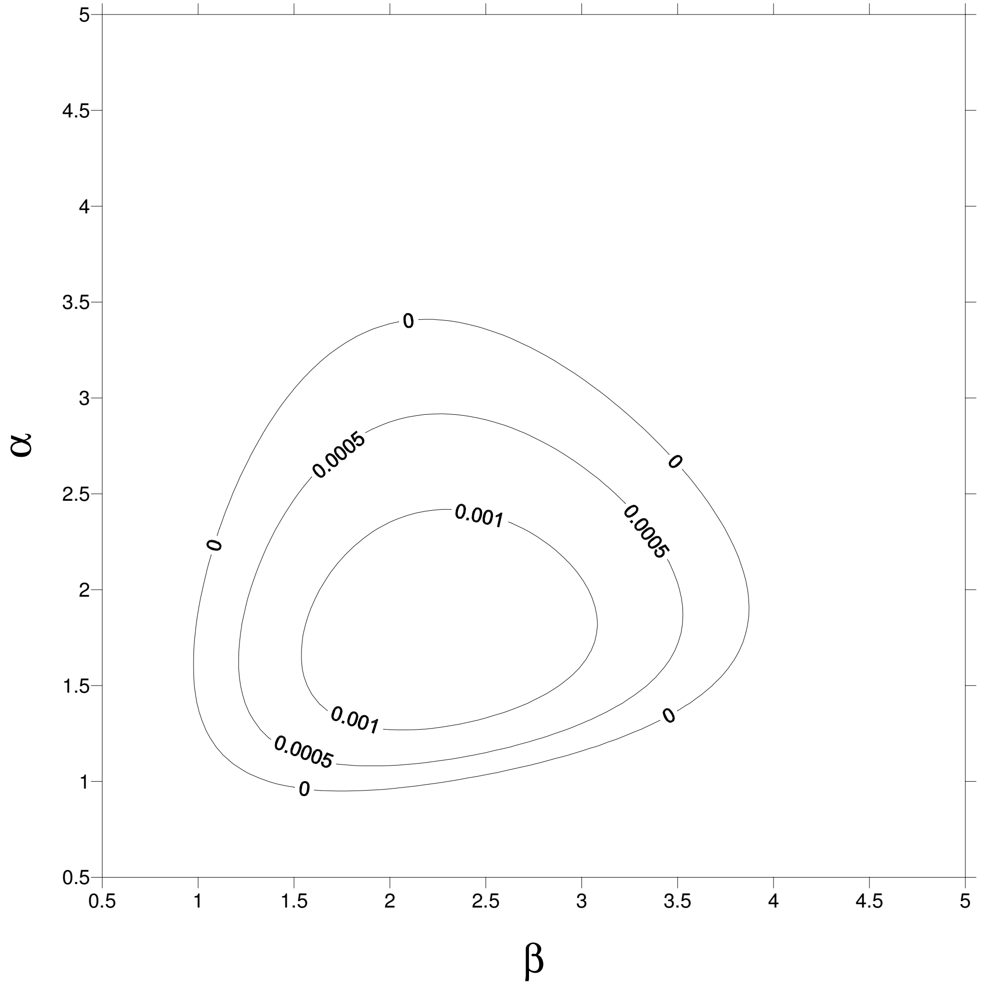
MOTIVATION II

Schoppa & Hussain, PoF 1998: large-scale streamwise vortices are known to produce a signifcant drag reduction.



In laminar regime, Floryan JFM 2003 has shown that sinusoidal suction creates such vortices.

Result from stability analysis with mean turbulent profile as base flow:



$Re = 3300, A = 0.004U_c$

MOTIVATION III

Floryan JFM 2003: the laminar case is qualitatively analogous to the flow over a wavy wall.

Many papers exist on turbulent flow over wavy walls. It is currently believed that the wavelength of the wavyness by itself does not play any role, von Röhr, JFM 2003.

The same is assumed by Jiménez *et al* (suction). Does the wavelength matter?

THE NUMERICAL METHOD

Our solver of the incompressible Navier–Stokes equations has:

- ➜ II-order equation for the normal vorticity and IV-order equation for the normal velocity, without pressure
- ➜ Fourier discretization in the homogeneous directions
- ➜ Fourth-order compact finite-differences over a 5-point unevenly spaced computational molecule in the wall-normal direction
- ➜ Three-substeps Runge–Kutta partially implicit time advancement
- ➜ Parallel execution on both shared-memory and distributed-memory computers

PARAMETERS OF THE SIMULATIONS

Computational parameters: the same as Kim, Moin & Moser in *JFM*, 1987 (longer integration time). $8 \cdot 10^6$ d.o.f.

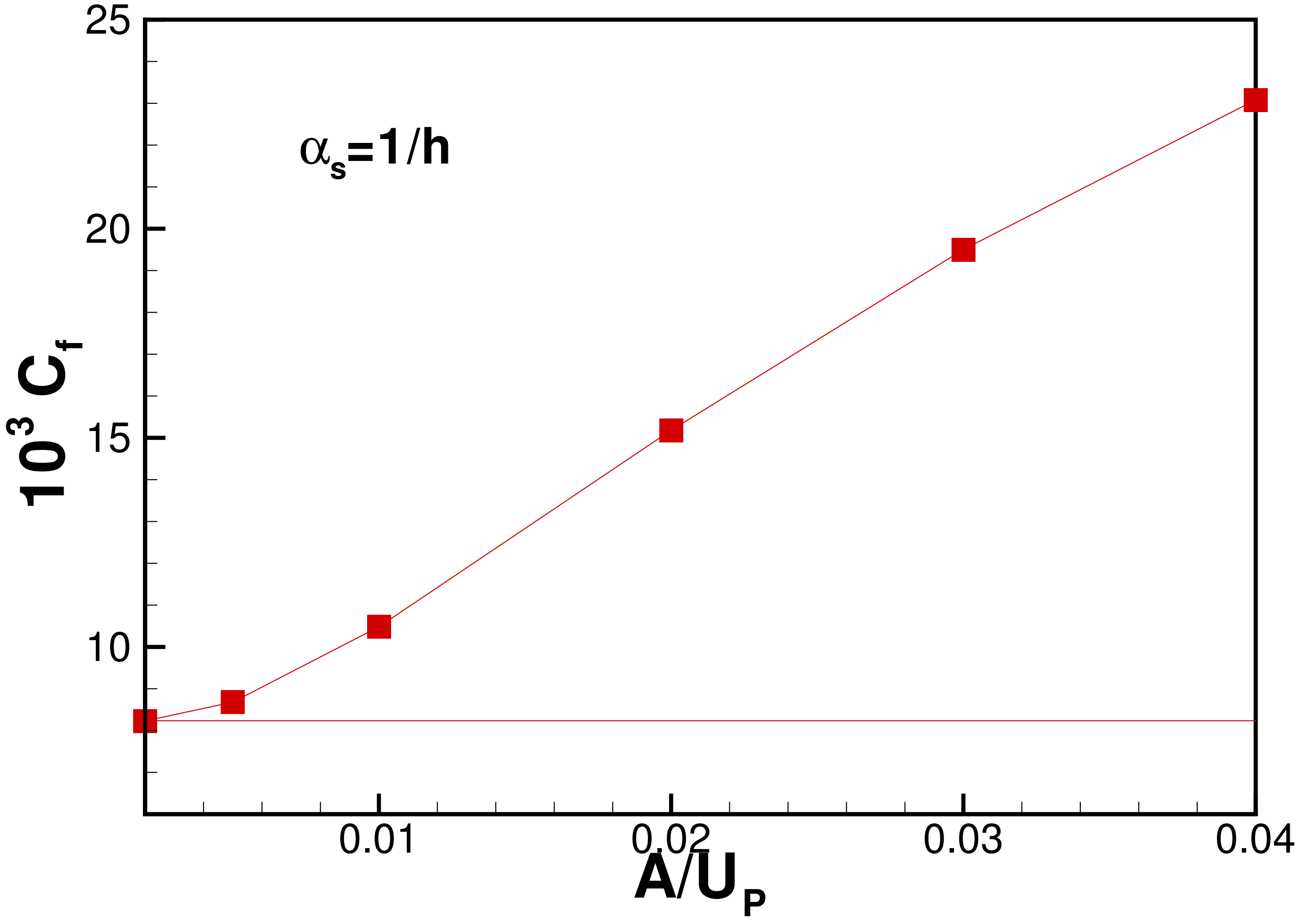
Plane turbulent channel flow at $Re_\tau = 180$.

- Periodic-box dimensions: $L_y = 2h \quad L_x = 4\pi h \quad L_z = 2\pi h$
- Spatial discretization: $N_x = 193 \quad N_z = 129 \quad N_y = 161$
- Spatial resolution: $\Delta x^+ = 11.7 \quad \Delta y^+ = 0.8$ to $4.5 \quad \Delta z^+ = 7.0$
- Temporal resolution: $\Delta t^+ \approx 0.15$
- Total integration time: $T \approx 600 h / U_c$

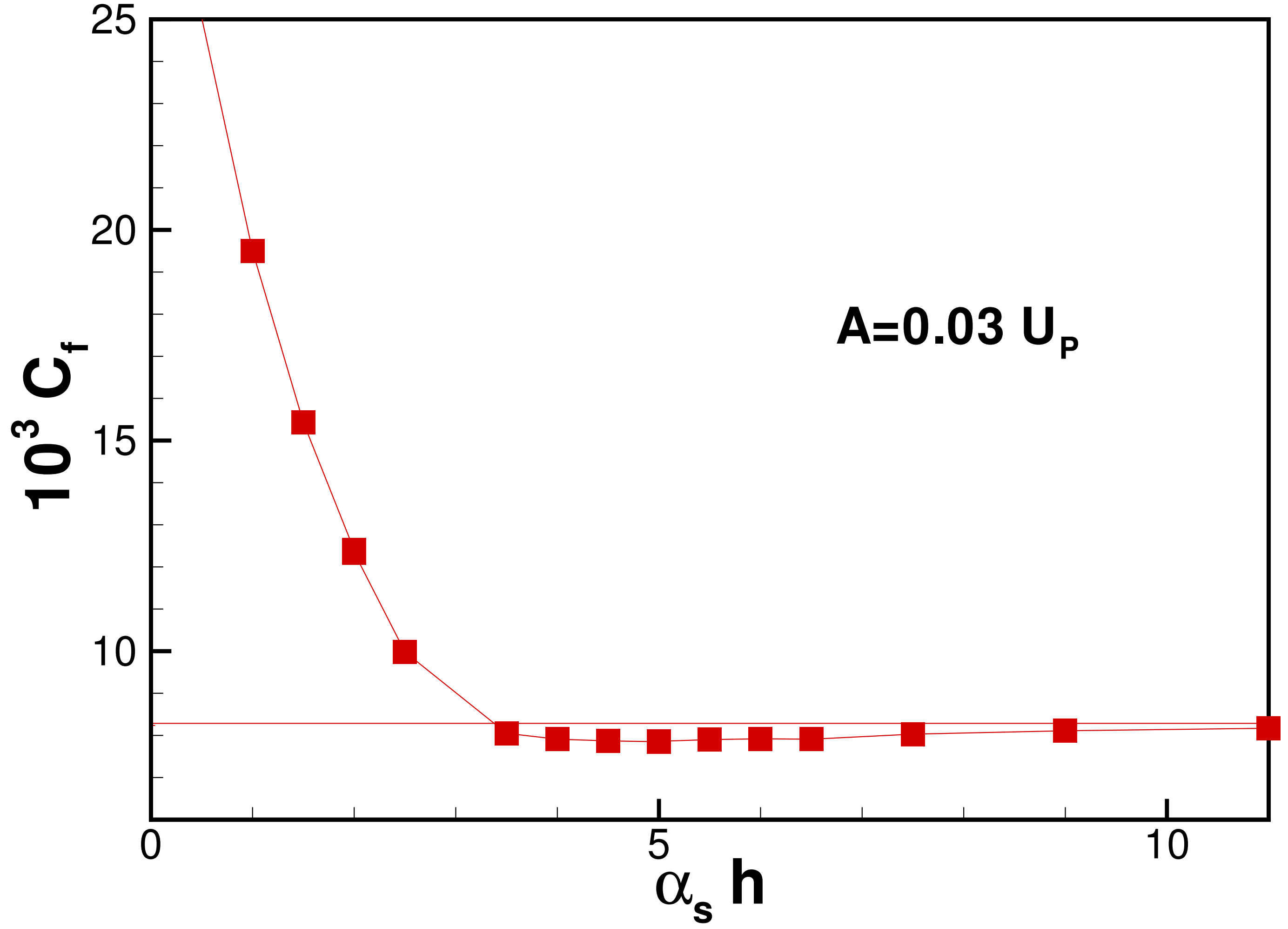
Calculations run on Itanium II machines of the SHARCNET Computing Center at the University of Western Ontario. Approx. 40 cases plus some accuracy checks.

FRICTION VS. SUCTION AMPLITUDE

$C_f = 2\tau/\rho U_b^2$. Reference: $C_f = 8.15 \cdot 10^{-3}$, within 0.3 % from KMM



FRICTION VS. SUCTION WAVELENGTH



DISCUSSION

① The effect is proportional to A at fixed α_s. The threshold of minimum A depends on α_s.

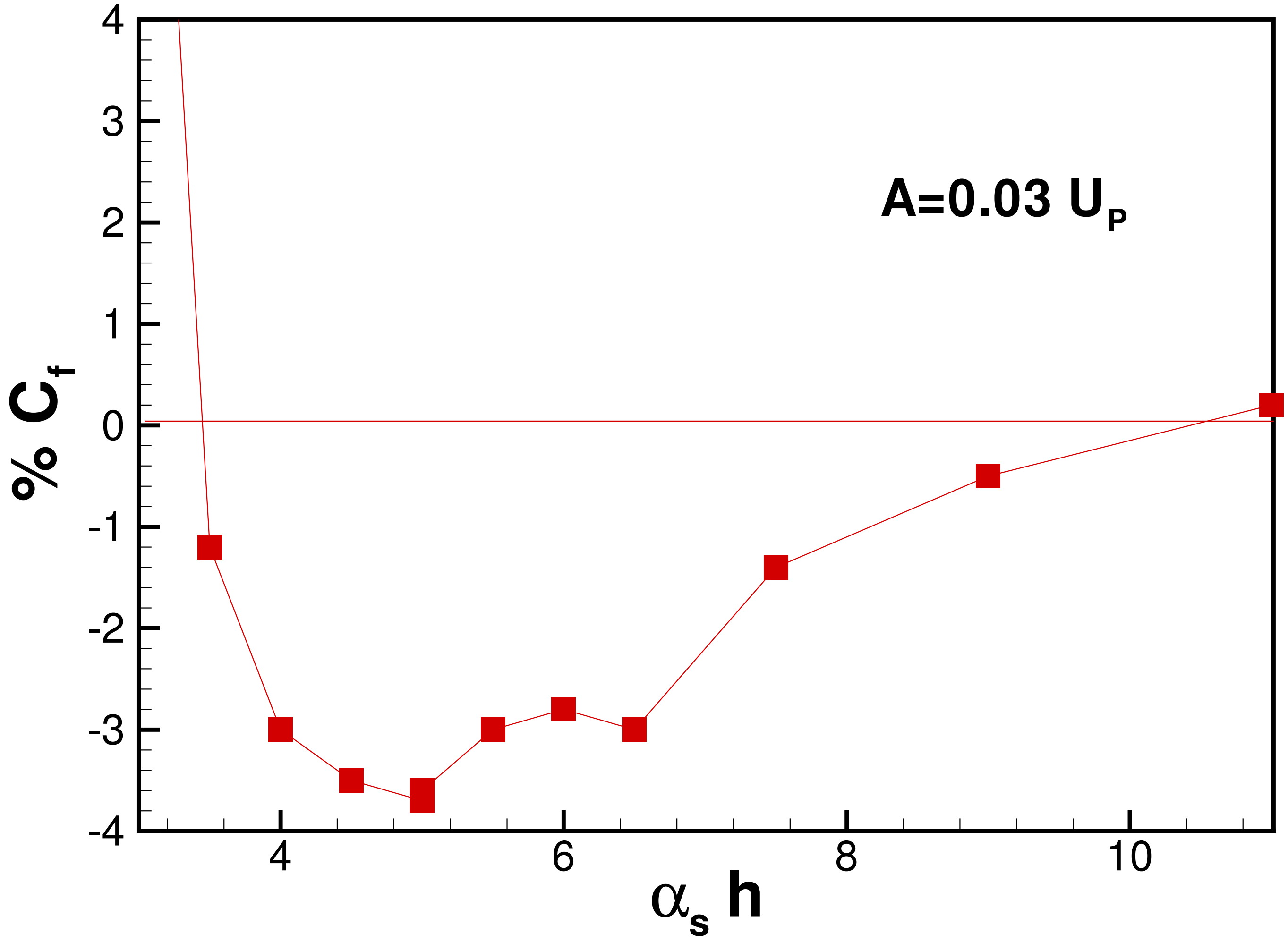
② A better parameter could be the product $A\lambda_s$ (flow rate)

③ Suction wavelength does matter!

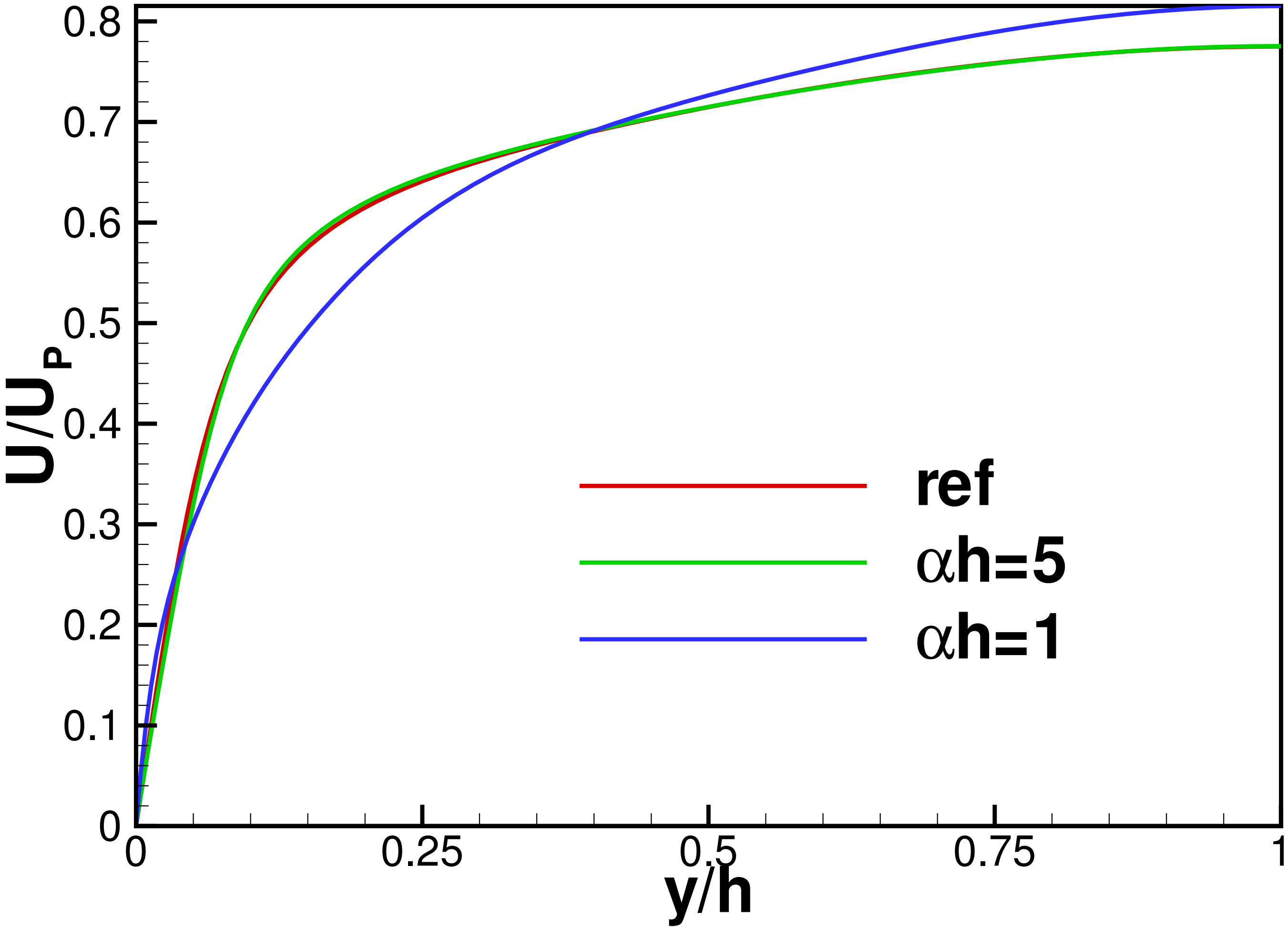
④ When $\lambda_s \rightarrow \infty$ the limit of uniform blowing + uniform suction is recovered. Agreement with $\lambda_s^+ \approx 4000$ from Jimènez, and with results from Sumitani & Kasagi.

Is the flow over a wavy wall really independent on the wavelength of the corrugation? Probably not...

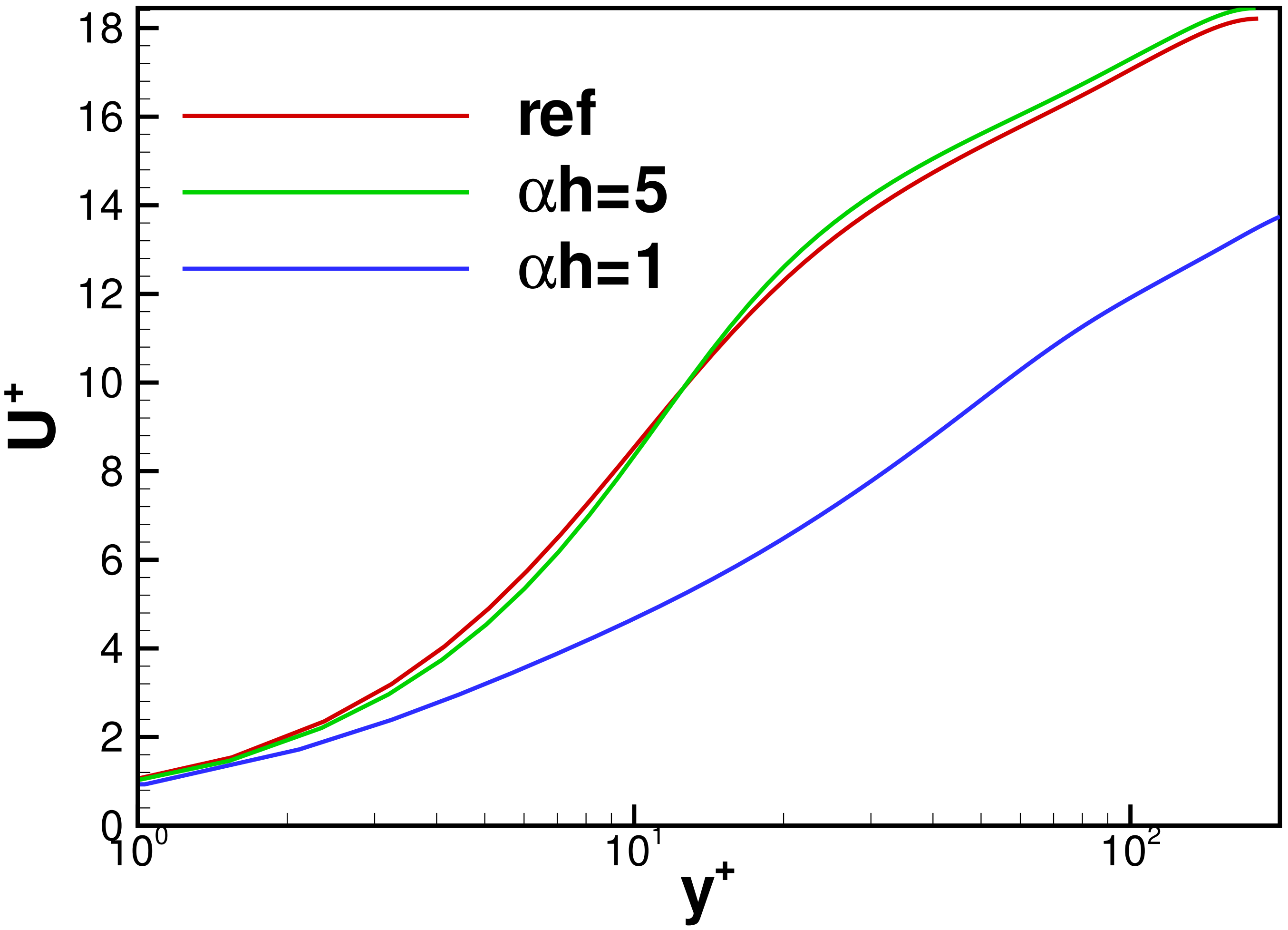
UNEXPECTED RESULT: SMALL DRAG REDUCTION



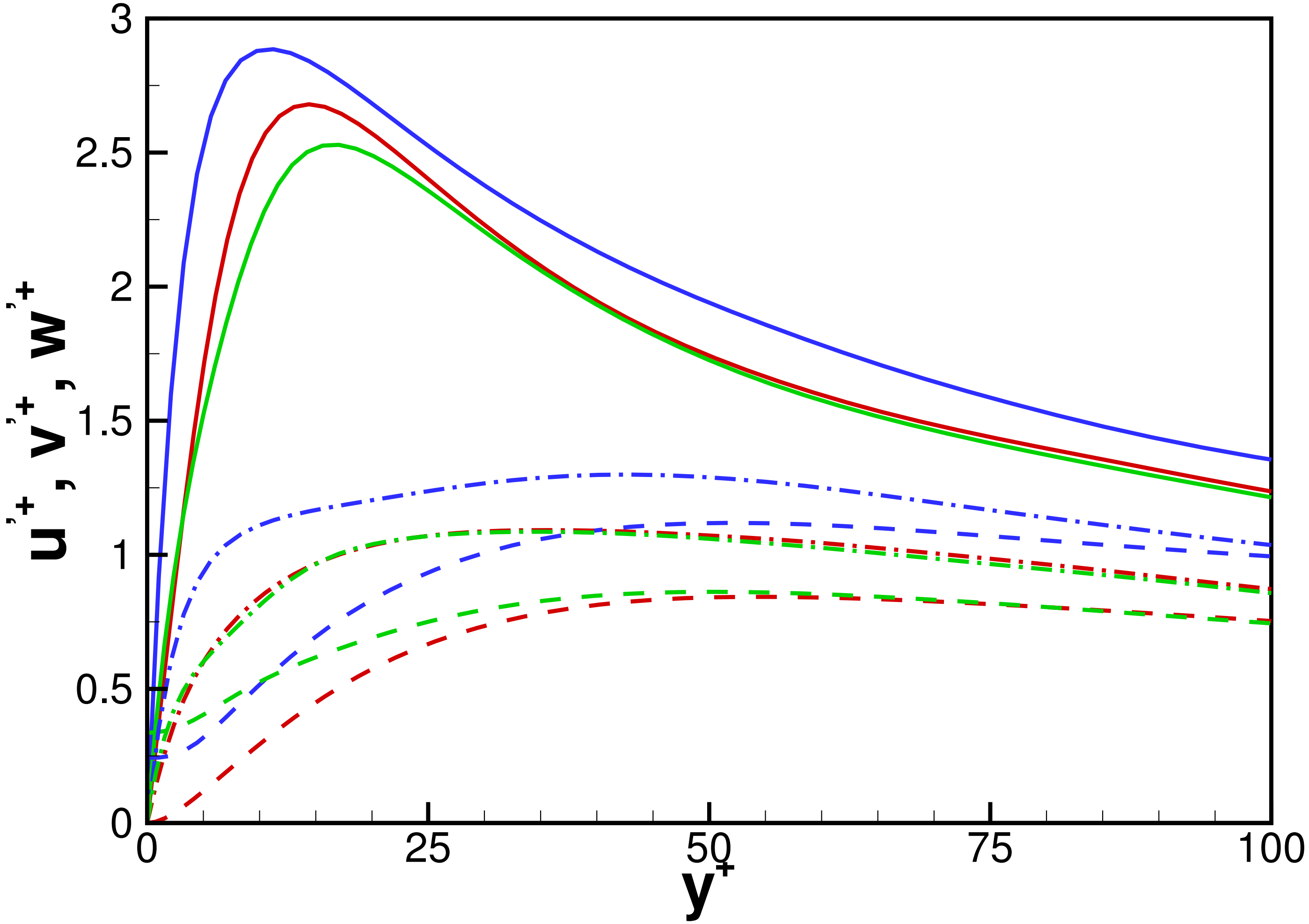
MEAN PROFILE



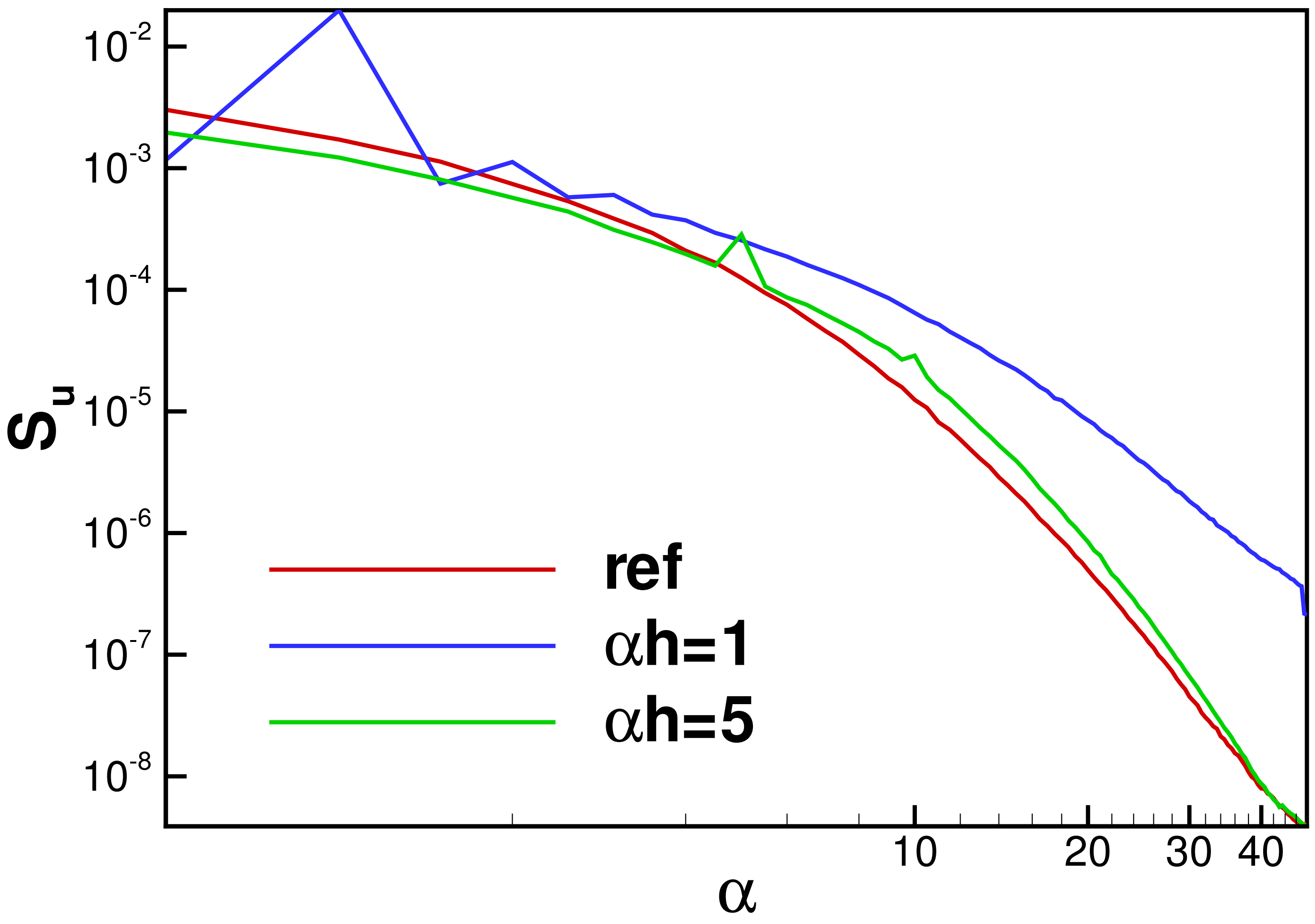
MEAN PROFILE IN WALL UNITS



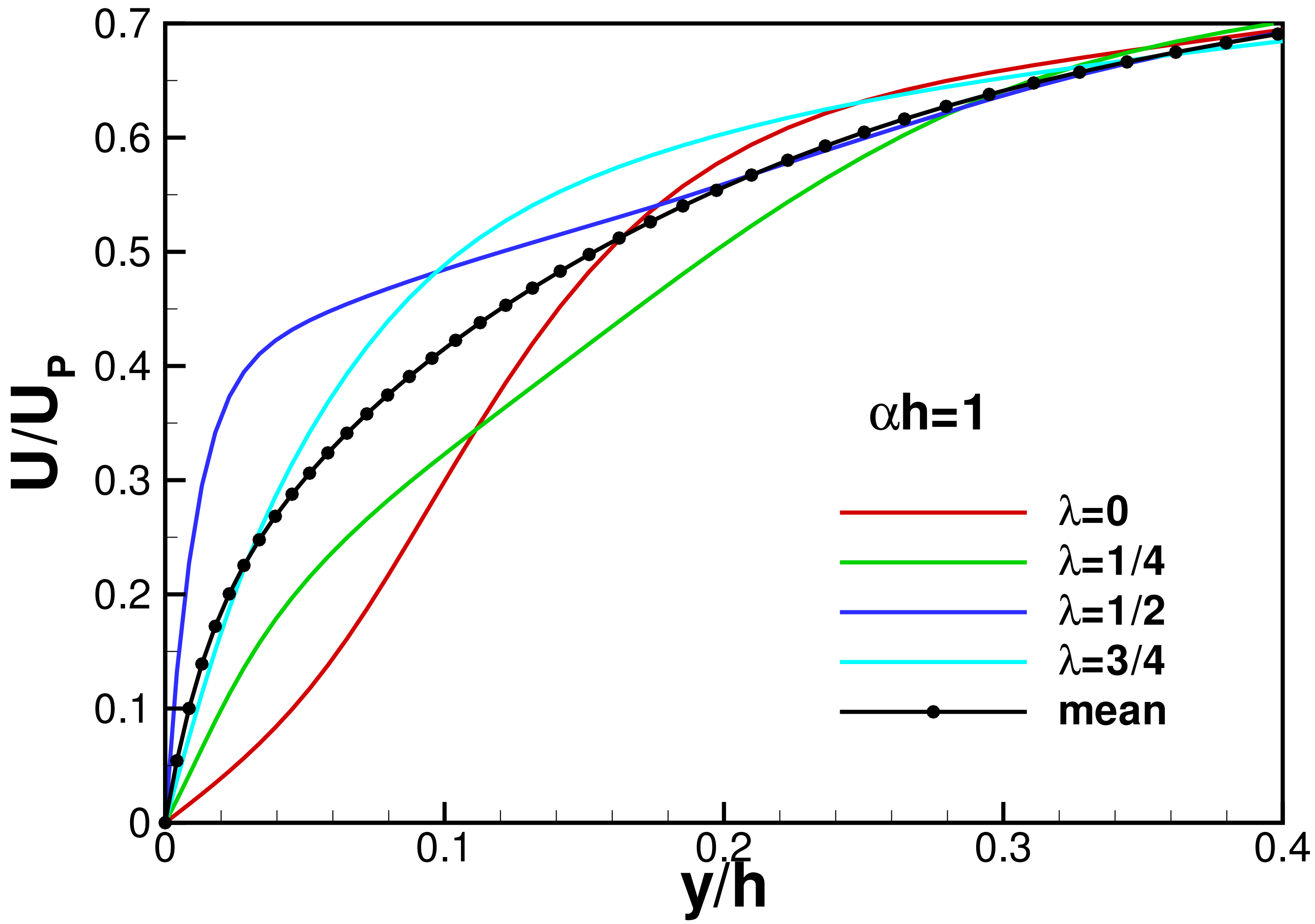
VELOCITY FLUCTUATIONS



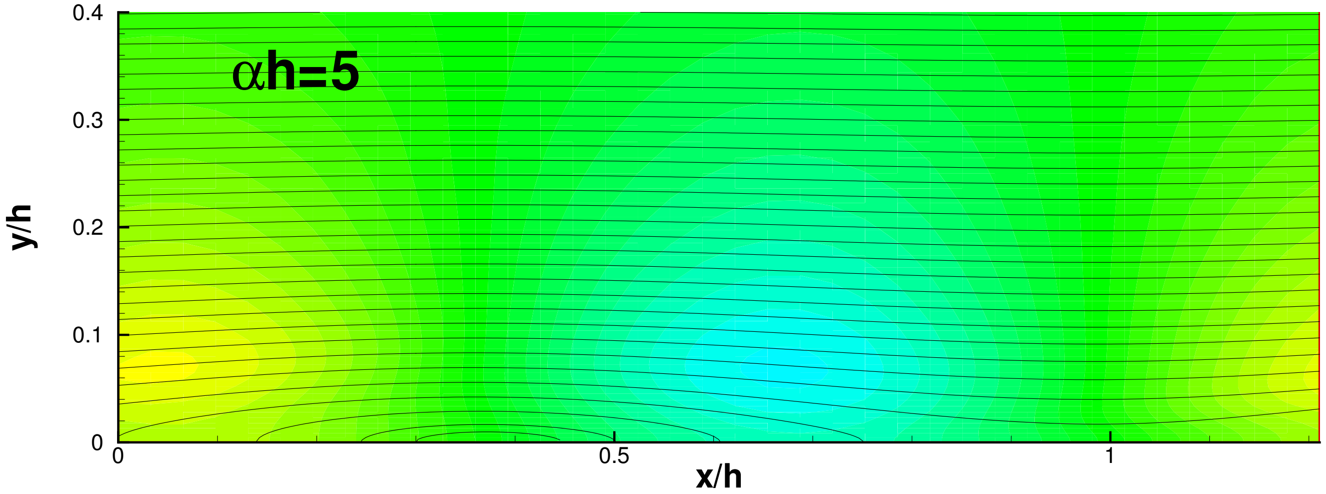
1D STREAMWISE SPECTRA

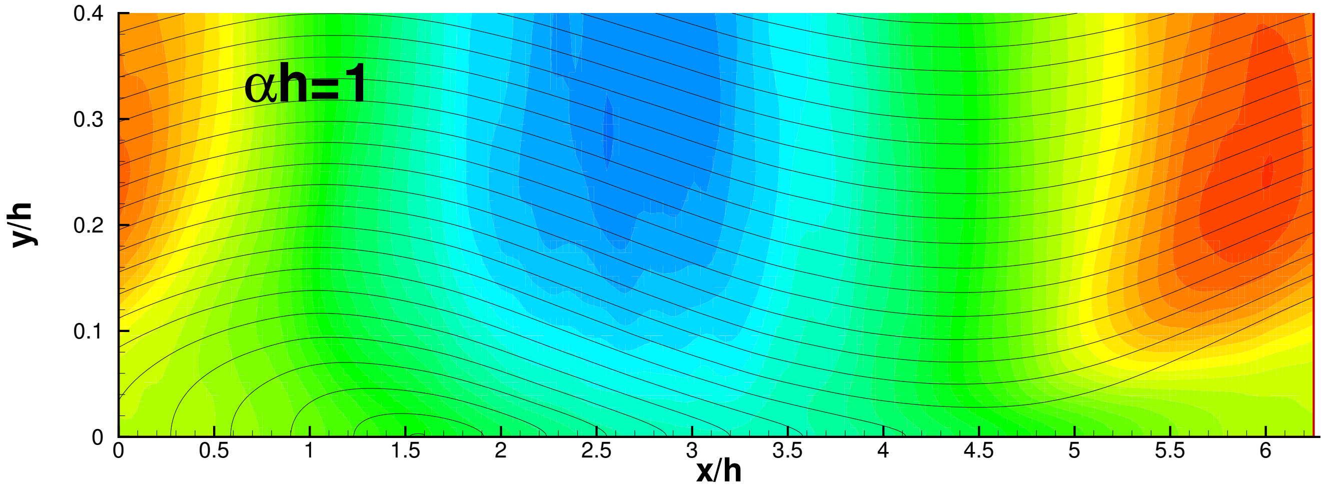


STREAMWISE DIRECTION IS NOT-HOMOGENOUS!

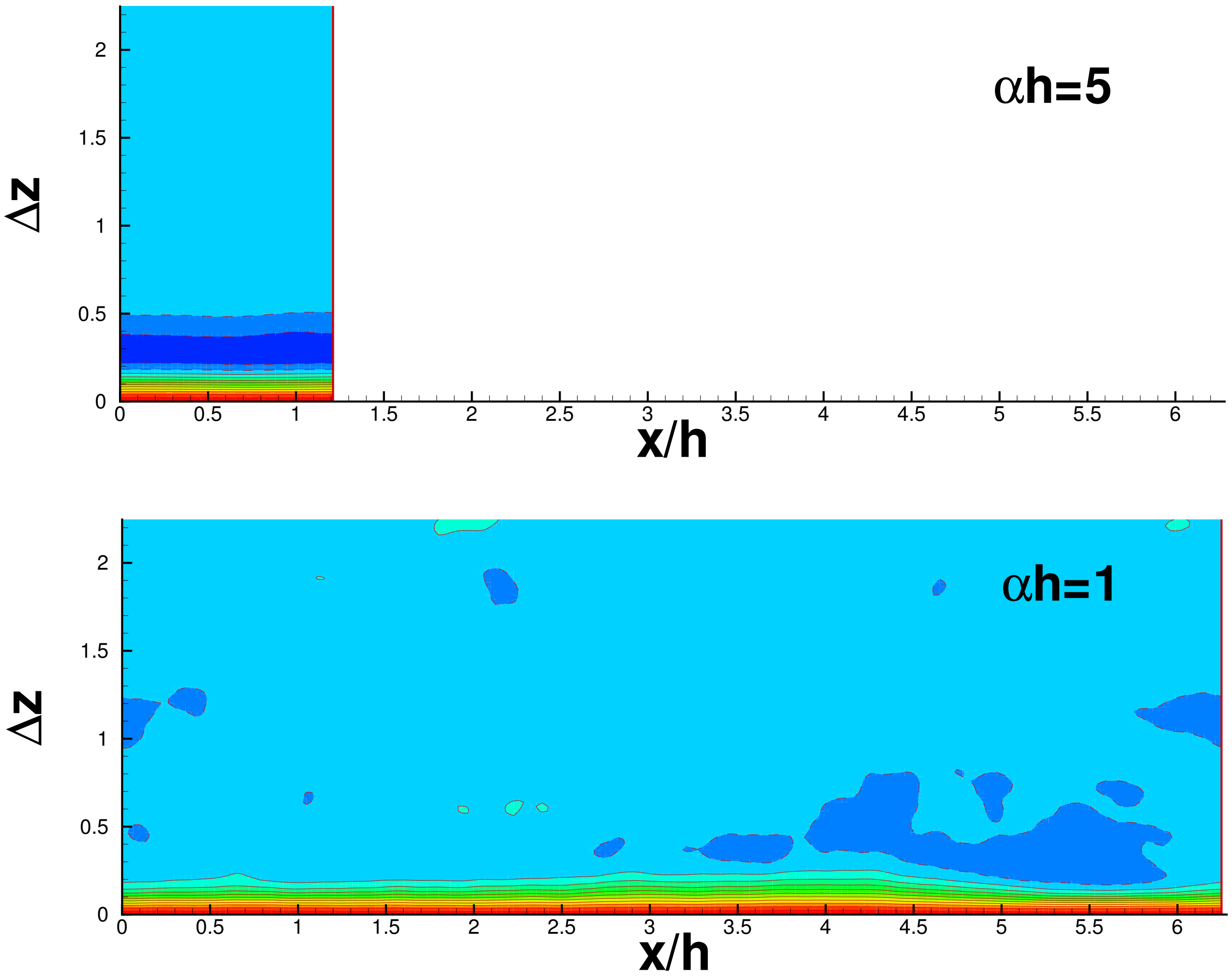


VERTICAL MEAN VELOCITY AND STREAMLINES



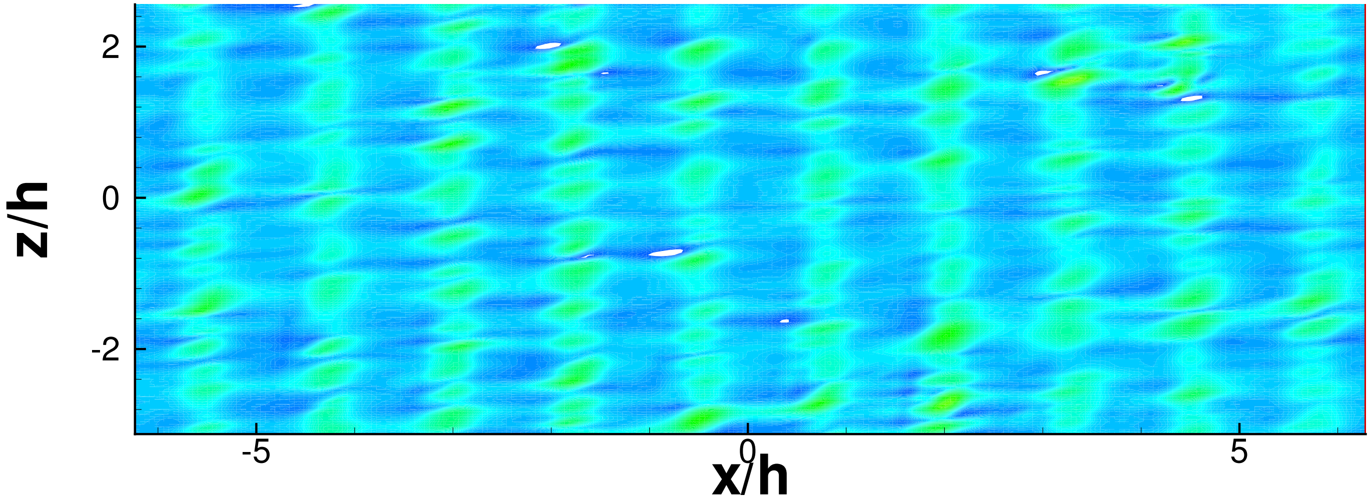


TRANSVERSAL CORRELATIONS, u AT $y^+ \approx 10$

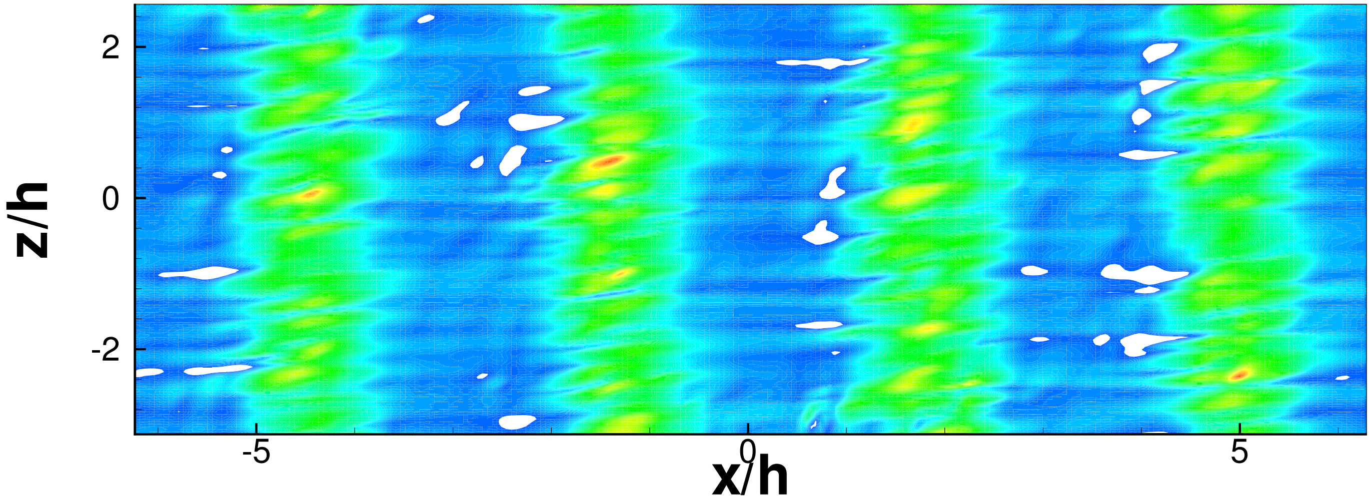


STREAMWISE FRICTION

$\alpha h=5$



$\alpha h=2$



CONCLUSIONS

Suction wavelength λ_s plays a fundamental role.

Dramatic drag increase at wavelenghts $\lambda_s^+ > 350$, towards the asymptotic value of uniform blowing and uniform suction. Usual turbulence structure (elongated low-speed streaks) disappear.

Small drag reduction below the threshold $\lambda_s^+ = 350$. Critical wavelength is related to the typical size of near-wall turbulent structures.

No evidence of large-scale vortices. Basic flow structure is a pair of large-scale spanwise rolls.