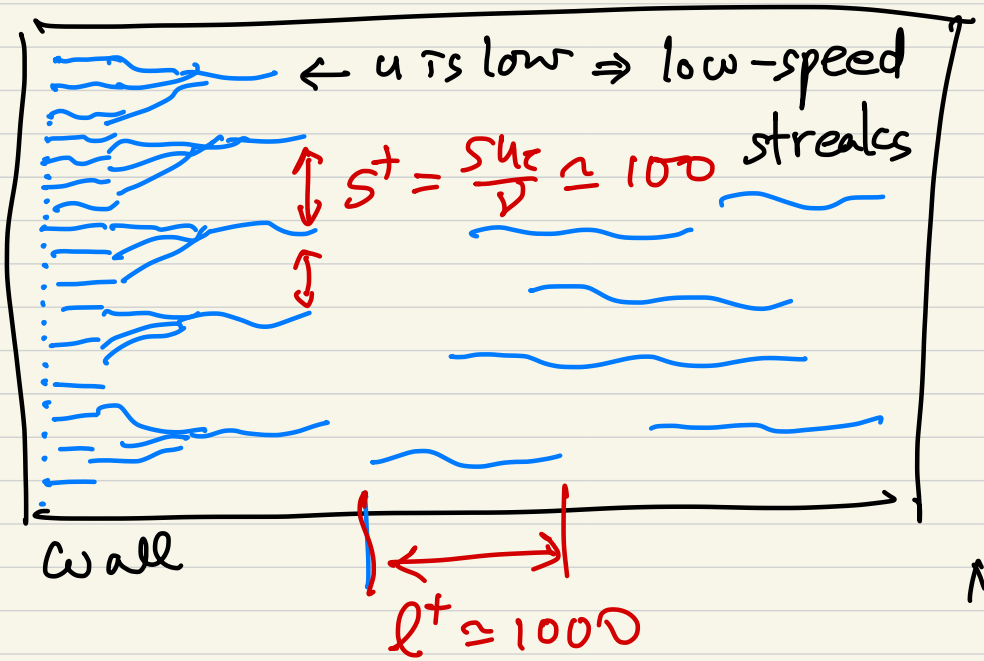
## 7.4 Turbulent structures

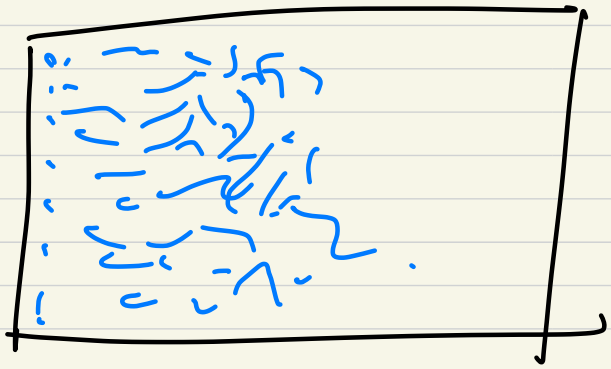
Kline & Robinson (1990), Robinson (1991)

Quasi-"coherent" structures in channel and boundary layer flows are

① low-speed streaks in $0 < y^+ \leq 10$




away from the wall



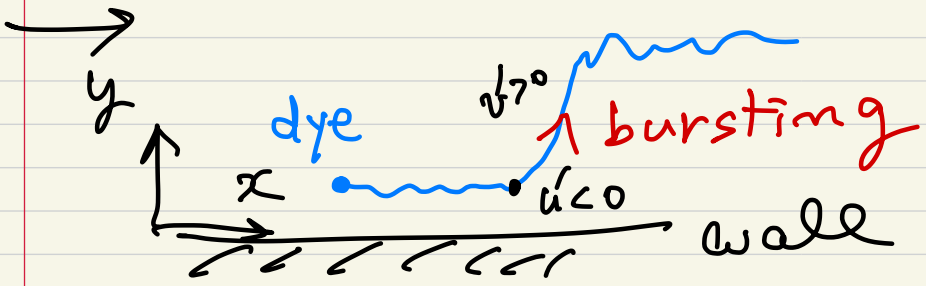
Kline et al. (1967)

flow viz. (experiment)

Moin & Kim (1982, LES)

Kim, Moin & Moser (1987, DNS)

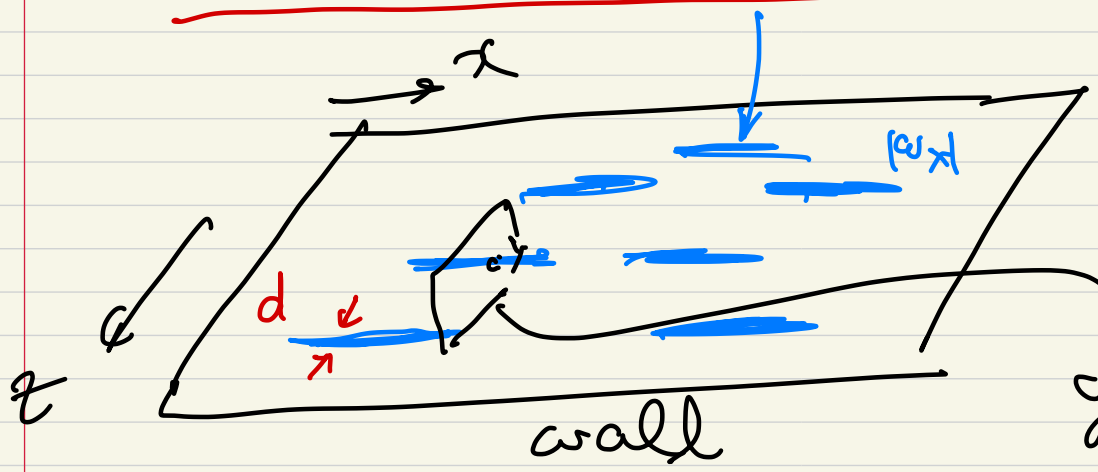
② ejection of low-speed fluid from the wall



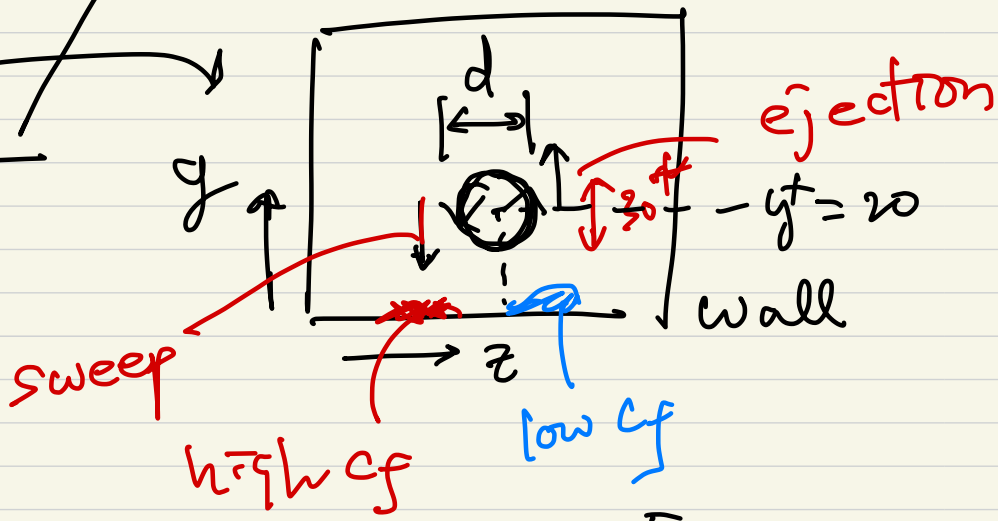

③ sweep of high-speed fluid toward the wall

④ vortical structures

- near-wall streamwise vortices : dominant vortical structures near the wall




$d^+ \simeq 30$ (Kim, Moin & Moser 1987)




$$d^+ = 30 = \frac{d u_\tau}{\nu}$$

KTX : $U_\infty = 100\ m/s$

$$u_\tau = \frac{U_\infty}{20 \sim 30} = 5\ m/s$$

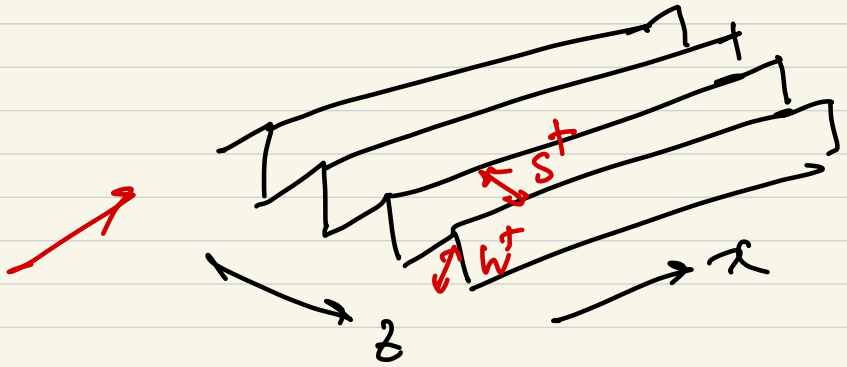
$$d = \frac{30\nu}{u_\tau} = \frac{30 \times 1.5 \times 10^{-5}}{5} \simeq 10^{-4}\ m = 0.1\ mm$$

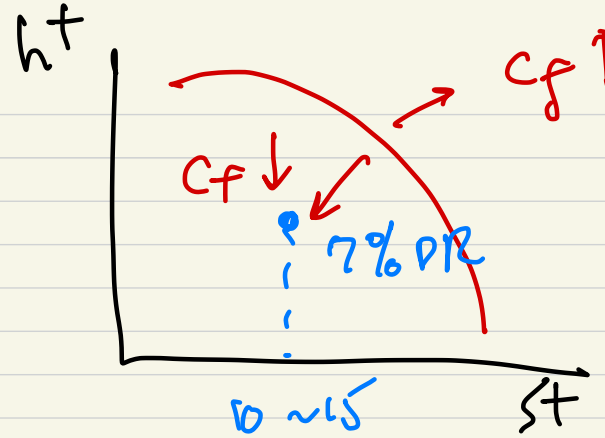
"riblets" ↑ sharkskin → 7% DR

what is the surface shape that provides lowest Cf ?

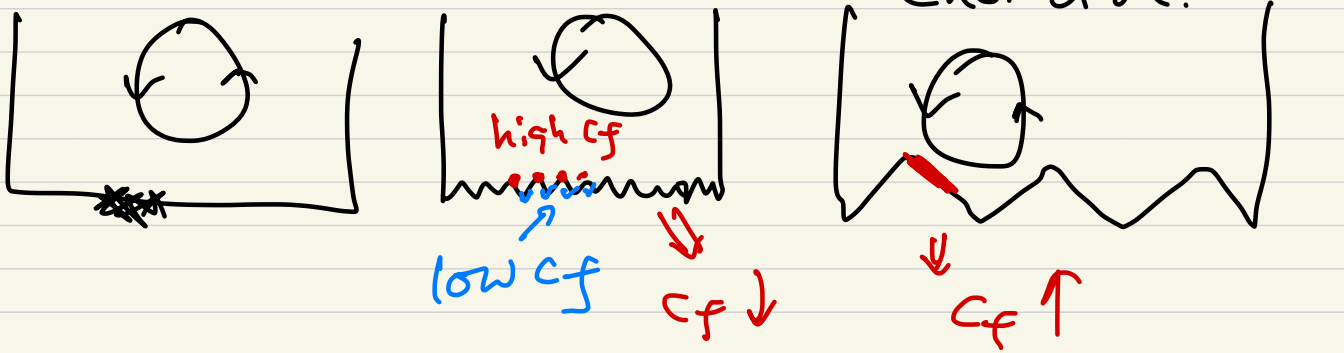
→ flat & smooth surface X

Walsh (1979, 1980, 1982)

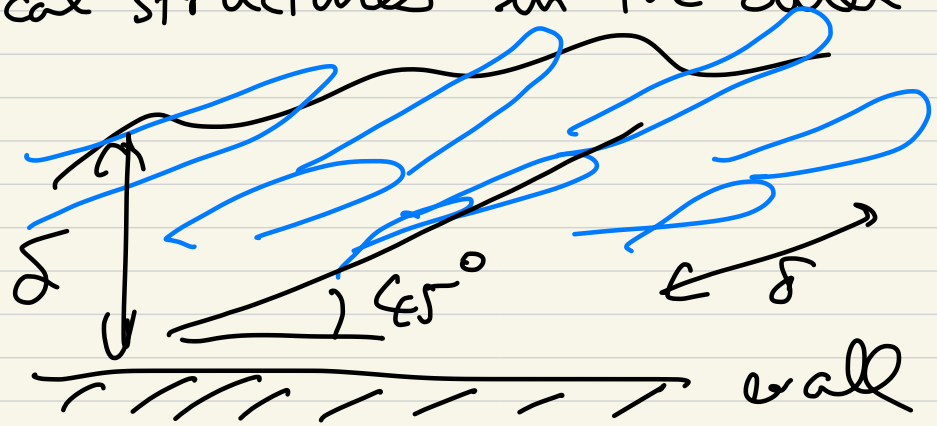



Choi et al. (1993)

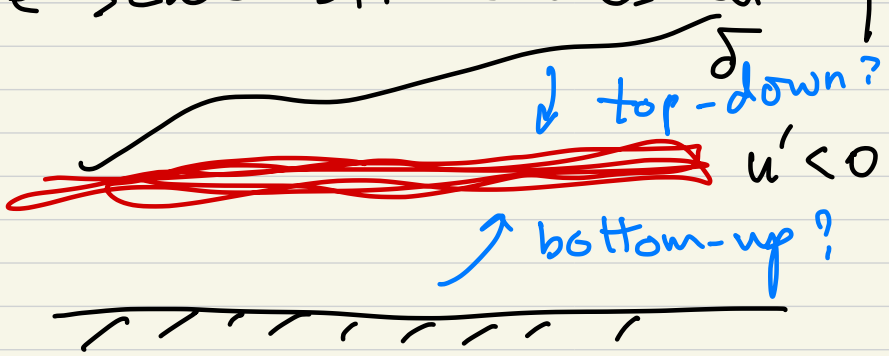



- Horseshoe or hairpin vortices are dominant vortical structures in the outer layer.

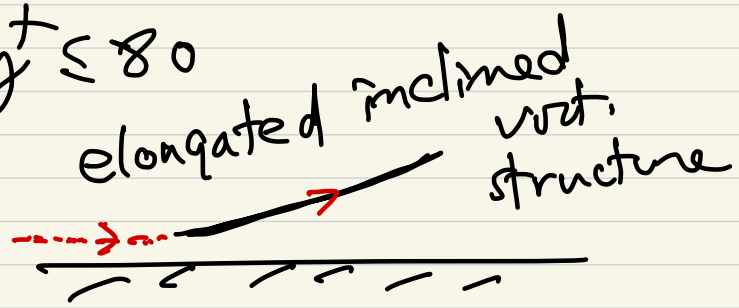



Wu et al. (20xx)

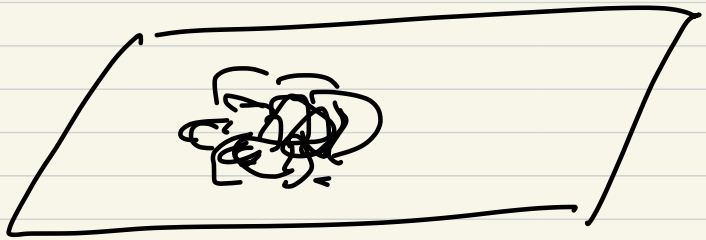
- large scale structures at $y \doteq 0.5\delta$




⑤ strong internal shear layers in $y^+ \leq 80$



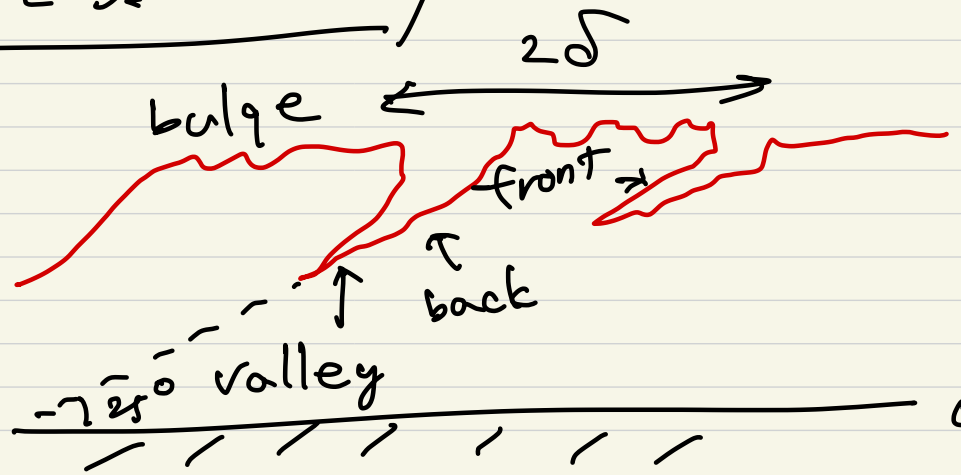

⑥ near-wall pockets

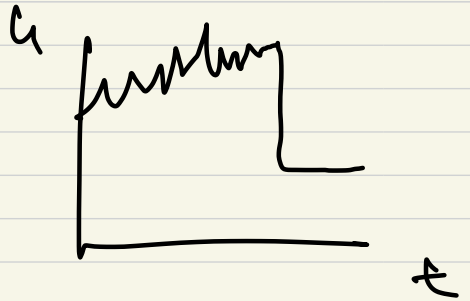


⑦ backs

↓

u changes abruptly



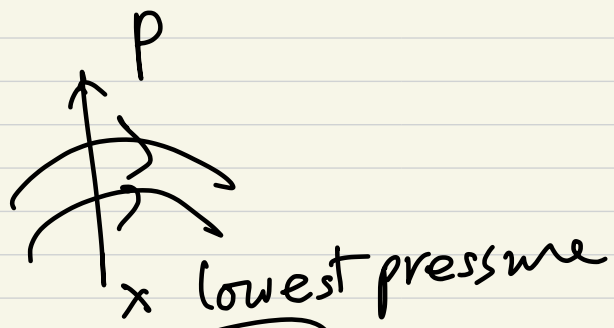



② large-scale motions in outer layer
including bulges, superlayer, deep valleys.

* How to identify vortical structures?

vortex vs. vorticity

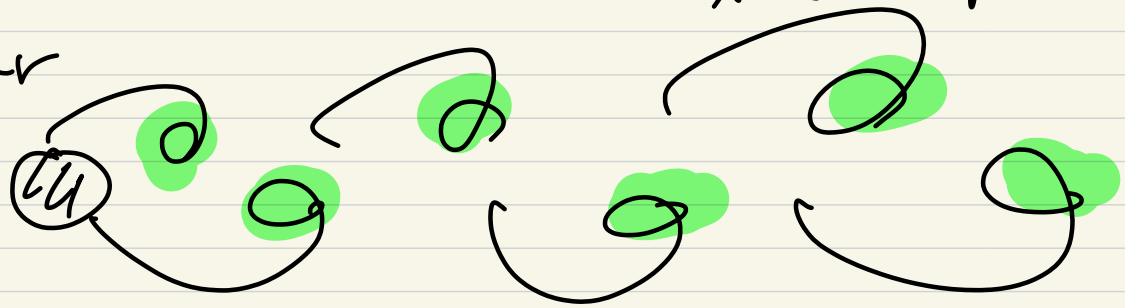
$\underline{\omega} = \nabla \times \underline{v}$




→ low pressure contour

⇓

large scale vortex only



invariants of velocity-gradient tensor

$\partial U_i / \partial x_j$

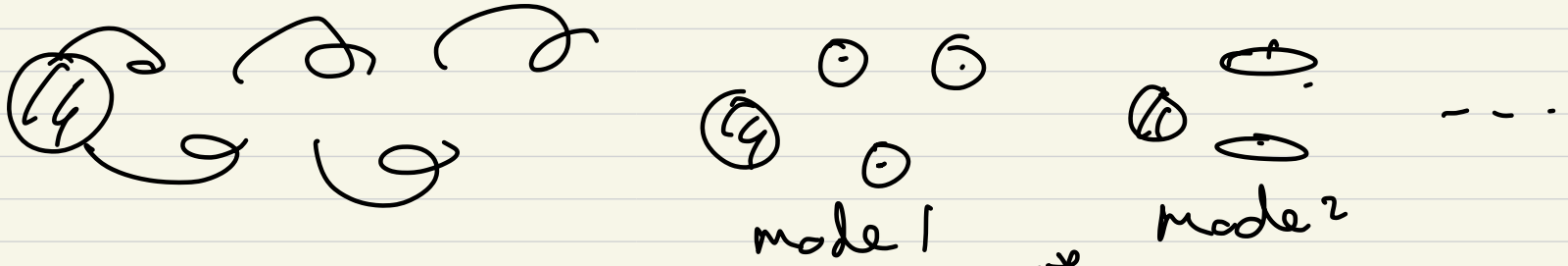
Jeong & Hussain (JFM, 1995) → $\lambda_2$ contour

Q-criterion

small-scale vortical structures

* Proper orthogonal decomposition (POD) – Lumley (1967)
Berkooz et al. (1993)

use two-point velocity correlation in space → identify motions which contain most energy.




$u(x,t) \xrightarrow{FT} \hat{u}(k,t)$


ch.8 Introduction to modeling and simulation – skip

ch.9 Direct numerical simulation (DNS)

↳ use my material rather than following textbook.

Ch. 10 Turbulent-viscosity model

LES (Large eddy simulation)

RANS (Reynolds-averaged Navier-Stokes eqs.)

↳ Use 'turbulence models & their application in hydraulics' by W. Rodi.

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**Turbulence simulation – DNS, RANS, LES, ---**

- Principle criteria of assessing different models

① level of description : $\langle U \rangle$, $U$, $\langle uv \rangle$, $uv$

② completeness : free-from flow-dependent specifications

DNS - complete, mixing-length model - incomplete

$l_m$

③ cost and ease of use

④ range of applicability

⑤ accuracy

CFD – an important tool in design of flow system

Rapid development of supercomputer capacity.

1990 CRAY C90 ≙ PC (2015)