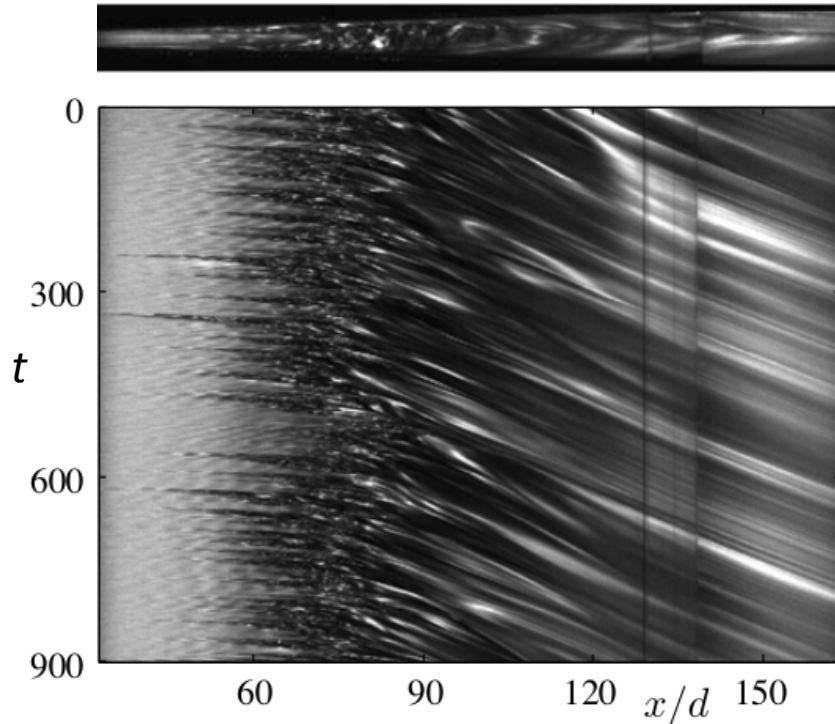# *Turbulence in a Gradual Expansion Circular Pipe Flow*
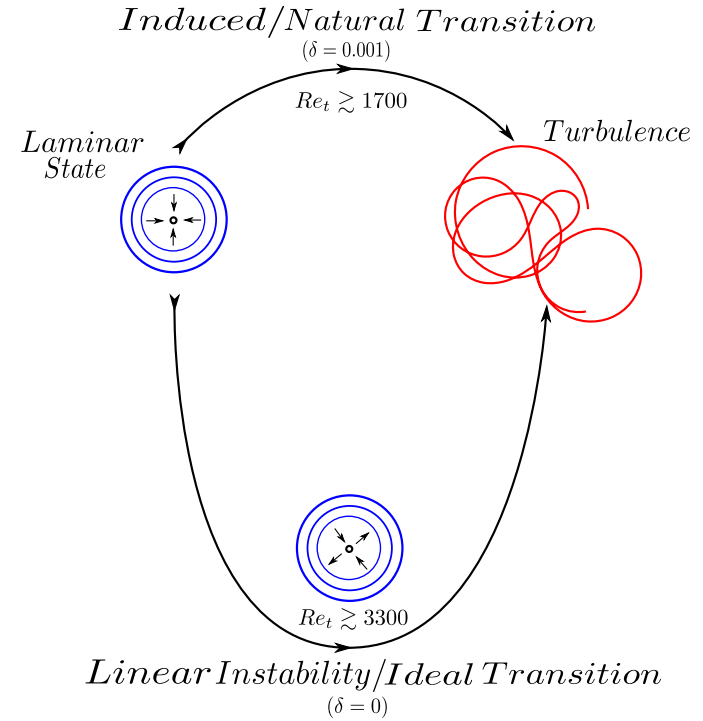
Kamal SELVAM, Jorge PEXINHO, Ashley P.WILLIS

Re = 800

Laminar – Turbulence – Laminar pattern
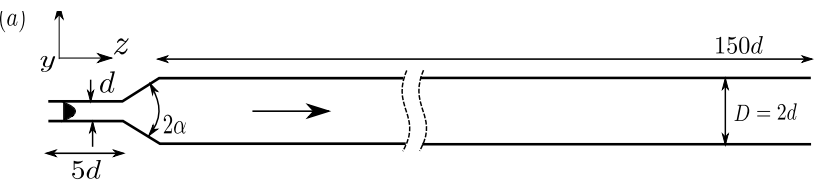
$$Re = \frac{Ud}{\upsilon}$$

- Sudden Expansion System is linearly stable for *Re* < **3273**
- Transition to Turbulence occurs early in experiments
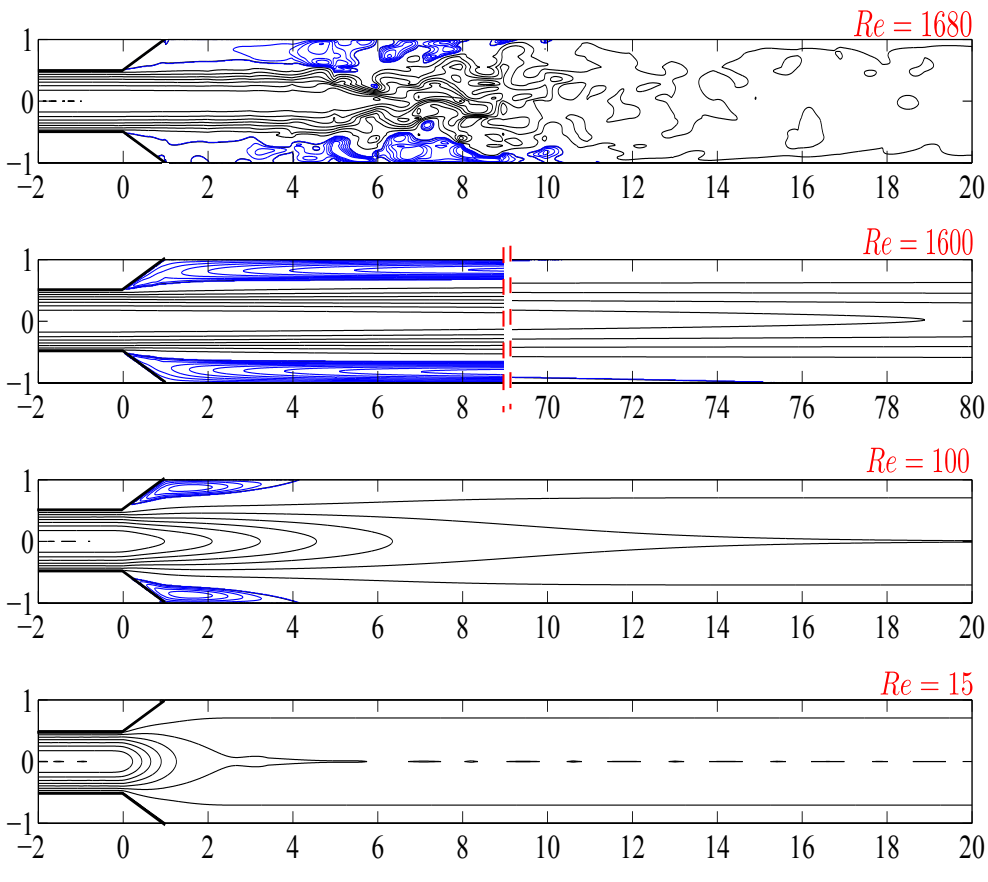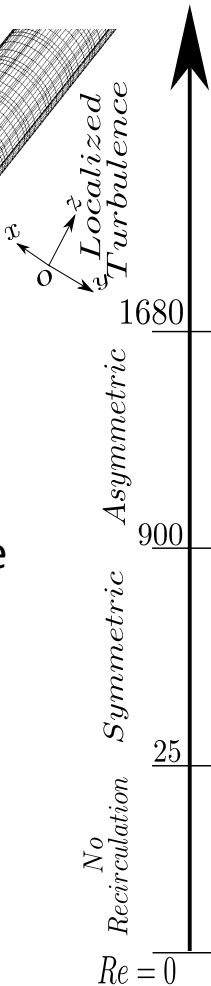- Imperfection in the experiments gets amplified

$Induced/Natural\ Transition$
$(\delta = 0.001)$

$Re_t \gtrsim 1700$

$Laminar\ State$

$Turbulence$

$Re_t \gtrsim 3300$

$Linear\ Instability/Ideal\ Transition$
$(\delta = 0)$
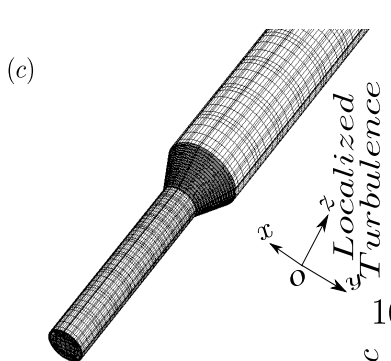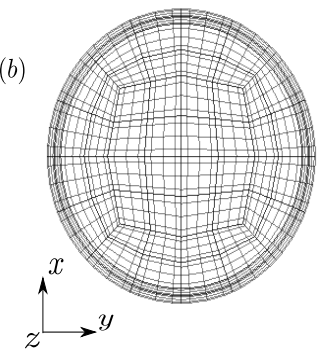
- Spectral Element Method (NEK5000)
- Adding a controlled finitie-amplitude to the numerical system

Transition to Turbulence

(a) schematic with labels: y, z, d, 2α, $5d$, $150d$, $D = 2d$

Re = 2000

(b)

(c) with axes x, y, z, O

Localized Turbulence

1680

Asymmetric

900

Symmetric

25

No Recirculation

$Re = 0$

Summary :

- Oscillation in flow occur before transition
- Transition occurs at **Re** = **1680**
- The Localized turbulence self-sustains even after removing perturbation
- Existence of hysteresis

$Re = 1680$

$Re = 1600$

$Re = 100$

$Re = 15$