Lecture 11

Shear flow transition – case study

AE209 Hydrodynamic stability

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Lecture outline

1. Transition in boundary layer
2. Transition in flow over a circular cylinder
3. Is transition relevant to turbulence?

1. **Transition in boundary layer**
2. Transition in flow over a circular cylinder
3. Is transition relevant to turbulence?

General features on instabilities in boundary layer

1. Boundary layer instability (TS wave) is **convectively unstable**.

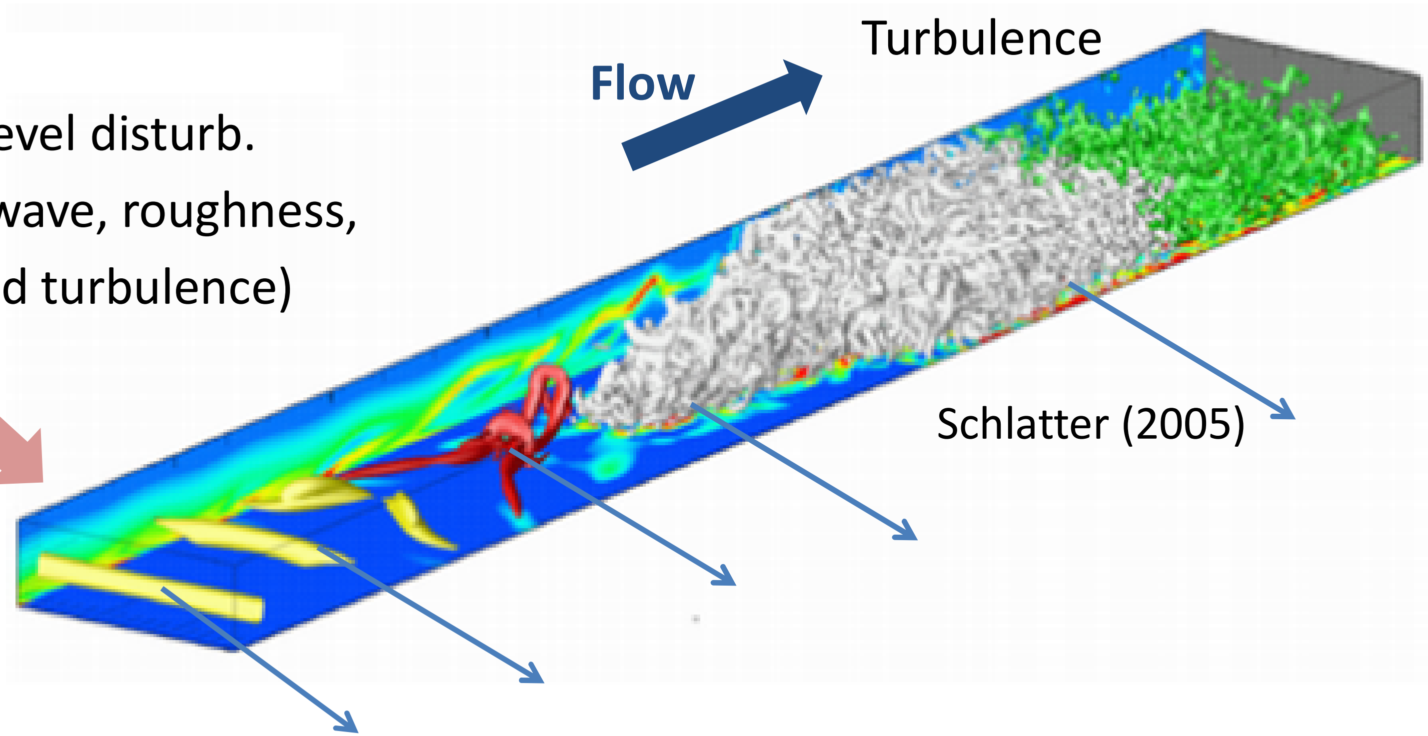
2. Large **transient growth** is also possible **below critical Reynolds number of TS instability**.

3. **Primary instabilities** (either TS wave or transient growth) undergo **secondary instability**, eventually leading to turbulence.

Scenario I : Modal transition via Tollmien-Schlichting wave

Secondary instabilities of Tollmien-Schlichting wave

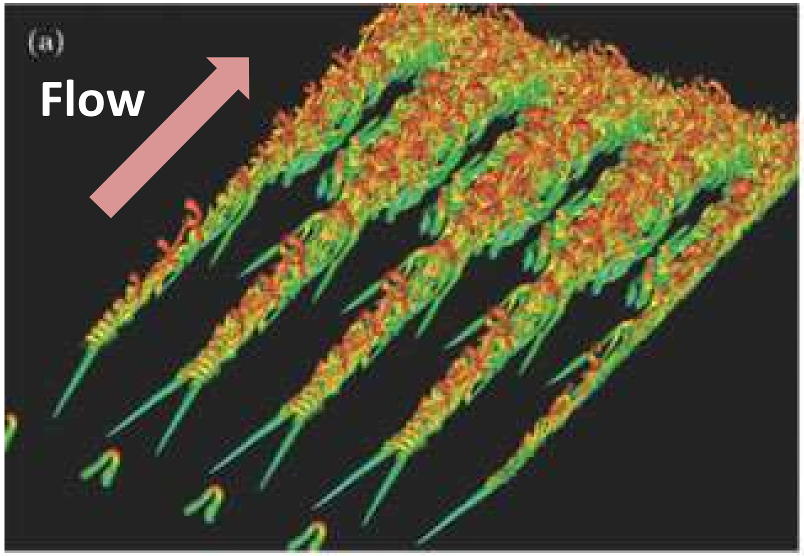
Very low-level disturb.
(Acoustic wave, roughness,
background turbulence)



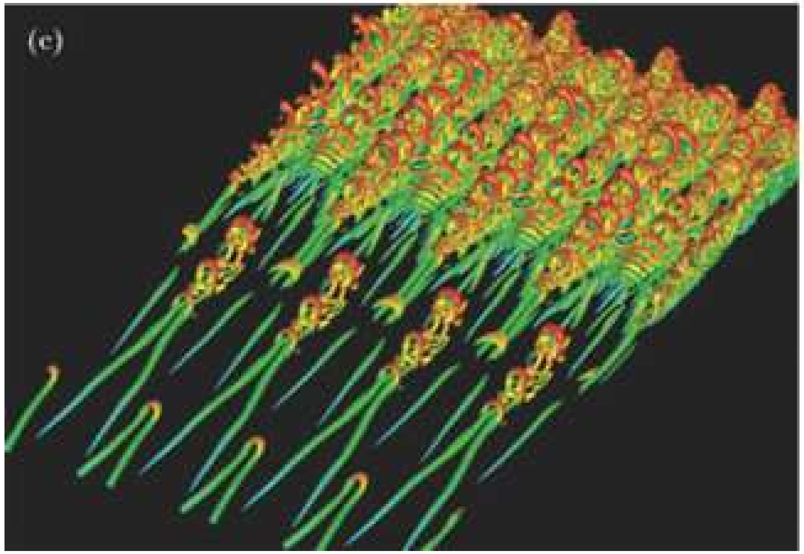
Boundary layer

Scenario I : Modal transition via Tollmien-Schlichting wave

Two types of secondary instabilities of TS wave



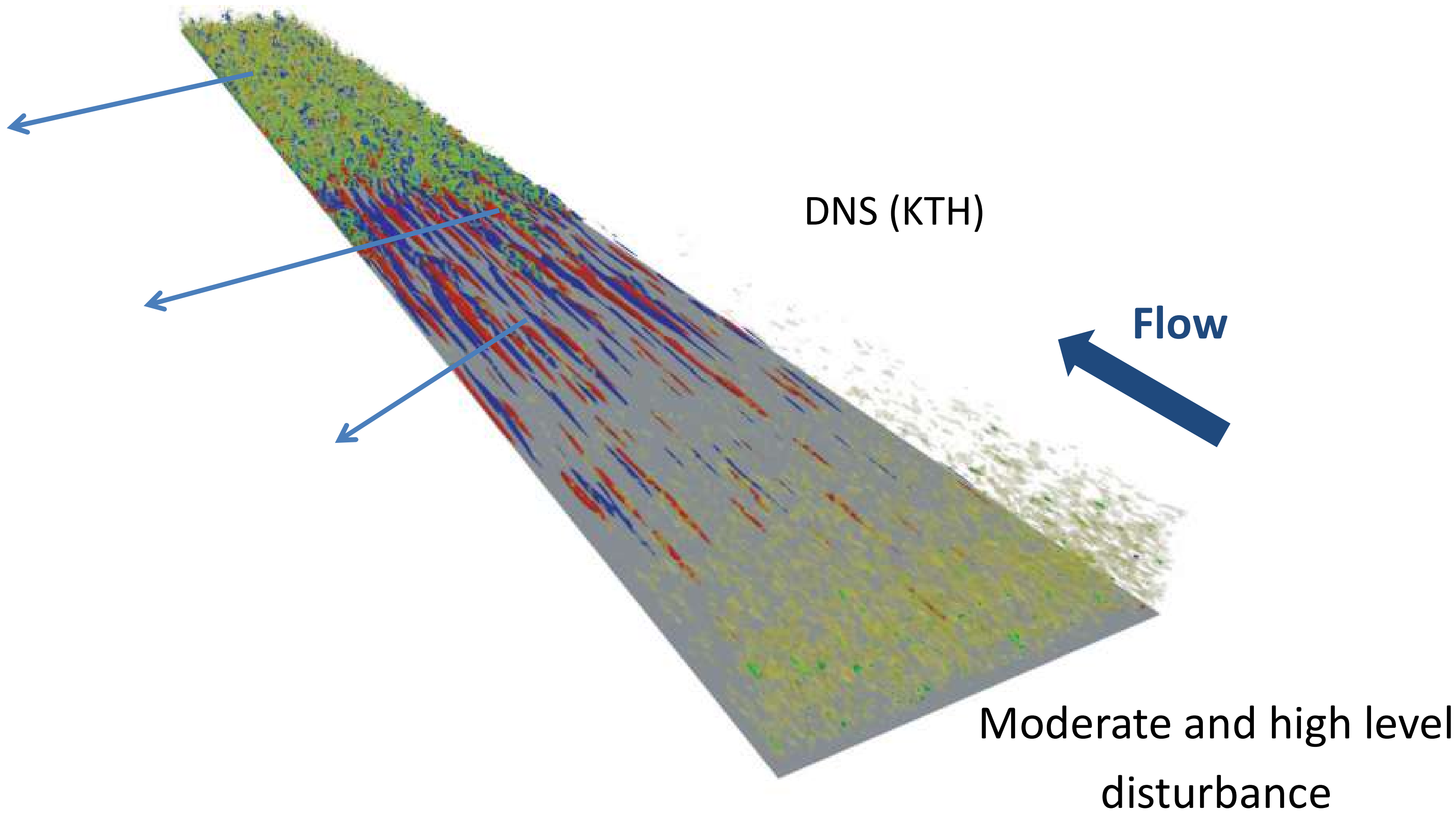
K-type transition
(Klebanoff 1962)



H-type transition
(Herbert 1988)

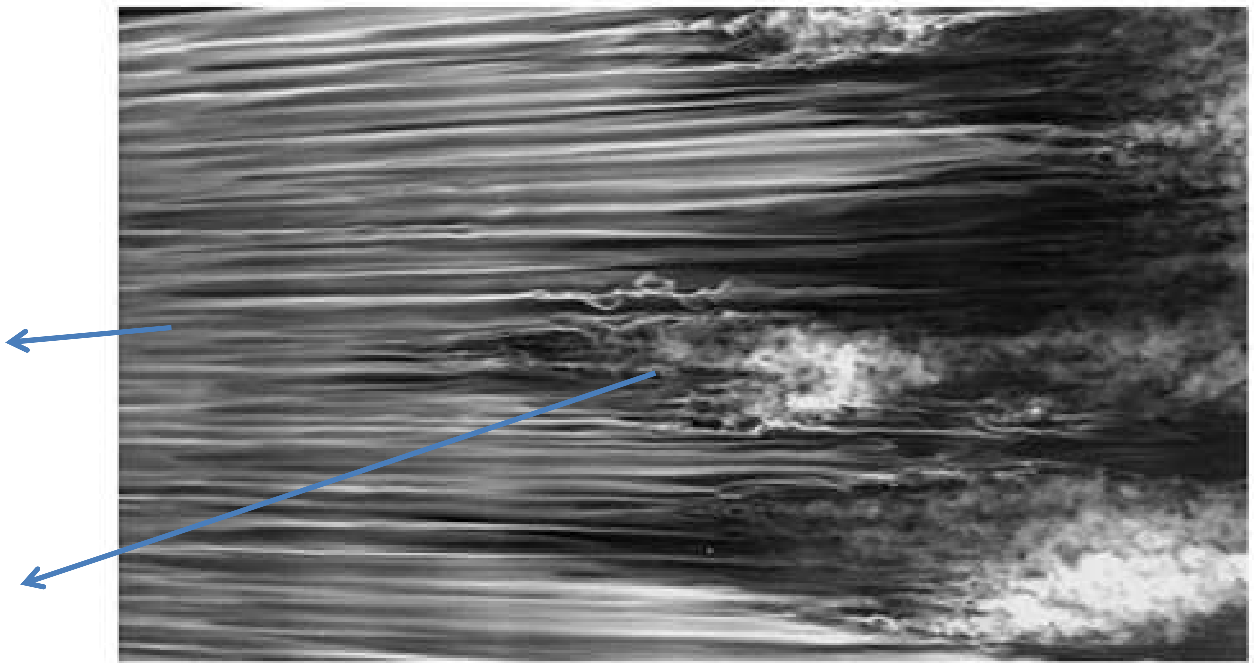
DNS by Sayadi et al. (2012)

Scenario II : Bypass transition via transient growth



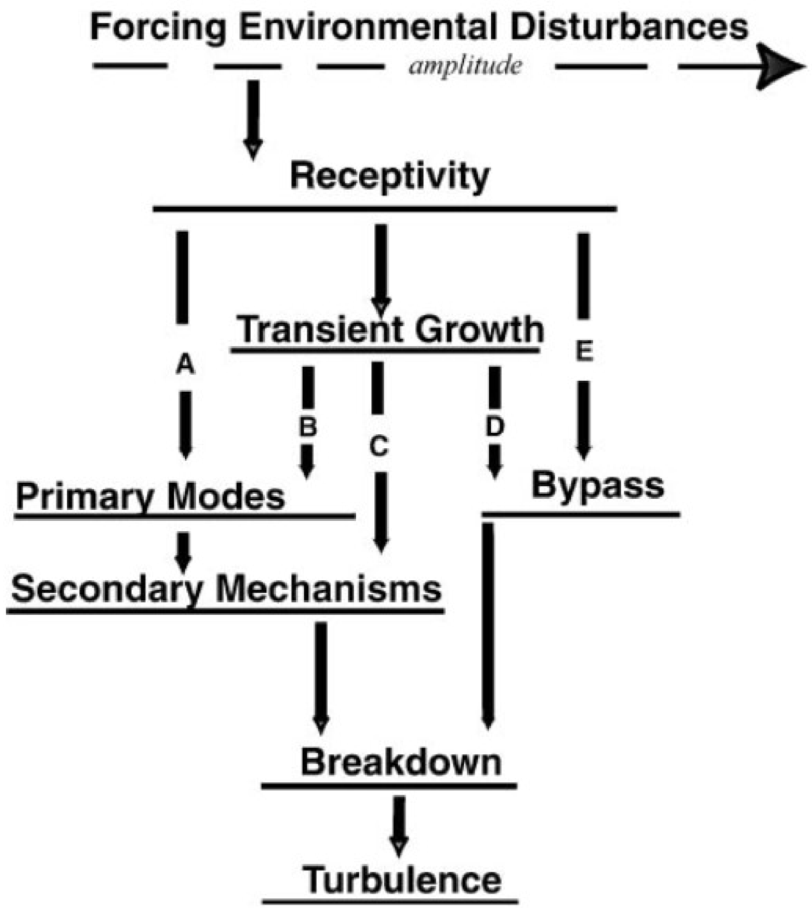
Scenario II : Bypass transition via transient growth

Flow



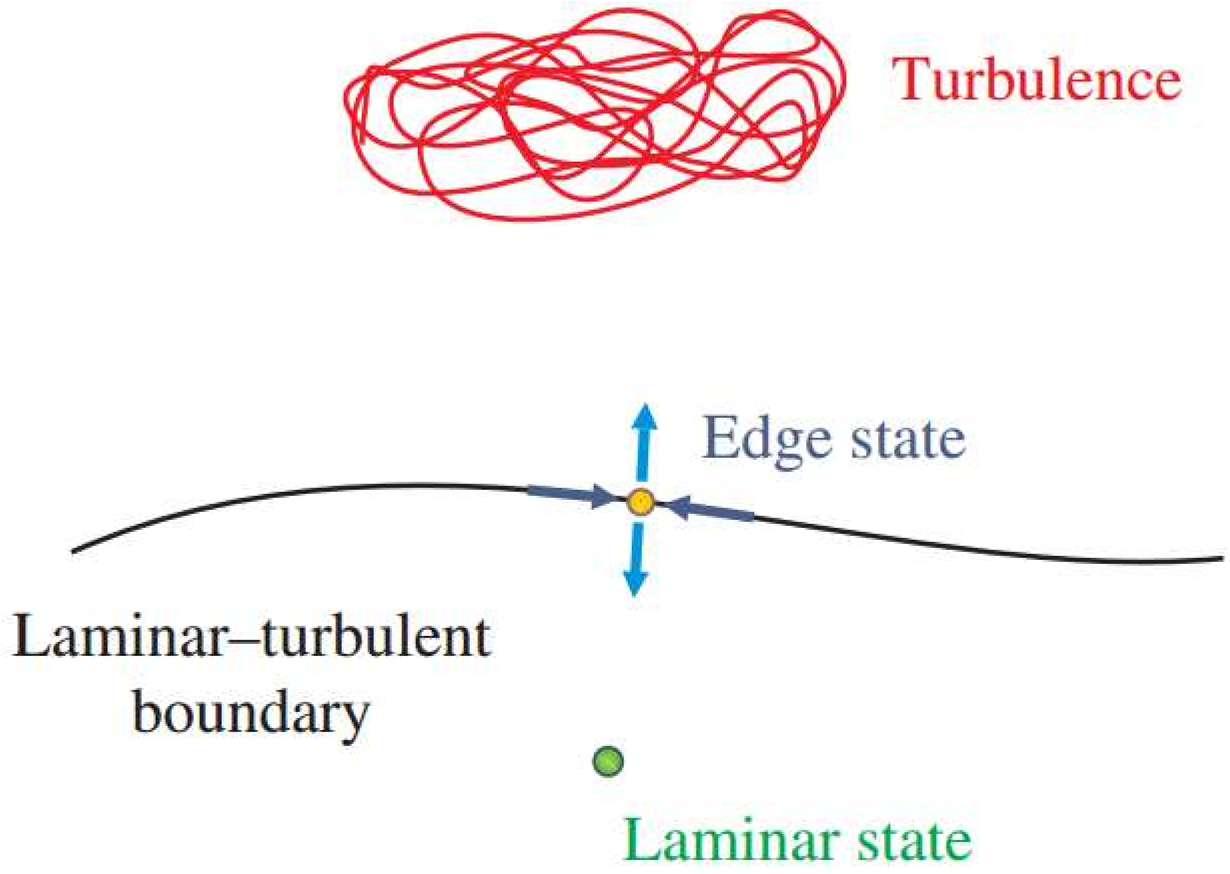
Matsubara & Alfredsson (2001)

Summary

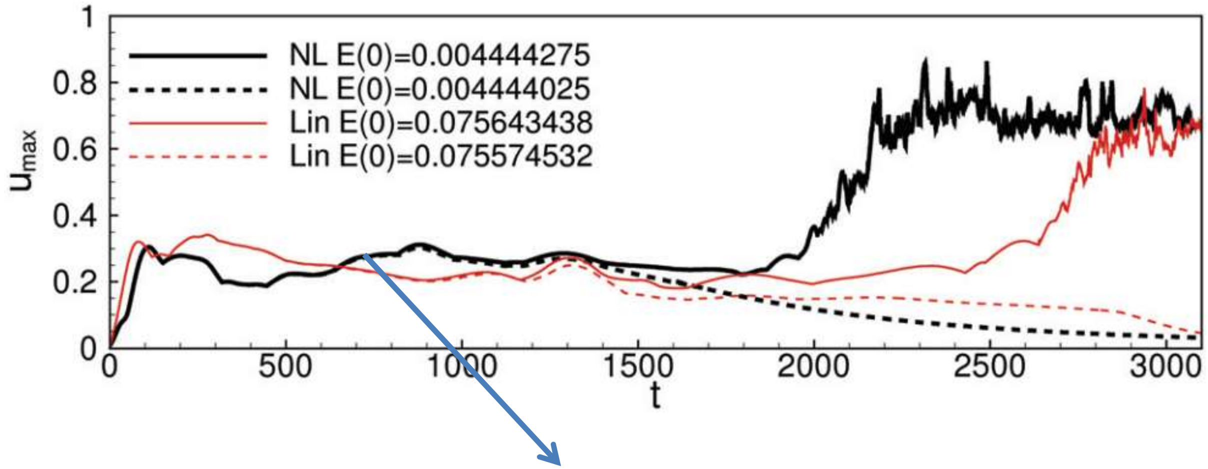


Morkovin (1994)

Beyond nonlinearity – Dynamical system approach (since mid 2000)

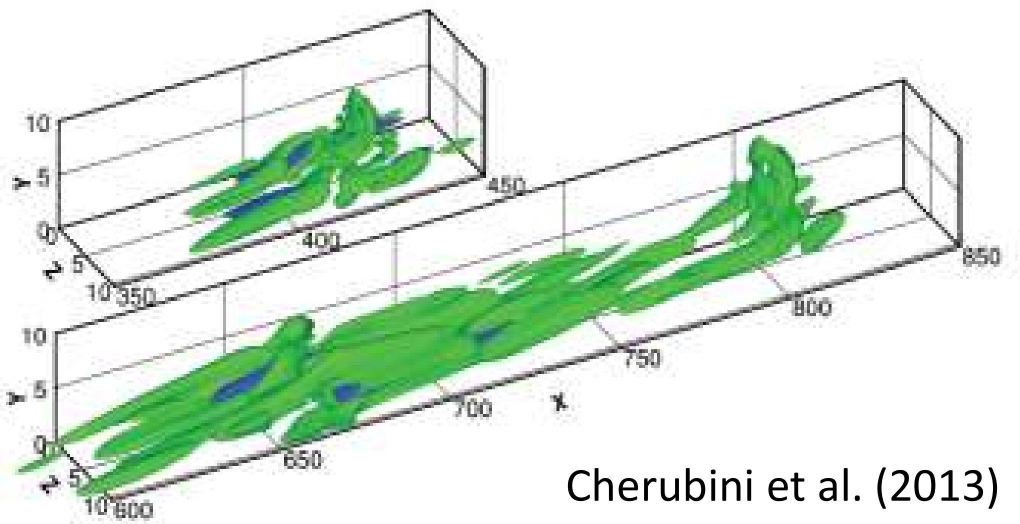


Edge state in boundary layer



$t = 300$

$t = 700$



Cherubini et al. (2013)

1. Transition in boundary layer
2. **Transition in flow over a circular cylinder**
3. Is transition relevant to turbulence?

Wake behind a circular cylinder

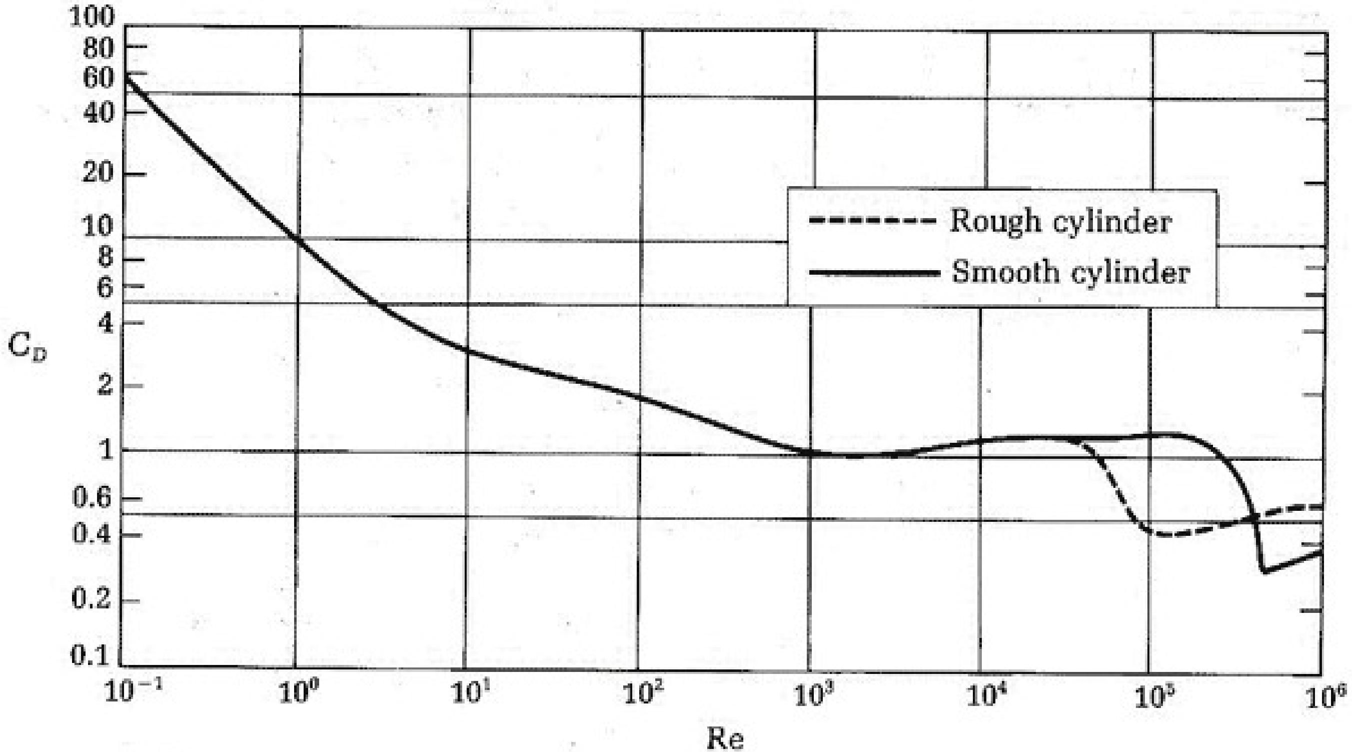
General features on instabilities in bluff-body wake

1. Instability (Karman vortex shedding) is **absolutely unstable** and is driven by **inflectional mechanism** (Rayleigh criterion).

2. The role of **transient growth** is **not very important** typically because the critical Reynolds number of instability itself is also quite low.

3. **Spatial development** is **not of main interest**, as the instability process is often dominated by the near-wake region.

Drag coefficient with Re

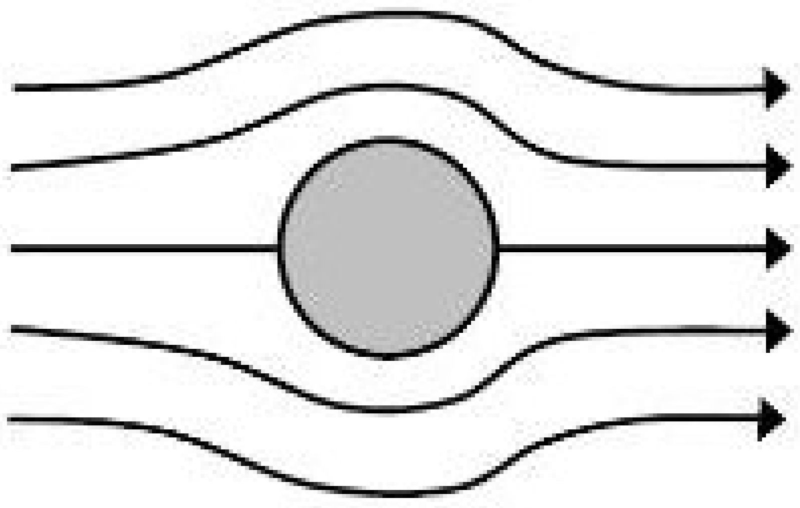


$$\mathrm{Re} = \frac{\rho U_\infty D}{\mu}$$

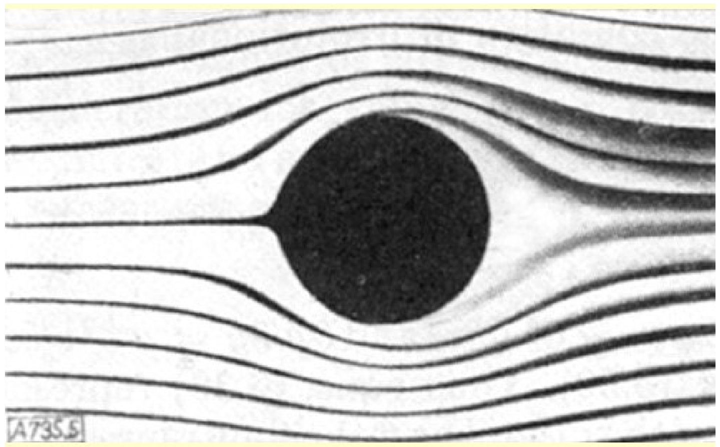
ρ = density of fluid (M/L^3)
U_∞ = free-stream fluid velocity (L/T)
D = diameter of cylinder (L)
μ = viscosity of fluid ($F \cdot T/L^2$)

Wake behind a circular cylinder

Creeping flow (0<Re<5): Hele-Shaw flow



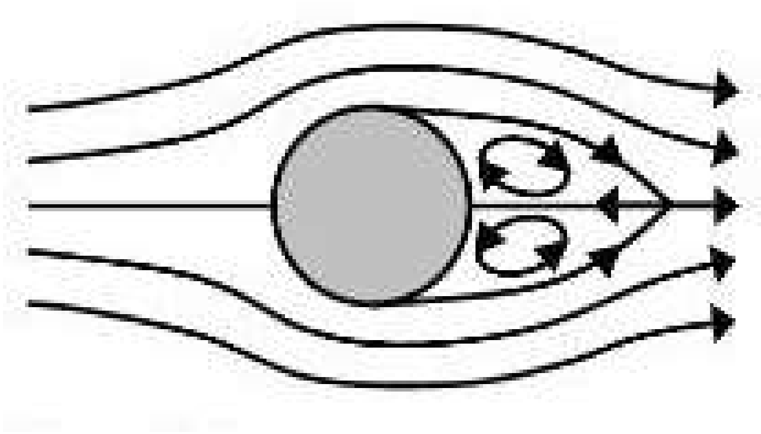
Sketch



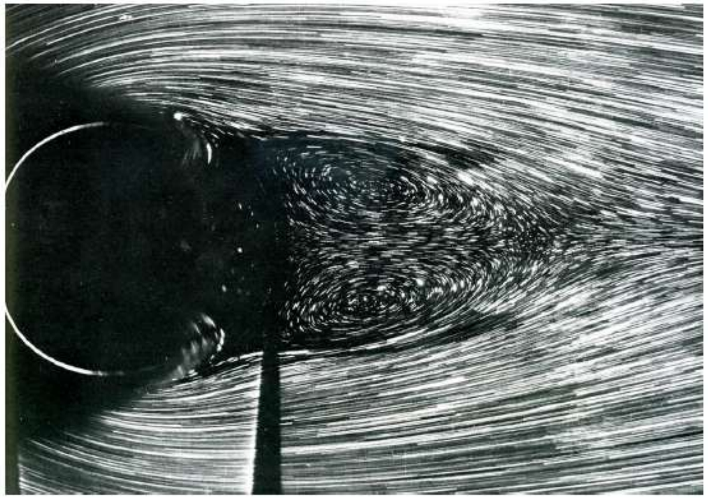
Schlichting (1979)

Wake behind a circular cylinder

Steady symmetric flow (5<Re<47)

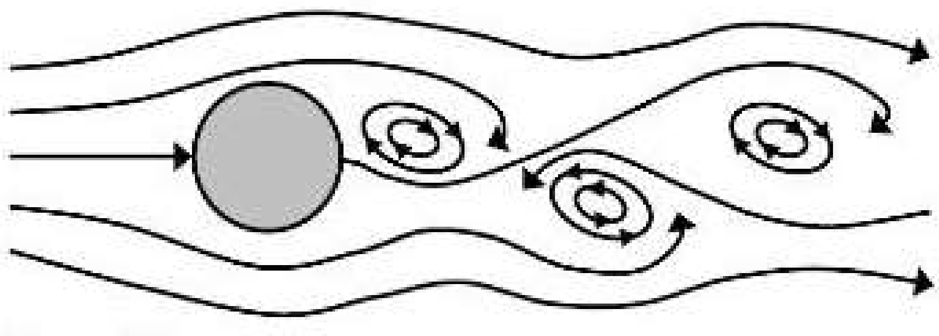


Sketch

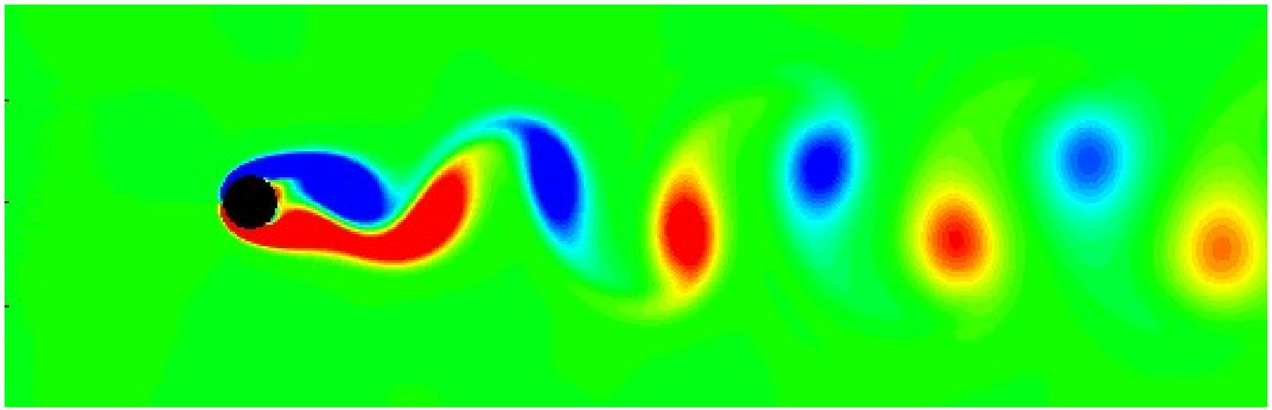


Coutanceau & Bouard (1977)

Two-dimensional laminar Karman vortex shedding (47<Re<189)



Sketch

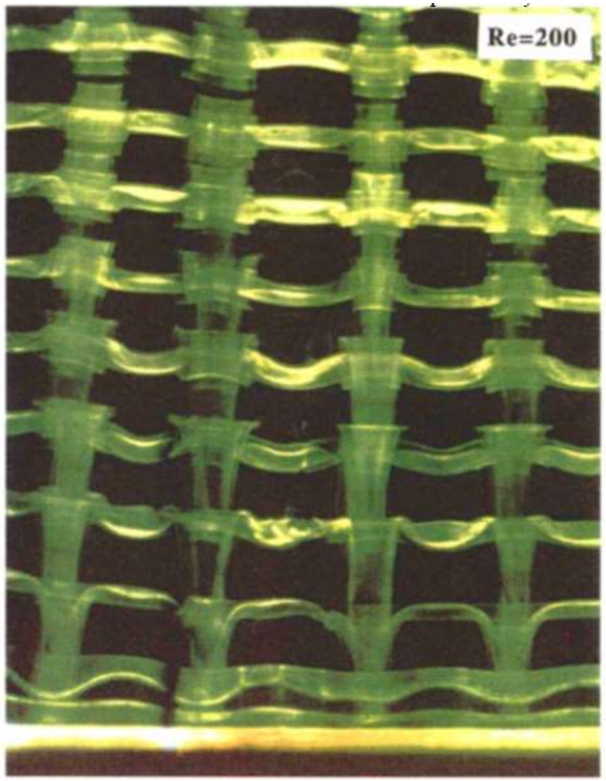


Hwang (2005) $\mathrm{Re}_D = 100$

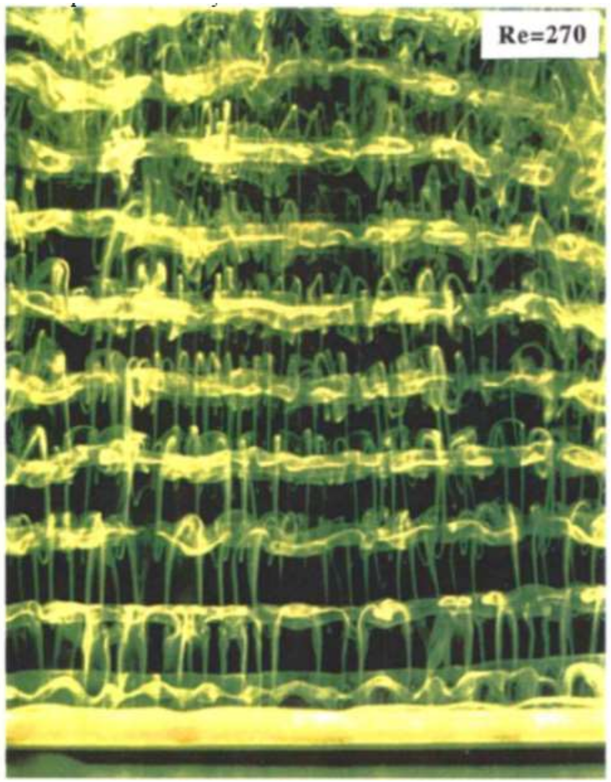
Wake behind a circular cylinder

Onset of three-dimensional Karman vortex shedding (189<Re<300)

Turbulence appears at far downstream (300<Re<1000)



Mode A $\mathrm{Re}_D = 200$

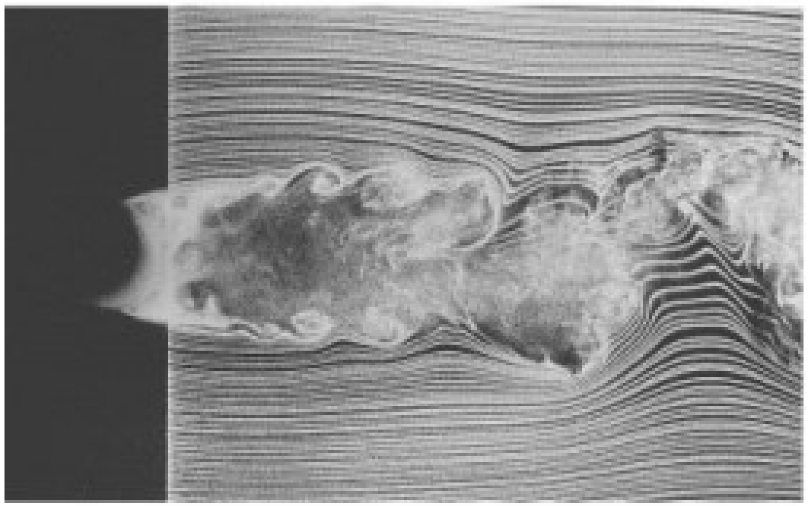


Mode B $\mathrm{Re}_D = 270$

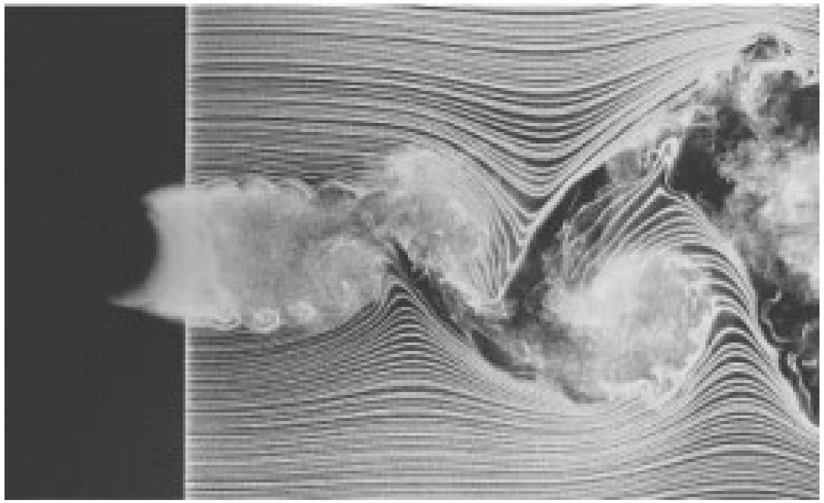
Williamson (1996)

Wake behind a circular cylinder

Instability in separating shear layer (1000<Re<15000)



$\mathrm{Re}_D = 7000$



$\mathrm{Re}_D = 10000$

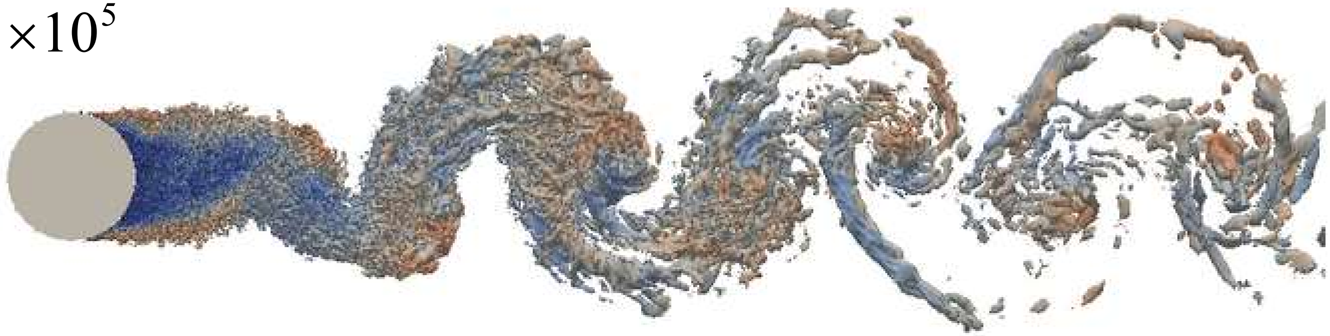
Prasad & Williamson (1997)

Wake behind a circular cylinder

Transition in boundary layer (15000<Re<10^6)

$\mathrm{Re}_D = 2.5 \times 10^5$

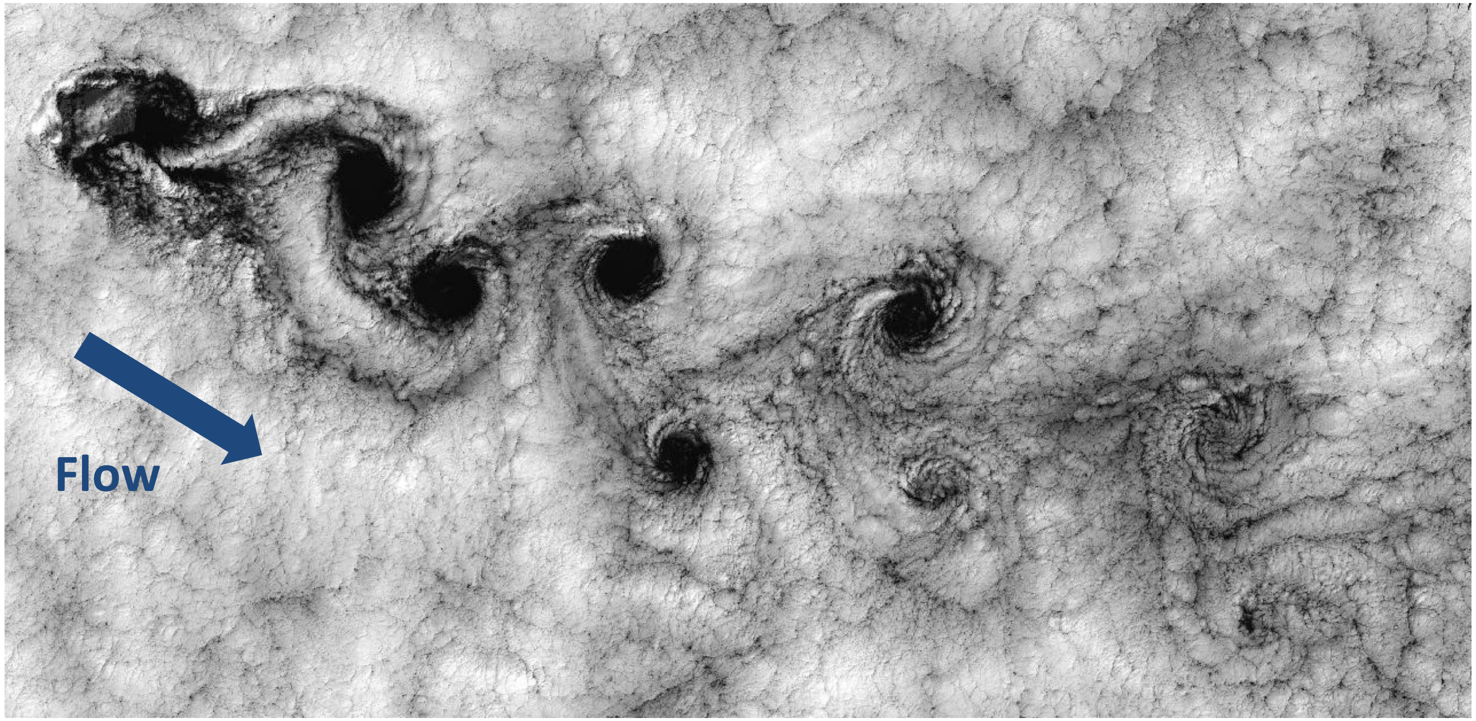
$\mathrm{Re}_D = 5.3 \times 10^5$



Lehmkuhal et al. (2014)

Wake behind a circular cylinder

Fully turbulent everywhere ($Re>10^6$)

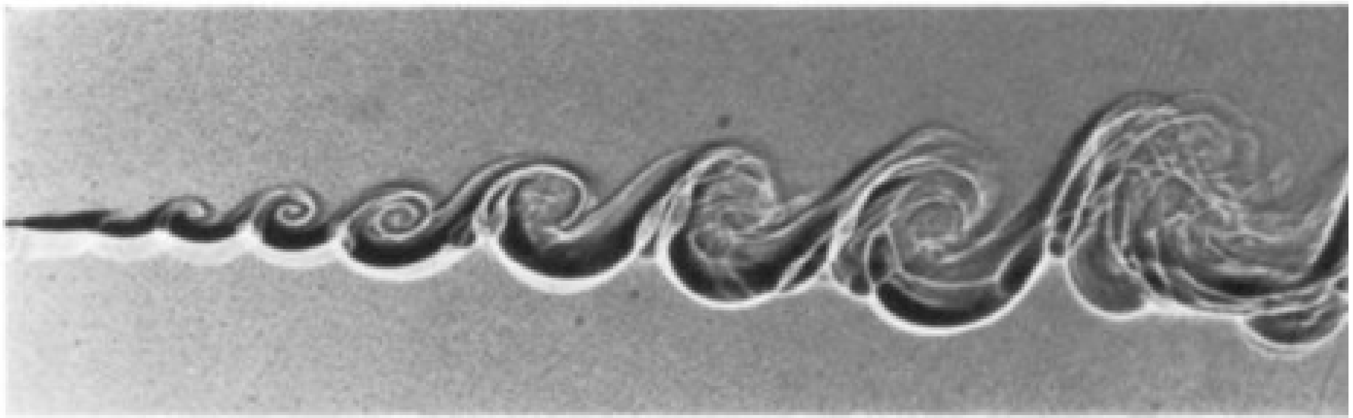


Lecture outline

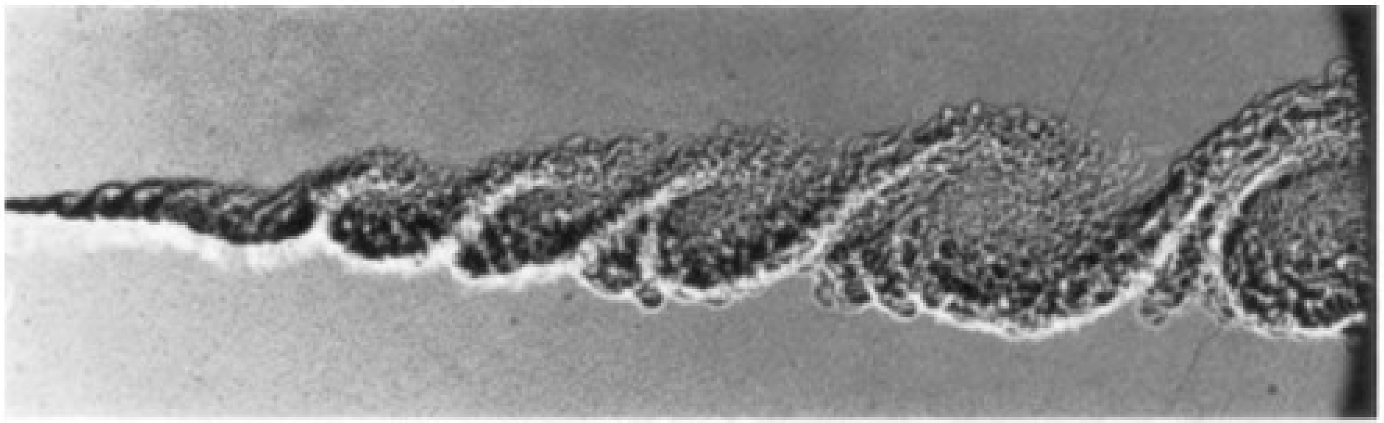
1. Transition in boundary layer
2. Transition in flow over a circular cylinder
3. **Is transition relevant to turbulence?**

Transitional and turbulent mixing layers

Low Re

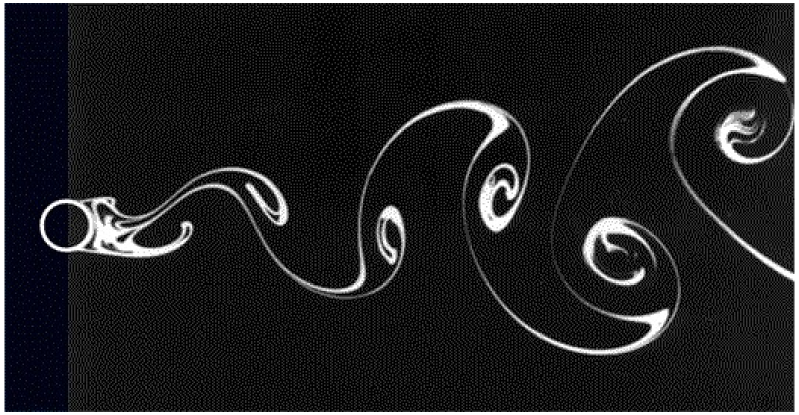


High Re



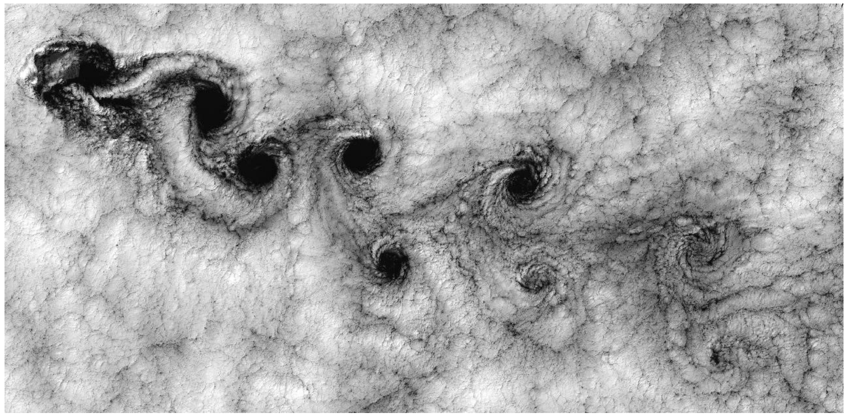
Brown & Roshko (1974)

Laminar and turbulent vortex shedding in bluff body wakes



Low Re

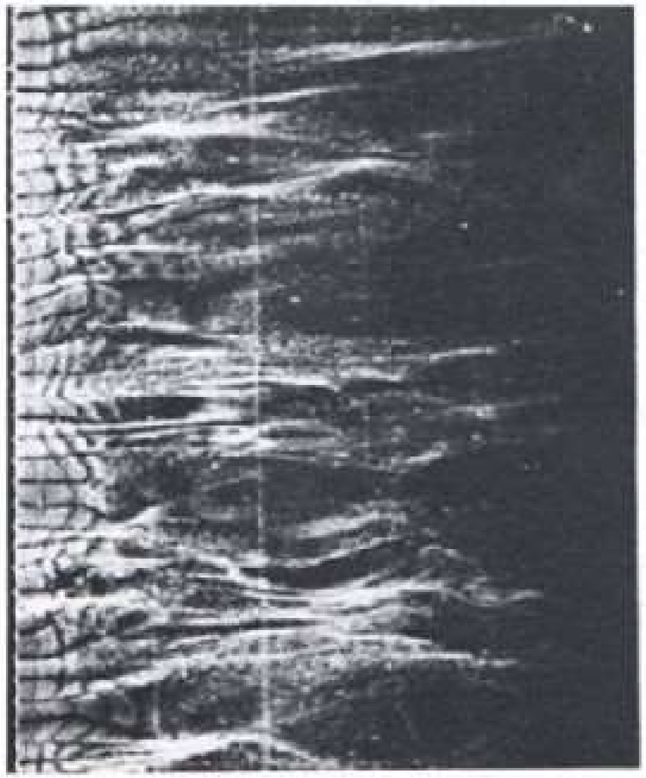
High Re



Boundary layers

Streaks in bypass transition

Matsubara & Alfredsson (2001)



Streaks in buffer layer

Kline et al. (1967)

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