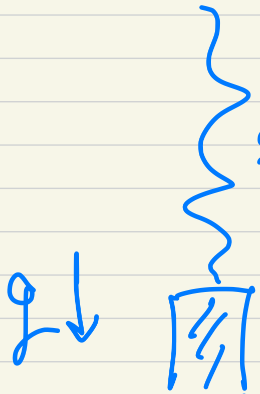
Part I. Fundamentals

Ch. 1 Introduction

1.1 Nature of turbulent flow ⇐ from Tennekes & Lumley's book.

Q: what is turbulence?



Characteristics of turbulent flows

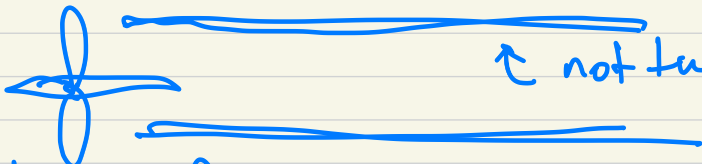
① irregularity (or randomness)

→ This makes a deterministic approach to turbulence problems impossible.

→ Instead, rely on statistical methods

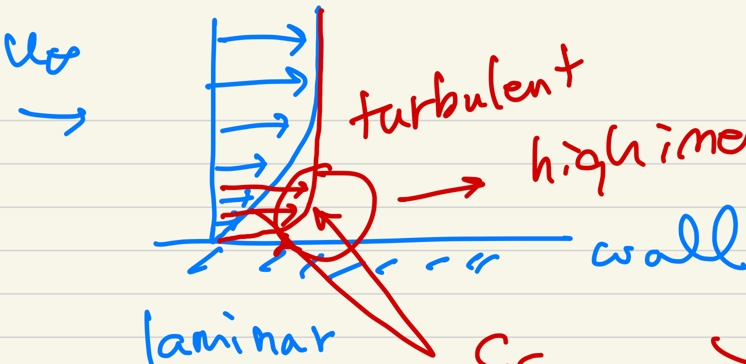
② diffusivity

→ causes rapid mixing and increased rates of momentum, heat and mass transfer.

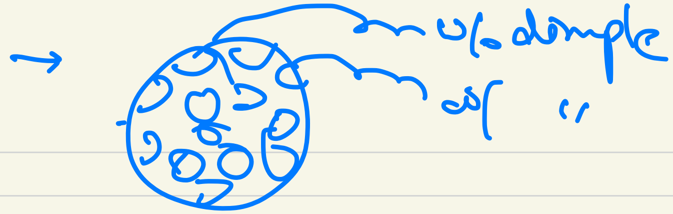


→ diffusivity prevents boundary layer separation on airfoils

" " " " on golf balls.



$C_{f_{turb}} > C_{f_{lam}}$



⇒ This feature is very important in eng. apps.

③ large (high) Reynolds number $Re = \frac{\rho U L}{\nu} = \frac{\rho U^2}{\nu U/L} = \frac{\text{inertia}}{\text{shear stress}}$

→ "nonlinear" interaction → no general sol.!

This makes turbulence research both frustrating and challenging.

④ 3-dimensional vorticity fluctuations

$$\underline{\omega} = \nabla \times \underline{V} \neq 0$$

vorticity velocity

→ turbulence is rotational and 3-dimensional.

$\underline{\omega} \neq 0$ high level of vorticity fluctuations

→ vorticity dynamics is very important.

(u, v, w) — 3D

- 2D velocity field (u, v) ⇒ only one component of vorticity exists.
  $w = 0$
  ↓
  has no vortex stretching → vorticity decays in time.

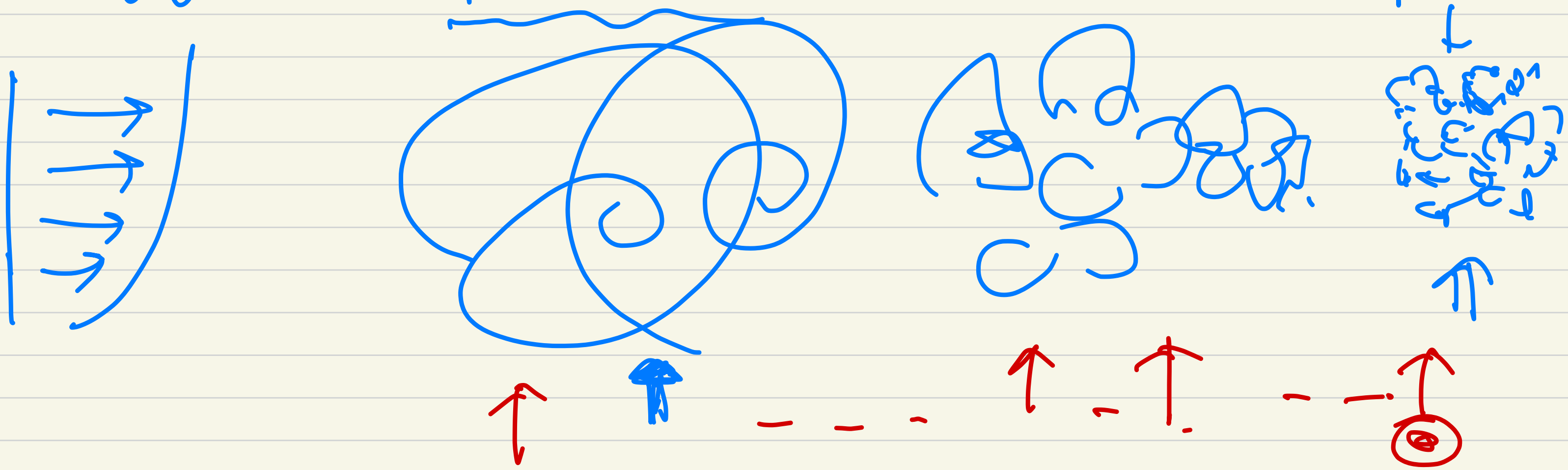
$$\frac{D\omega_j}{Dt} = \omega_i \frac{\partial u_j}{\partial x_i} + \nu \nabla^2 \omega_j \quad : \text{vorticity eq.}$$

$\omega_i \frac{\partial u_j}{\partial x_i} \to 0$ in 2D velocity field

⑤ dissipation

→ turbulent flows are always dissipative.

mean energy → large scale production —energy cascade→ small scale dissipation



⑥ continuum

smallest scale of turbulence >> molecular length scale

⑦ turbulent flows are flows.

→ Not a feature of fluids but of fluid flow.

↑ molecular viscosity — ↑ eddy viscosity

? ft of flow

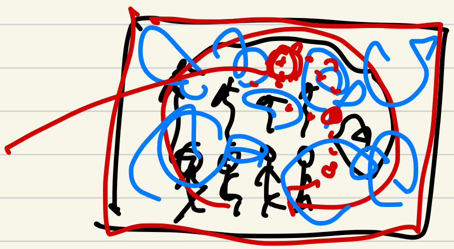
Not " " fluid.

1.2 Study of turbulent flows

• turbulent flow —— large scales ⇐ depends on boundary.

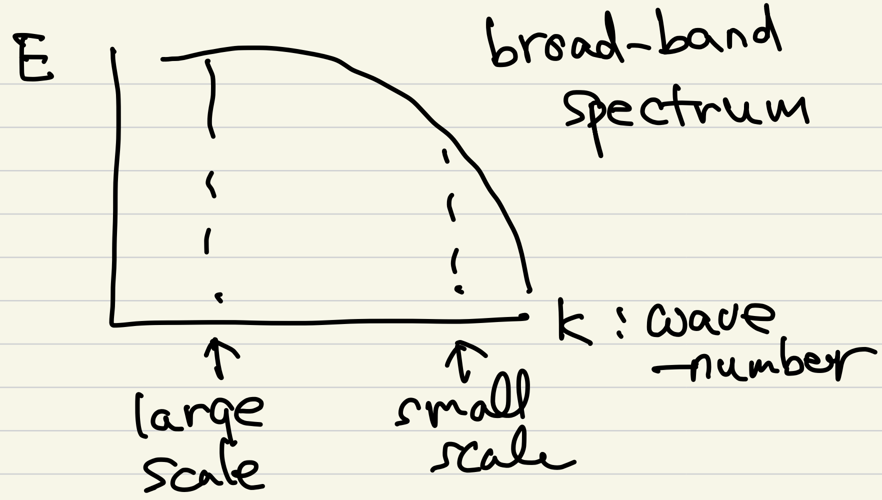
small scales ⇐ has universal character, indep. of flow geometry.

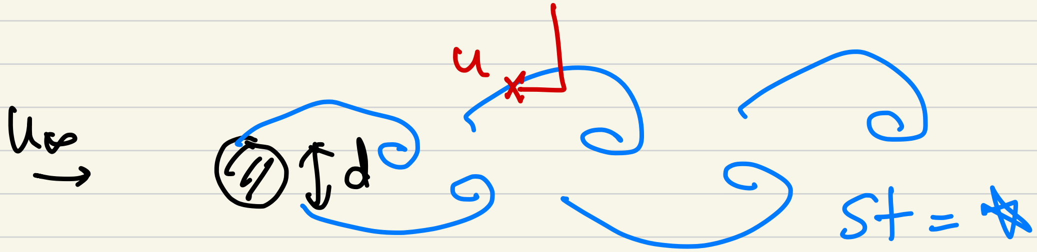
turbulence theory → indep. of flow geometry



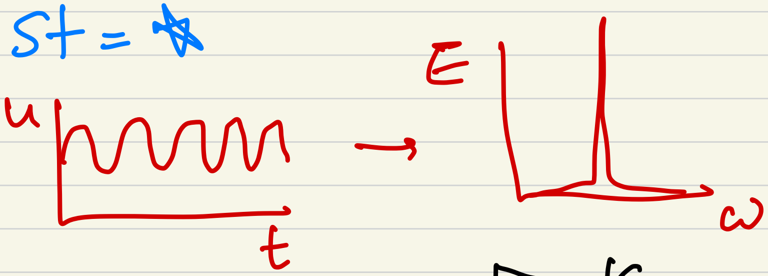
$$u(x,t) \xrightarrow[\text{in } x]{FT} \hat{u}(k,t)$$

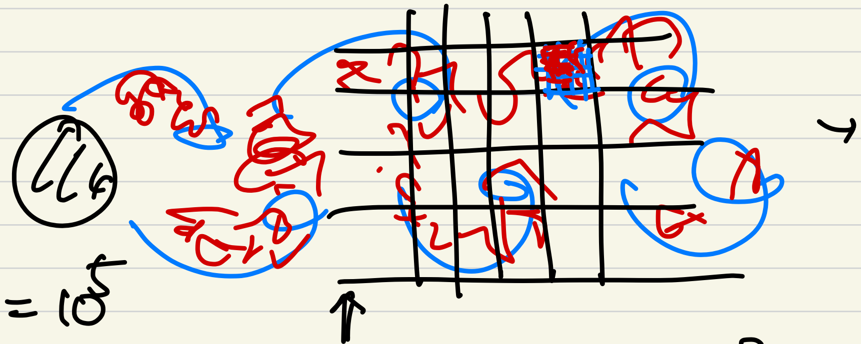
$$E(k) = \hat{u}\,\hat{u}^*$$: energy spectrum



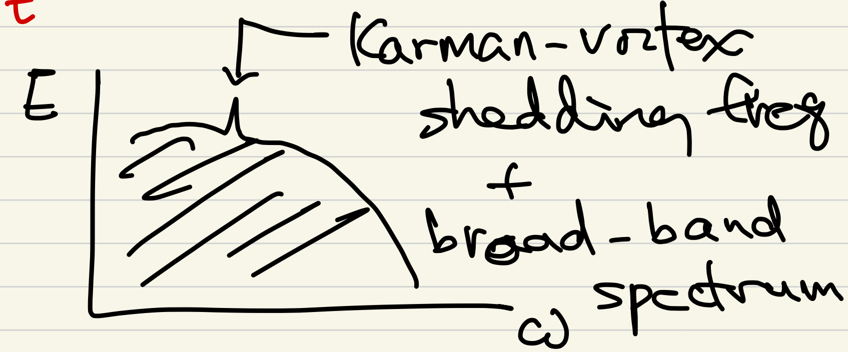


Re = 100 : unsteady laminar flow





Re = 10^5



exp. or CFD
- Reynolds averaged Navier-Stokes eq. (RANS)
- large-eddy simulation
- direct numerical simulation

- Studies on turbulent flows
  - discovery (finding, understanding) → Part 1
  - modeling → Part 2.
  - control

Stop