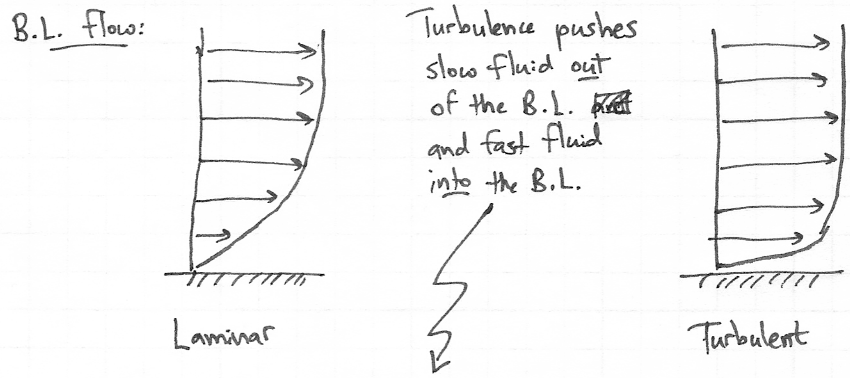
Introduction

Turbulence: The apparent random three-dimensional motion of fluid.

Rough, working definition

Turbulence is of great practical importance because its presence can dramatically change the properties of a flow.

1. Turbulence enhances transport of momentum, energy, or species.



This leads to enhanced drag!

2. Turbulence enhances mixing (i.e., diffusion).

In a stationary or laminar fluid, the radius of a drop of fluid satisfies:

$$\frac{dR}{dt} = \frac{2\gamma}{R}$$

R = radius of fluid drop
γ = diffusion coefficient (10^{-5} cm/s for water)

Thus, for water, the radius doubles after 27 hours!

In a turbulent flow, this occurs much faster.

3. Turbulence delays separation of boundary layers.

→ This leads to reduced drag!

Thus, turbulence sometimes helps and sometimes hurts.

In engineering, there are two main goals in studying turbulence:

1. Prediction of turbulence effects.

2. Control or modification of turbulence.

Though turbulence is difficult to precisely define, turbulent flows have certain defining characteristics. Turbulence is:

1. Three-dimensional and three component,
2. Characterized by a multitude of spatial and temporal scales,
3. Unpredictable or random in its details,
4. Characterized by the presence of "vortical" structures,
5. A 3-D unsteady solution of the Navier-Stokes equations,
6. Characterized by high Reynolds number,
7. Dissipative.

Question: How do we get unpredictable solutions from a deterministic set of equations?

The answer is due to two observations:

1. In any turbulent flow there are unavoidable perturbations in initial conditions, boundary conditions, and material properties.
2. Turbulent flows display an acute sensitivity to such perturbations

Deterministic Chaos

So what can we hope to predict?

1. Statistical properties.
2. Generic features.