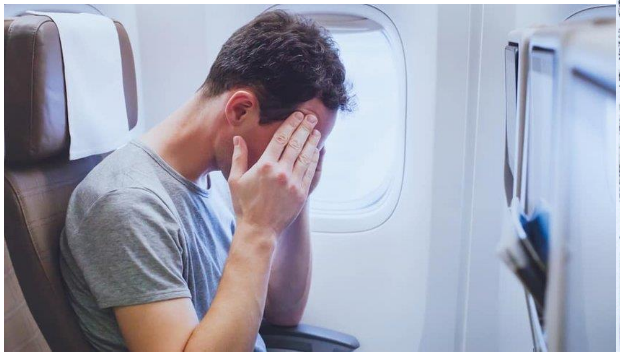
Chapter 6 Introduction Incompressible Turbulent Flow

1. Introduction



It is often claimed that there is no good definition of turbulence (see, *e.g.*, Tsinober [3]), and many researchers are inclined to forego a formal definition in favor of intuitive characterizations. One of the best known of these is due to Richardson [4], in 1922:

Big whorls have little whorls,
which feed on their velocity;
And little whorls have lesser whorls,
And so on to viscosity.

T. von Kármán [5] quotes G. I. Taylor with the following definition of turbulence:

> *"Turbulence is an irregular motion which in general makes its appearance in fluids, gaseous or liquid, when they flow past solid surfaces or even when neighboring streams of the same fluid flow past or over one another."*

Hinze, in one of the most widely-used texts on turbulence [6], offers yet another definition:

> *"Turbulent fluid motion is an irregular condition of the flow in which the various quantities show a random variation with time and space coordinates, so that statistically distinct average values can be discerned."*

Chapman and Tobak [1] have described the evolution of our understanding of turbulence in terms of three overlapping eras: *i*) statistical, *ii*) structural and *iii*) deterministic. We shall further explore this viewpoint in the next section, but here we point out that a more precise definition of turbulence is now possible within the context of ideas from the deterministic era. Namely,

> *"Turbulence is any chaotic solution to the 3-D Navier–Stokes equations that is sensitive to initial data and which occurs as a result of successive instabilities of laminar flows as a bifurcation parameter is increased through a succession of values."*

Modern definition superior as (1) specifies equations; (2) requires random behavior described by deterministic equations; (3) requires three dimensionalities; and (4) sensitivity to initial conditions.

2. Historical Background

Three eras of turbulence studies: http://web.engr.uky.edu/~acfd/lctr-notes634.pdf

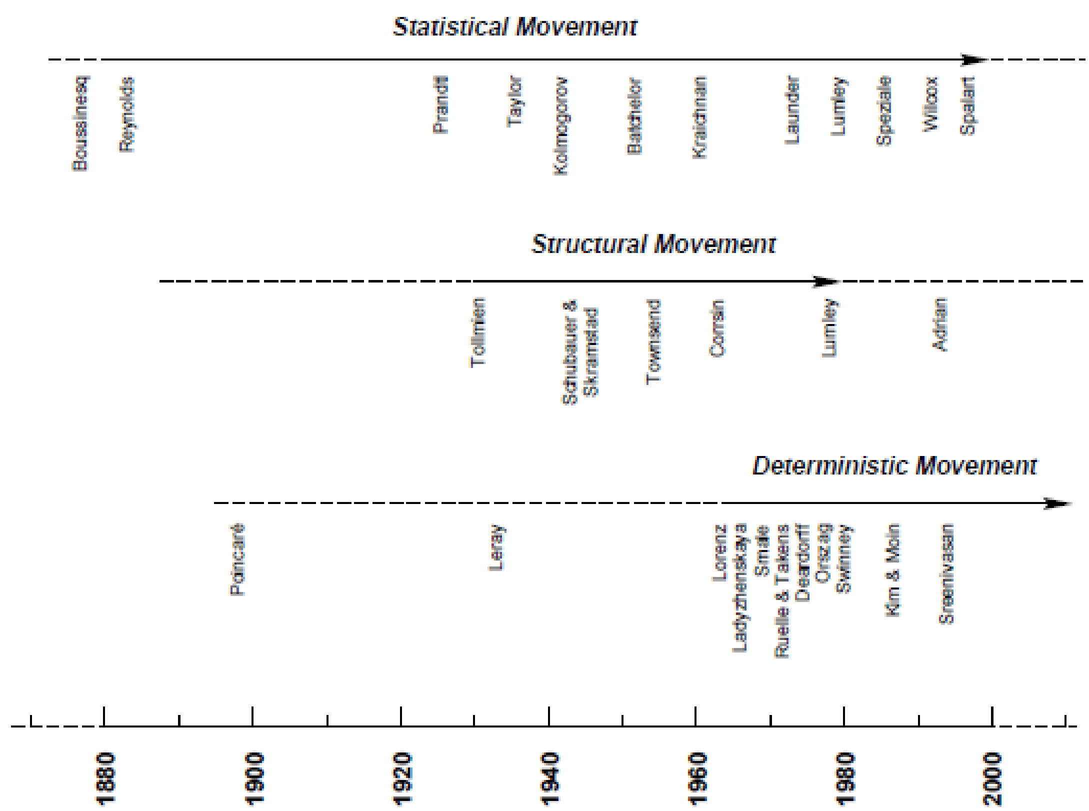


Figure 1.3: Movements in the study of turbulence, as described by Chapman and Tobak [1].

Structural movement: coherent structures and short bifurcation sequences

Statistical movement: uses statistics via systematic approximations to the averaged “unclosed equations” or by intuition and analogy.

Deterministic movement: The idea of the deterministic turbulence has been suggested about a decade ago. In contrast to the usual (random) turbulence, the deterministic turbulent flows have reproducible instantaneous structure, representing one particular-realization from infinite number of possible ones.

3. Basic Concepts
    a. Randomness and fluctuations
    b. Nonlinearity
    c. Diffusion
    d. Vorticity/eddies/energy cascade
    e. Dissipation
    f. Example Experimental Data for Wall Flows
    g. Closure Problem and Arrow of Time
4. Averages, Correlations and Spectra
5. Instantaneous and RANS Equations
    a. Summary of RS and TKE for Different Flows
6. Scales of Turbulence
7. Free Shear Flows
    a. Free Shear Flow Coherent Structures
8. Wall Flows
    a. Wall Flow Coherent Structures
9. Turbulence Modeling (Abstract)
    a. RANS Modeling
    b. LES Modeling
    c. Hybrid RANS LES Modeling
10. DNS