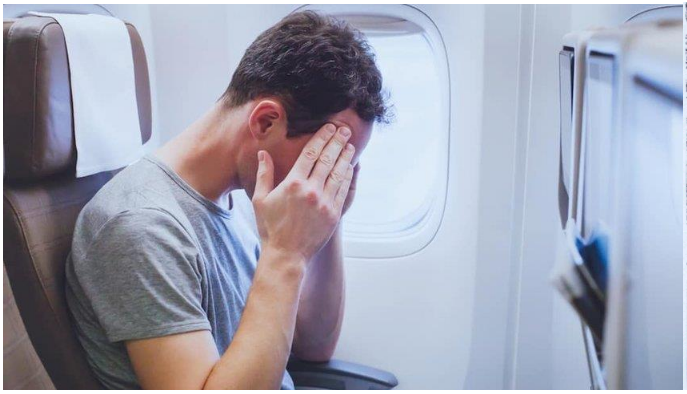
Chapter 1 Introduction

1. Definition of turbulence



Airplane turbulence: not just when bumpy ride due large scale natural atmospheric turbulence, but also in BL and near wake even for smooth ride, which highlights the wide range of the scales of turbulence both in space and time.

Leonardo was able observe this fact and process. His very interesting notebooks: mirror writing, not always complex ideas and questions but also repetitive writing, as he was self-educated; and truly, at least in my mind, genius of all geniuses. Concerning turbulence he posed the questions: (1) where in the water is the turbulence generated; (2) where does the turbulence in the water persist for a long time: and (3) where does the turbulence in the water come to rest.

We now know turbulence originates at the large scales driven by source mechanism and then undergoes Richardson cascade whereby it continuously breaks down to smaller and smaller eddies from the energy containing range to the inertial sub range to the dissipation range.

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.

Key concepts:

1. random state with coherent statistically deterministic structures
2. nonlinearity which is main driver of wide range of scales
3. many flows have Re similarity for the larger scales
4. rotational and three dimensional
5. faster larger dispersion/diffusion/mixing momentum, heat, material vs. laminar flows
6. Analogy molecular diffusion driven by random molecular motions, which defines viscosity, but in the case of turbulence due turbulence fluctuation over a wide range of scales.

Tools of analysis:

1. mathematical physics and statistical analysis
2. dimensional analysis
3. scaling analysis
4. experimental and numerical methods.

2. Historical background

Three eras of turbulence studies:
https://uknowledge.uky.edu/me_textbooks/2/

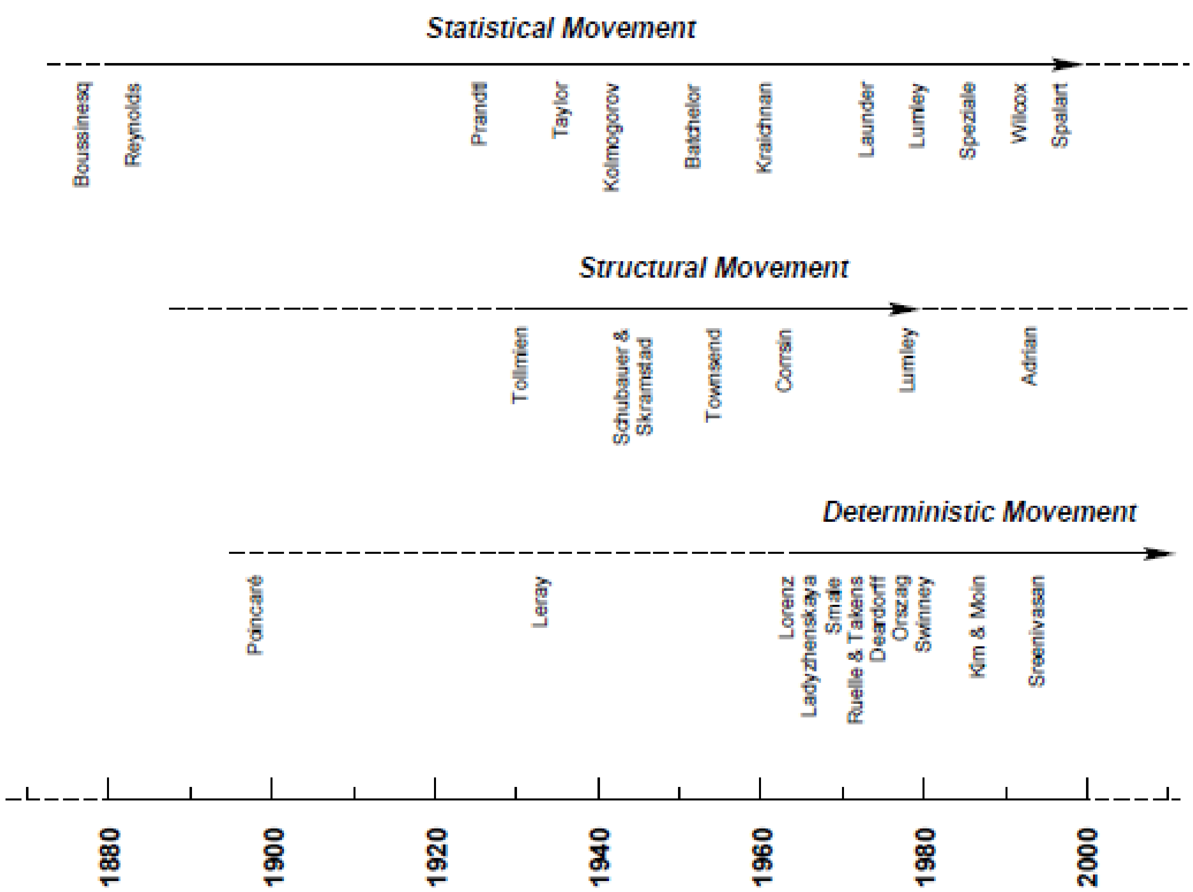
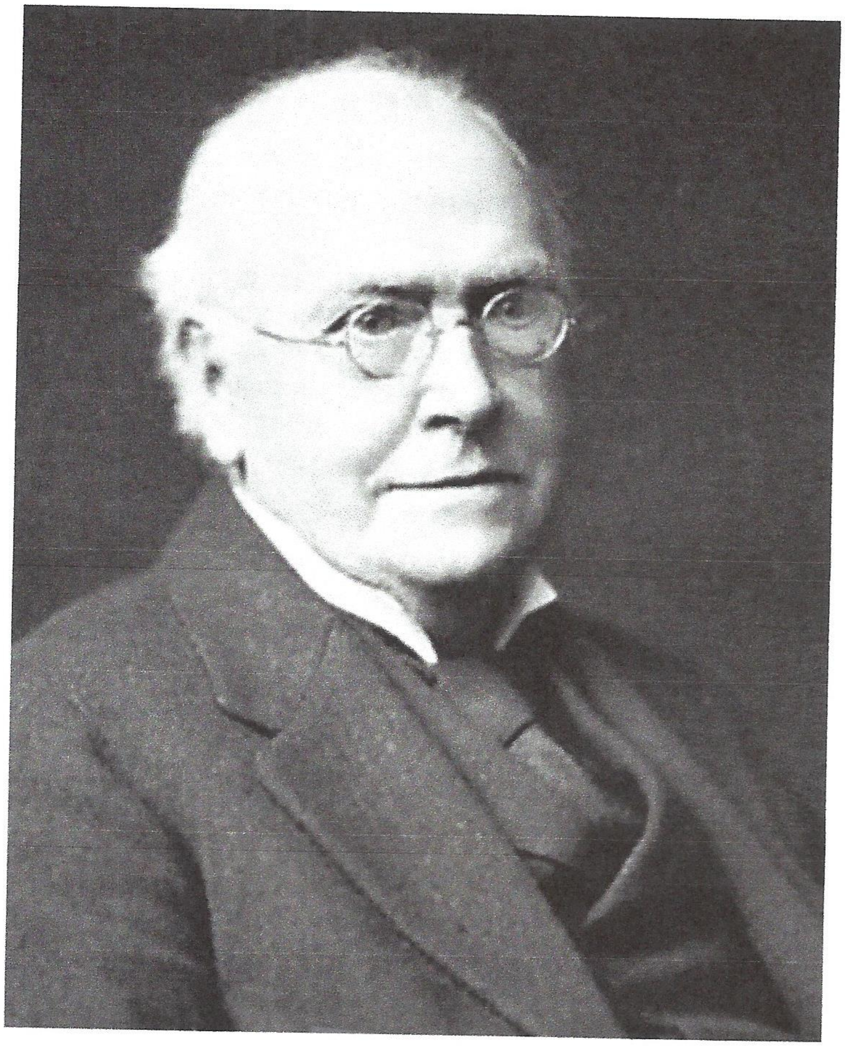


Figure 1.3: Movements in the study of turbulence, as described by Chapman and Tobak [1].

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.



SIR HORACE LAMB

Sir Horace Lamb (1849–1934) is best known for his extremely thorough and well-written book, *Hydrodynamics*, which first appeared in 1879 and has been reprinted numerous times. It still serves as a compendium of useful information as well as the source for a great number of papers and books. If this present book has but a small fraction of the appeal of *Hydrodynamics*, the authors would be well satisfied.

Sir Horace Lamb was born in Stockport, England in 1849, educated at Owens College, Manchester, and then Trinity College, Cambridge University, where he studied with professors such as J. Clerk Maxwell and G. G. Stokes. After his graduation, he lectured at Trinity (1822–1825) and then moved to Adelaide, Australia, to become Professor of Mathematics.

After ten years, he returned to Owens College (part of Victoria University of Manchester) as Professor of Pure Mathematics; he remained until 1920.

Professor Lamb was noted for his excellent teaching and writing abilities. In response to a student tribute on the occasion of his eightieth birthday, he replied: "I did try to make things clear, first to myself . . . and then to my students, and somehow make these dry bones live."

His research areas encompassed tides, waves, and earthquake properties as well as mathematics.