ESSENTIALS OF TURBULENCE - Assignment 1
Film Notes on Turbulence

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1 Introduction

The word "Turbulence" gives a sense of something disorderly, something which looks random. Despite being so difficult to define, turbulence is something really ubiquitous. Effective mixing is one of the key characteristics of turbulent flows. These flows are greatly irreproducible in nature, and have vorticity distributed non-uniformly in all the three dimensions. Thus, the three dimensional nature of turbulent flows is yet another speciality of turbulent flows. Two dimensional flows, having scalar voriticity are not really turbulent.

2 Quantifying Turbulence

Certain experimental observations led to some reasoning behind the kind of flows which behave in a turbulent manner. A low viscosity fluid is more likely to have a time dependent irregular flow at a velocity similar to that of a highly viscous fluid. At sufficiently low viscosities, the pressure drop no longer decreases and starts increasing, indicating the turbulent nature of the flow.

As experimentally established by Osborne Reynolds, the onset of turbulence depends upon what we know as the "Reynolds Number", a dimensionless function of the flow parameters. The Reynolds number indicates that a higher flow velocity and a higher flow geometry diameter push forward the turbulent nature of flows.

Although the Reynolds number has different values for different setups; still for lower values (< 2000), the flow is dominated by viscous forces and hence, does not become turbulent. At intermediate values of Reynolds number ($< 10{,}000$), it is possible to maintain the laminar nature of the flow by reducing perturbations effectively.

3 Mixing

The low Reynolds number flows only experience molecular mixing, which is very slow. As the Reynolds number is increased; perturbations initiate, and at the onset of turbulence, rapid mixing happens in the system. The increasing pressure drop can be visualised as a mixing of momentum. Turbulence, thus increases the rate of momentum transfer to the walls, thus requiring a greater pressure gradient for compensation.

4 Turbulent Transport and Reynolds Stress

Turbulence causes appreciable amount of cross-stream motion, and thus the cross movement of properties also takes place. This is termed as *turbulent transport*, which occurs whenever there is some gradient of a mean property. The advection terms give rise to Reynolds Stresses, and decomposition of flow velocity into the mean and fluctuating part results in a non-linear N-S equation, difficult to solve analytically.

5 Fully Developed Turbulent Flows

Once the flow becomes turbulent, the Reynolds number fails to provide sufficient insight in case of large scale motions. However, a higher Reynolds number jet has a finer small scale structure than the other. This is related to the dissipated energy. For same energy dissipation, a greater viscosity fluid has a greater characteristic scale.

6 Energy Cascade and Small Scale Similarity

When a large scale motion becomes turbulent, some of its energy is converted into turbulent energy. These larger scales, being unstable, break into smaller scales transferring energy to the smaller scales. Once the scales are small enough, viscosity takes over and dissipates the energy.

The small scales lose all of their directional behaviour at high Reynolds number and becomes locally isotropic. Also, the small scale structures do not have any correlation with the nature of large scale flow. The small scales behave similarily for all kinds of turbulence. The Reynolds number is also a quantification of the ratio of the size of the largest scales to the smallest scales.

7 Buoyancy and Turbulence

Sometimes, even for huge values of Reynolds numbers, the flow is still not turbulent. One of the contributor to this are the buoyancy effects. For setups with lower density fluids on the upper region, the buoyancy effects oppose the cross stream motions. This occurs in the atmosphere and is commonly known as *inversion.*

8 Small Scale Intermittency

Turbulent flows are more complicated than Gaussian random processes. Even if the large scale motion assumes a Gaussian form, the properties depending on the small scale motions follow non-Gaussian characteristics. This seems to be one of the fundamentals of the turbulent energy cascade nature.