CFD Turbulence

Lecture 18

ME EN 412
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Outline

Turbulent Length Scales

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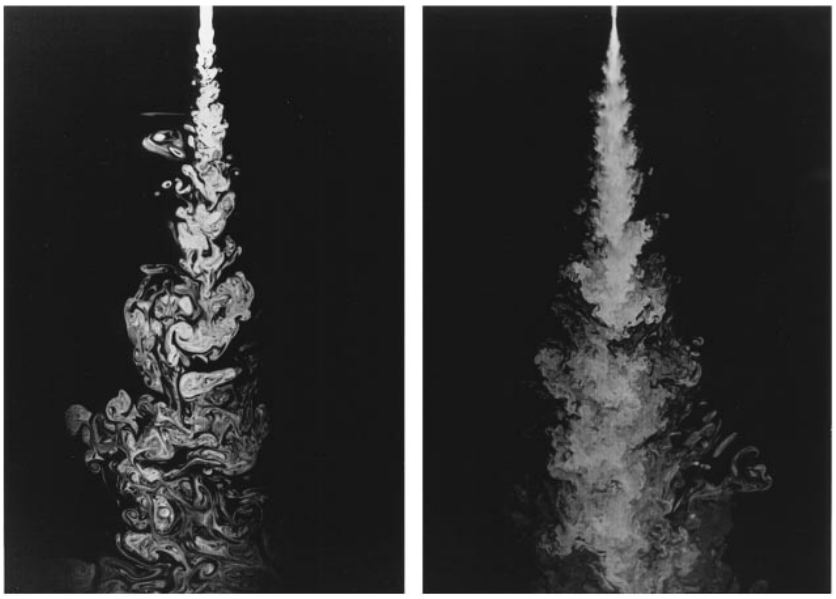

Re = 2,500 Re = 10,000

The mixing transition in turbulent flows, Paul E. Dimotakis

Direct Numerical Simulation (DNS)

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In a DNS simulation, the Navier-Stokes equations are solved without any turbulence modeling, meaning that all spatial and temporal scales are resolved.

Example: YouTube

Reynolds Averaged Navier Stokes

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$$\langle X \rangle = E[X] = \int_{-\infty}^{\infty} x f(x) dx$$

where $f(x)$ is a probability density function.

for a discrete variable we would express this as

$$\langle X \rangle = \sum_{i=1}^{\infty} x_i p_i$$

Reynolds decomposition

$$u = \langle u \rangle + u'$$

Example: 2D Incompressible Navier Stokes

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

$$\rho\left(\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right)$$

With time averaging:

$$\frac{\partial \langle u\rangle}{\partial x} + \frac{\partial \langle v\rangle}{\partial y} = 0$$

$$\rho\left(\langle u\rangle\frac{\partial \langle u\rangle}{\partial x} + \langle v\rangle\frac{\partial \langle u\rangle}{\partial y}\right) = -\frac{\partial \langle p\rangle}{\partial x}$$
$$+ \frac{\partial}{\partial x}\left(\mu\frac{\partial \langle u\rangle}{\partial x} - \rho\langle u'^2\rangle\right) + \frac{\partial}{\partial y}\left(\mu\frac{\partial \langle u\rangle}{\partial y} - \rho\langle u'v'\rangle\right)$$

and similarly, for the y-equation

Reynolds stresses

Note the new terms of the form

$$-\rho V_i V_j$$

Large Eddy Simulation

Large Eddy Simulation

Example: YouTube