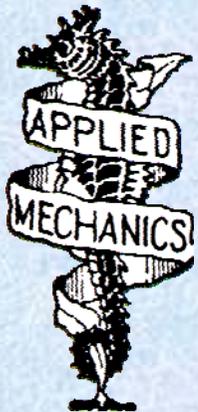


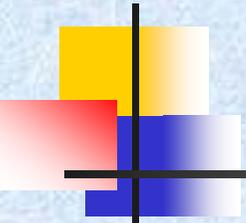
Introduction of the Fluid Dynamics

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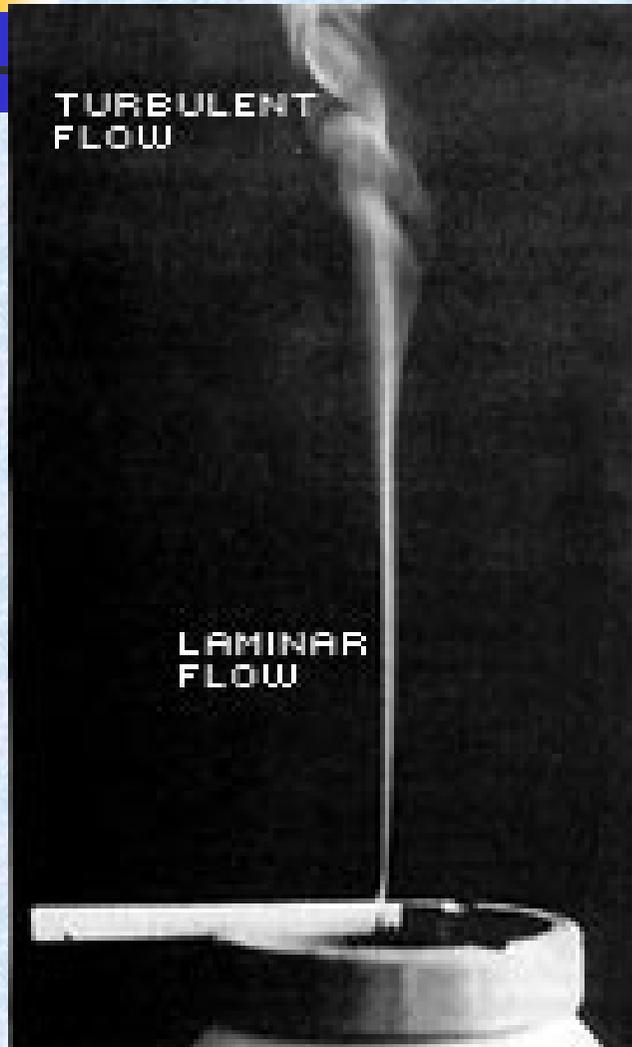


What is Fluid ? What is Flow ?

- ◆ Let us first define the meaning of **fluid** and **flow**.
- ◆ A liquid, gas, air, and blood etc is all **fluid**.
- ◆ **Flow** is the continuous movement of a fluid from one place to another place.

What is Laminar Flow ?

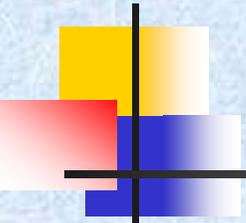
What is Turbulent Flow ?



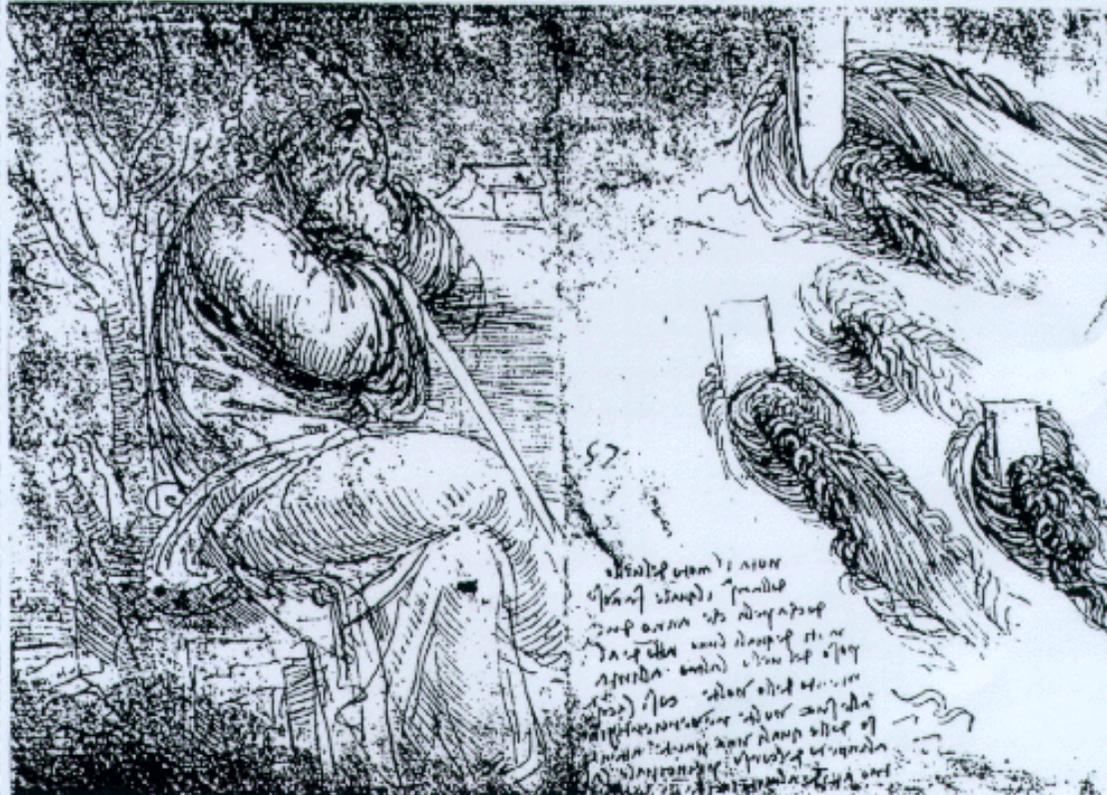
Smoke rising from cigarette



Rapids



Research in Turbulence



The first person that described and studied turbulence was probably Leonardo da Vinci (1452-1519).

Where does Turbulent Flow occur ?

Here are a few examples of turbulent flows:

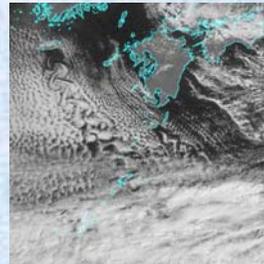
1. The wake of a ship or submarine is turbulence.
2. The swirls and eddies in a fast flowing river are turbulence.
3. The air currents in the atmosphere are turbulence.
4. Turbulence was observed when volcano erupts.
5. The outer layer of the Sun, i.e. the convection zone, is highly turbulence.



Wake of submarine



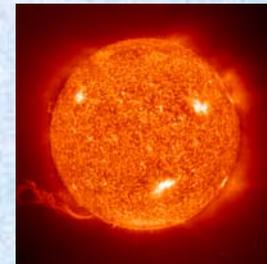
Rapids



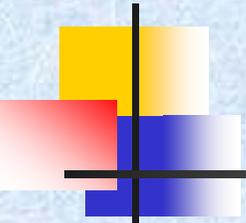
Air currents
In the atmosphere



Eruption



The sun



What is Incompressible ? What is Viscous ?

- ◆ **Incompressible** : Neither compression nor the expansion are done, and the density (mass) does not change.
- ◆ **Viscosity** : All the existing fluids (water and air etc) have the character of the viscosity.

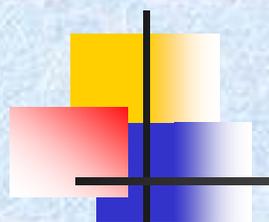
What is Bluff Body Flow ? ①



Karman vortex street behind a cylinder placed in uniform flow.
Re ~ 300 [Courtesy: Sadotoshi Taneda; from An Album of Fluid Motion by Van Dyke (1982)]

Scale : Very Small

Application of FDM to CFD

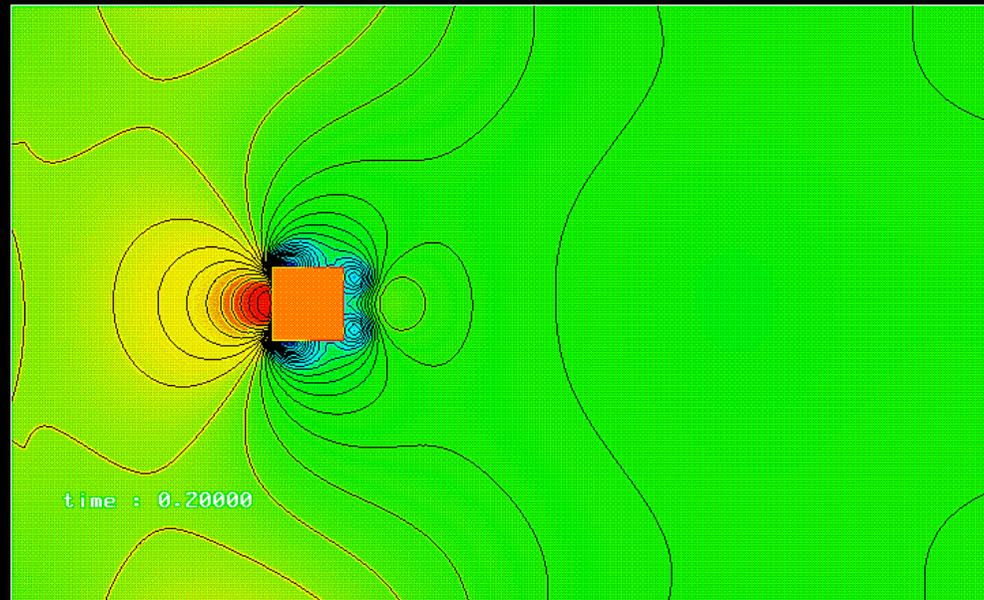

$$\left[\begin{array}{l} \frac{\partial u_i}{\partial x_i} = 0 \\ \frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{\text{Re}} \frac{\partial^2 u_i}{\partial x_j \partial x_j} \end{array} \right.$$

Continuity equation

Navier-Stokes equation

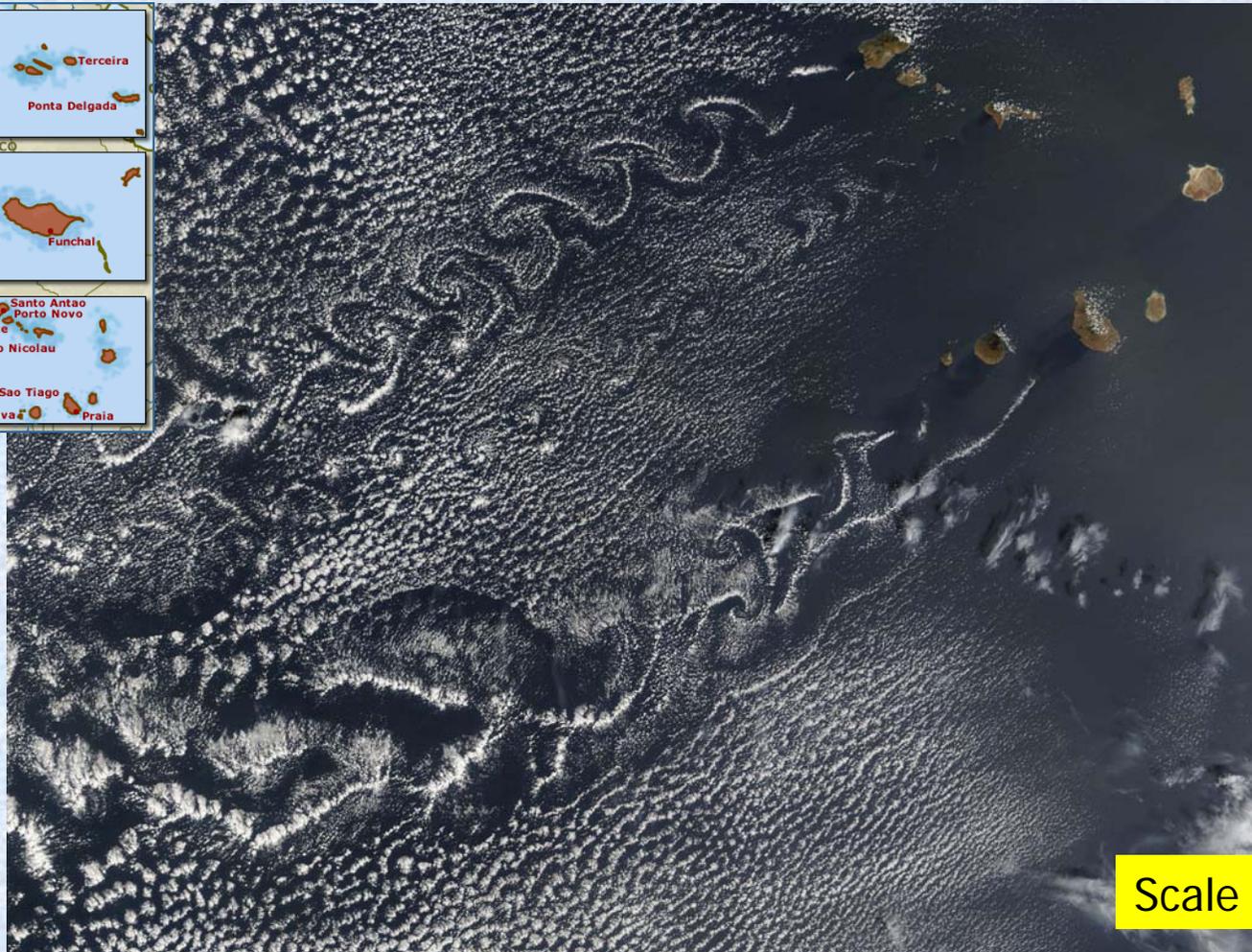
Temporal term Convective term Pressure Gradient term Viscous term

Re : Reynolds number



A DNS of flow past a square cylinder at $Re=1000$.
This code is based on a Cartesian uniform staggered grid (151*91 mesh).
The Sommerfeld Radiation Condition is used for the outflow boundary.

What is Bluff Body Flow ? ②



Scale : Very Large

Credit Jeff Schmaltz

Low-level winds rushing over the Cape Verde Islands off the coast of northwestern Africa created cloud vortex streets, as seen in this true-color Terra MODIS image from January 5, 2005. The vortex streets tend to create patterns of swirls and curves in a roughly symmetrical pattern, though as can be seen here, the lower vortex street is much more disorganized - to the point that the typical features are almost unrecognizable. Cloud vortices are also known as von Karman vortices