ME 6125: Mechanics of Viscous Fluid

- 3.00 credit hours (Sunday: 4:30-6:00 PM; Wednesday: 7:30-9:00 PM)
- **Course content**

  Equations of motion for viscous fluid;

  boundary layer analysis for laminar and turbulent flow;

  theories of turbulence;

  jet, wakes and separated flows.

- **Course teacher**

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ME 6125: Mechanics of Viscous Fluid

Assessment

1. Assignment	20%
2. Presentation	20%
3. Final Exam:	60%

Presentation

- Selected from a journal
- The following Journal paper have to be used
  - Journal of Fluid Mechanics
  - Physics of Fluids,
  - ASME journal.
  - Physical Review

ACADEMIC OFFENCES

Students must write their assignments in their own words.

If students take an idea, or a passage of text from book, journal, web etc, they must acknowledge this by proper referencing such as footnotes or citations.

Plagiarism is a major academic offence.

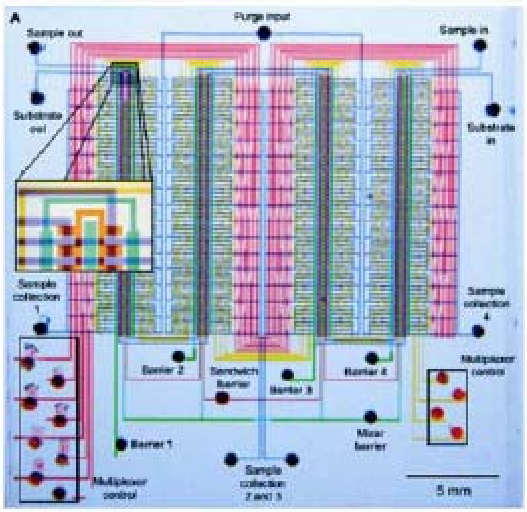
Fluid Dynamics: an introduction

- The science of fluid dynamics describes the motion of liquids and gases and their interaction with solid bodies.
- It is a broad, interdisciplinary field that touches almost every aspect of our daily lives, and it is central to much of science and engineering.
- Fluid dynamics impacts defense, homeland security, transportation, manufacturing, medicine, biology, energy and the environment.
- Predicting the flow of blood in the human body, the behavior of microfluidic devices, the aero-dynamic performance of airplanes, cars, and ships, the cooling of electronic components, or the hazards of weather and climate, all require a detailed understanding of fluid dynamics, and therefore substantial research.

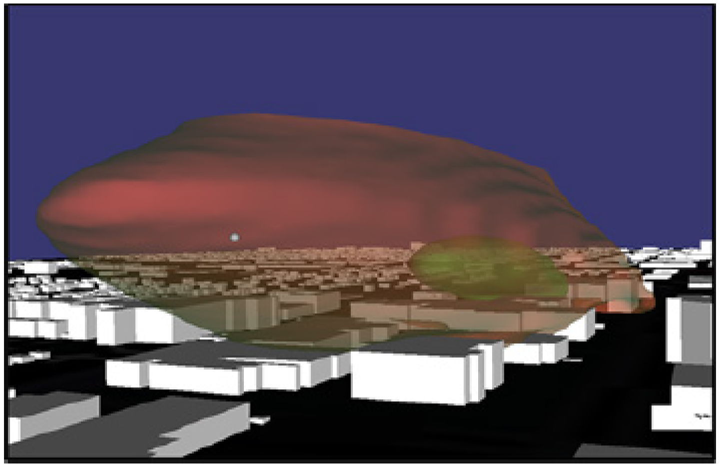
Fluid Dynamics: an introduction

- The governing equations describing the fluid motions in a physical system are the Navier-Stokes equations.
  - have no general analytical solution, and
  - computational solutions are challenging.

Fluid Dynamics: an introduction



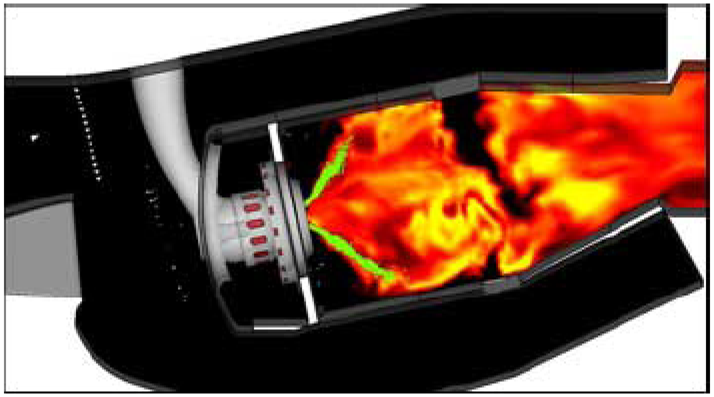
Microfluidic device containing 2056 integrated channels (Thorsen et al., Science, 2002). Such devices are revolutionizing biomedical science.



Nested model simulation of a toxic vapor plume in Oklahoma City.

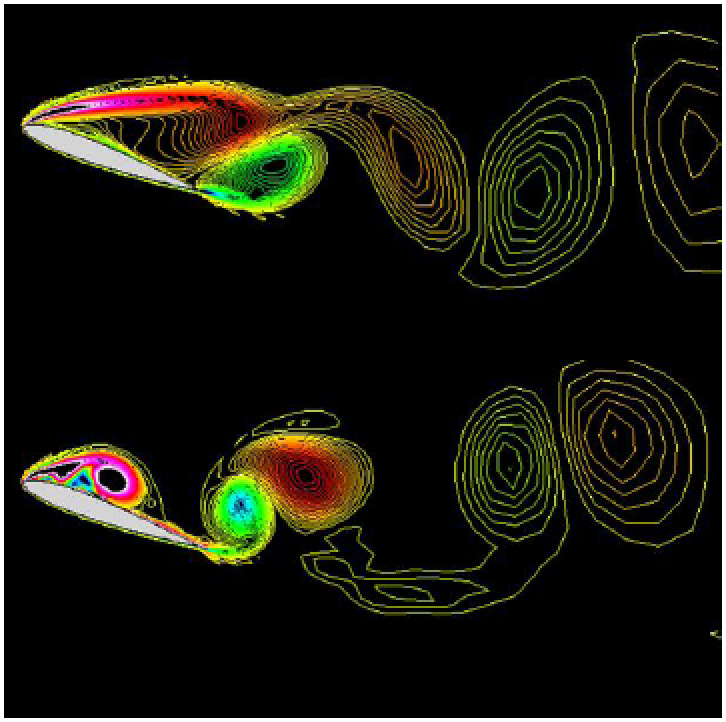
Fluid Dynamics: an introduction

Computer simulation of the turbulent wake behind a truck (Fluent, Inc.).

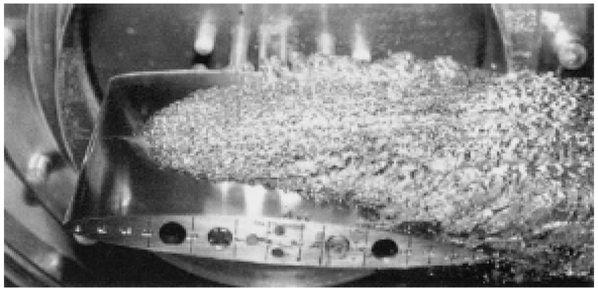


Computer simulation of a gas turbine combustor, showing the fuel spray (green) (Stanford Uni-versity).

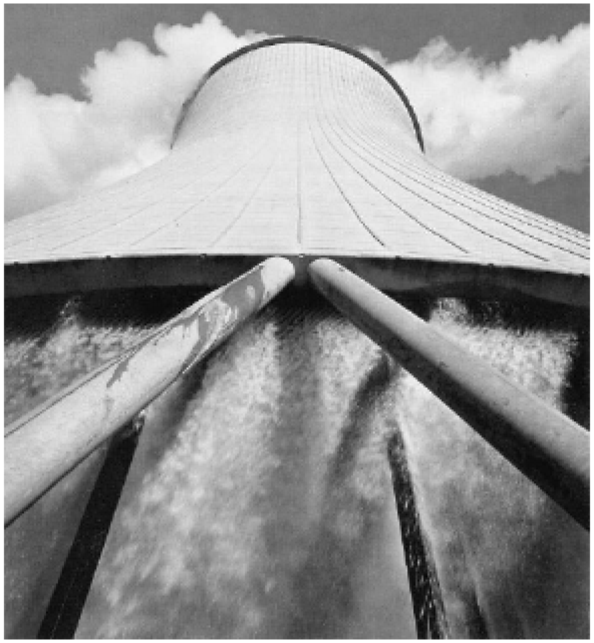
Fluid Dynamics: an introduction



Flow separation on an airfoil at a high angle of attack can be delayed by periodic blowing and suction through small holes, to reduce drag. Top, uncontrolled; bottom, controlled (S.-C. Huang and J. Kim,UCLA).

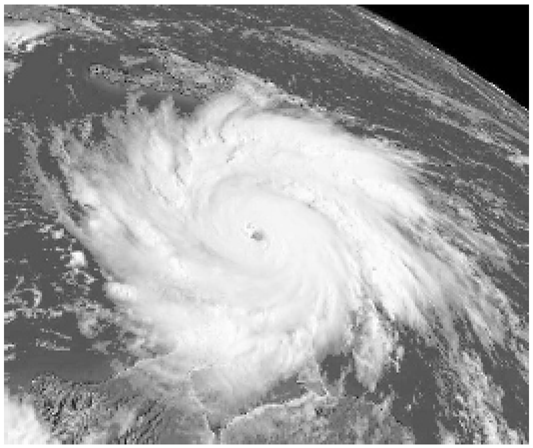


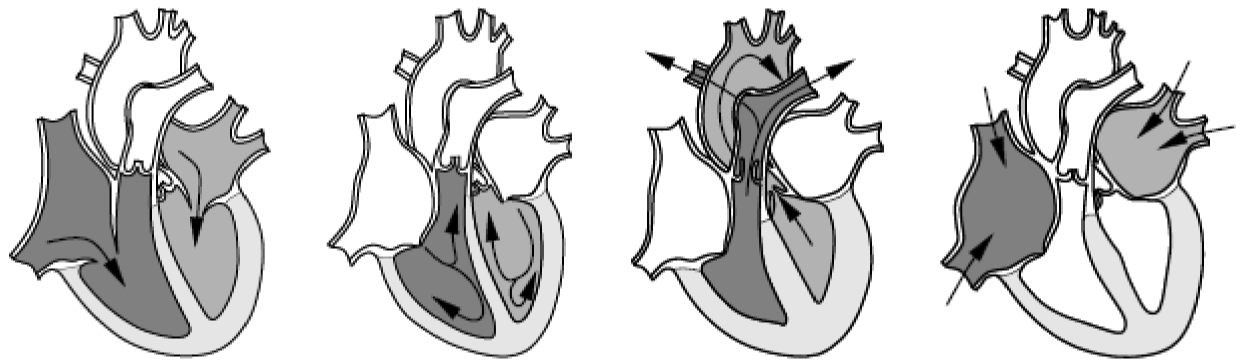
Cavitation at an underwater foil



Wet cooling tower

Fluid Dynamics: an introduction



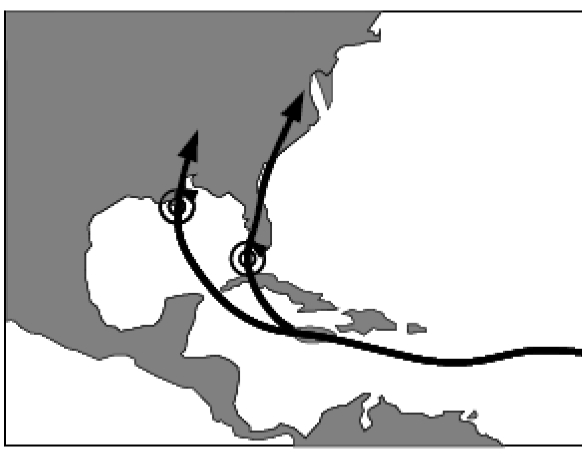


inward flow
mitral valve open

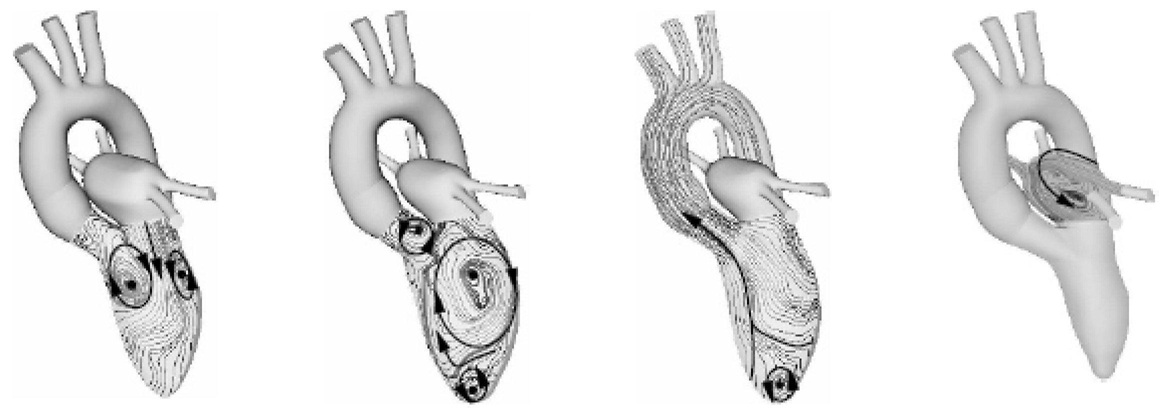
ventrical conctraction

outward flow
aortic valve open

ventrical relaxation



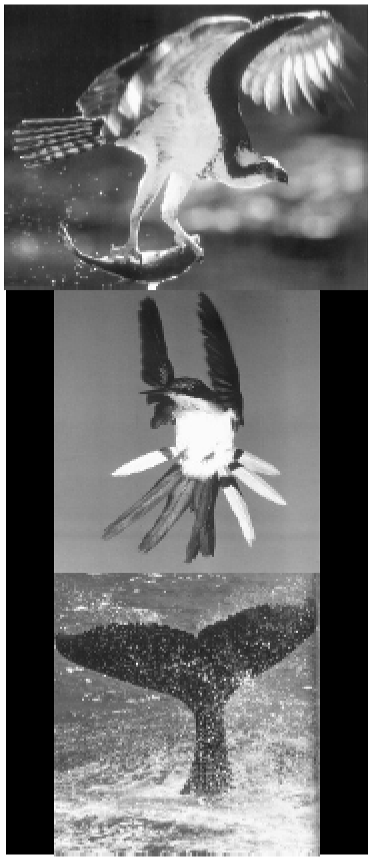
Path of Hurricanes

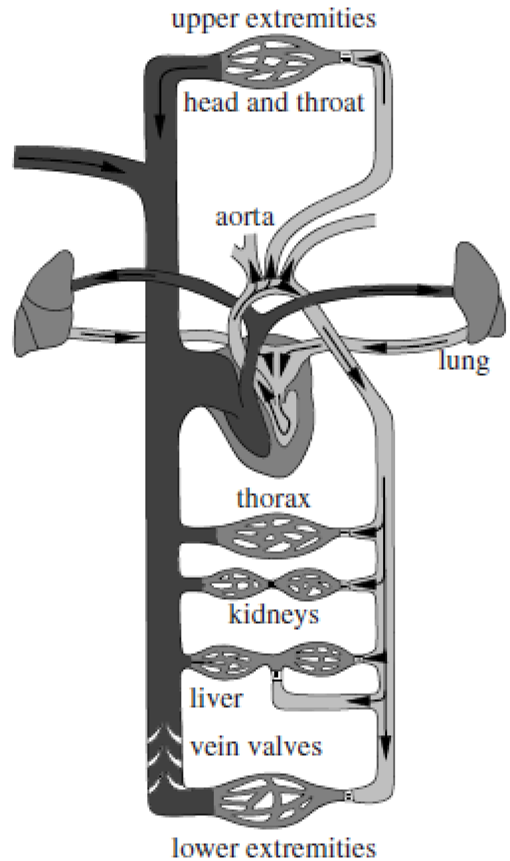


Flow simulation of the left heart ventricle, atrium and aorta

Flow of the human heart

Fluid Dynamics: an introduction





Flight and swimming motion of animals

Blood circulation in the human body

Fluid Dynamics: an introduction

- The outcomes from this future research will have enormous impact.
- For instance, they will
  - lead to improved predictions of hurricane landfall and strength by understanding the mechanisms that govern their formation, growth, and interaction with the global weather system.
  - speed the development of fusion power by helping to understand and control the instabilities that currently limit the energy densities that are achieved.
  - lead to more efficient vehicles, by reducing the friction between the vehicle surface and the surrounding air.
  - lead to a new generation of microscale devices that will include combustors to replace batteries, advanced flow control devices to cool electronic systems, and labs-on-a-chip to manipulate and interrogate DNA. Already, the number of channels in micro-fluidic devices is growing at a rate faster than the exponential growth in electronic data storage density.

Fluid Dynamics: an introduction

References

- RESEARCH IN FLUID DYNAMICS: Meeting National Needs,
  A Report of the U.S. National Committee on Theoretical and Applied Mechanics
  Winter, 2006. www.usnctam.org

- Prandtl–Essentials of Fluid Mechanics. Editor: Herbert Oertel, 2010, Springer.

Fluid as a Continuum

- When we deal with fluid motion, in many fluid engineering cases the dynamics of a molecule, or the molecular structure of the fluid body, does not explicitly come into effect.
- At the scale of molecular motion, properties of the fluid body, such as density, are typically subject to extreme variation with respect to the instantaneous distance of the frame.
- While, for the motion of fluid flow, the macro-motion with the scale of flow channel or external object takes place, thus we may apply the "continuum hypothesis", with which the fluid body has a continuous structure in the instantaneous frame of space, as schematically indicated in Fig. 1.1.
- let us denote
  - L_m *as the small scale (molecular scale), which can be taken as the* mean free path of the molecule;
  - L_l *as the large scale, which can be the* characteristic length of the geometric configuration of fluid motion.
  - there may exist an intermediate length scale *Li* , where a certain effect of a molecule or the molecular structure retains the properties of fluid.

Fluid as a Continuum

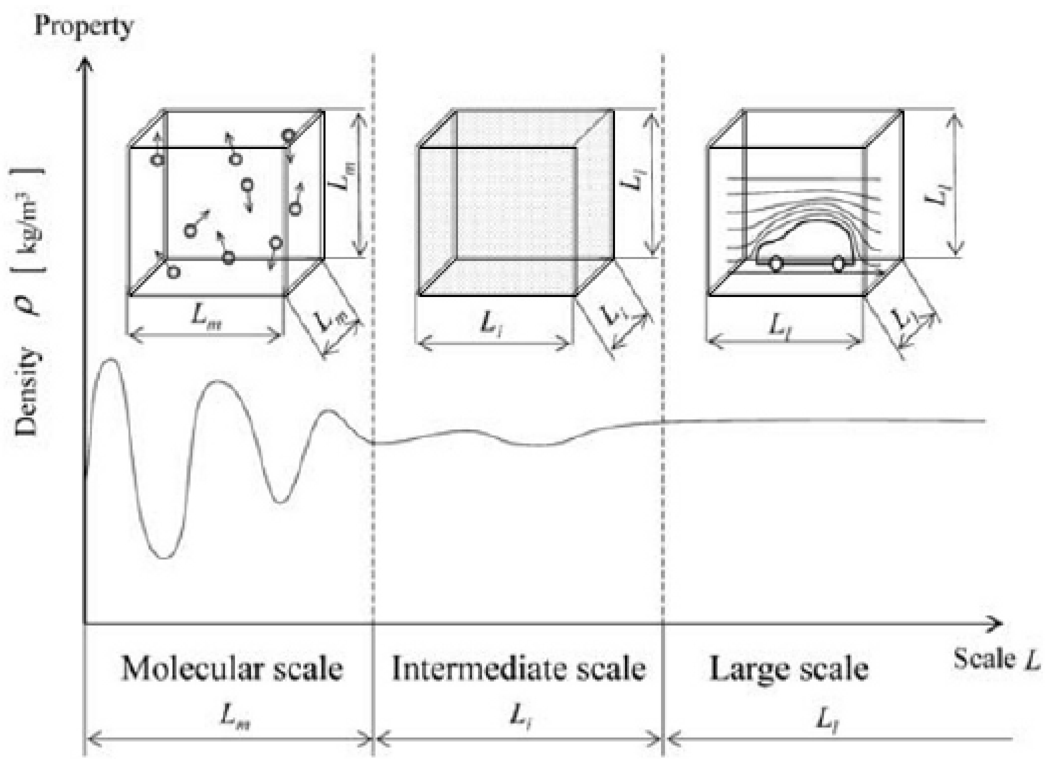


Figure 1.1: Property variation with scale

(as typically seen with properties such as density ρ)

Fluid as a Continuum

- In order to quantify the effect of the scale in the properties of fluid, and consequently to the dynamics of fluid motion, we will take the ratio between the actual characteristic length of flow geometry, typically L_l *, and* the mean free path of the molecules (the correlation length of the molecules) L_m *, such that we get the following formula where is called the* Knudsen number

$$\Gamma = \frac{L_m}{L_l}$$

- in a general sense, continuum hypothesis in particular , is normally valid when $\Gamma \ll 1$.
- Henceforth we shall make two assumptions:
  - first, that in every case, the flow of fluid has a small Knudsen Number, with which the scale of momentum of flow is far longer than the correlation length of the molecules; and
  - second, that the fluid body has a continuous structure.

Fluid as a Continuum

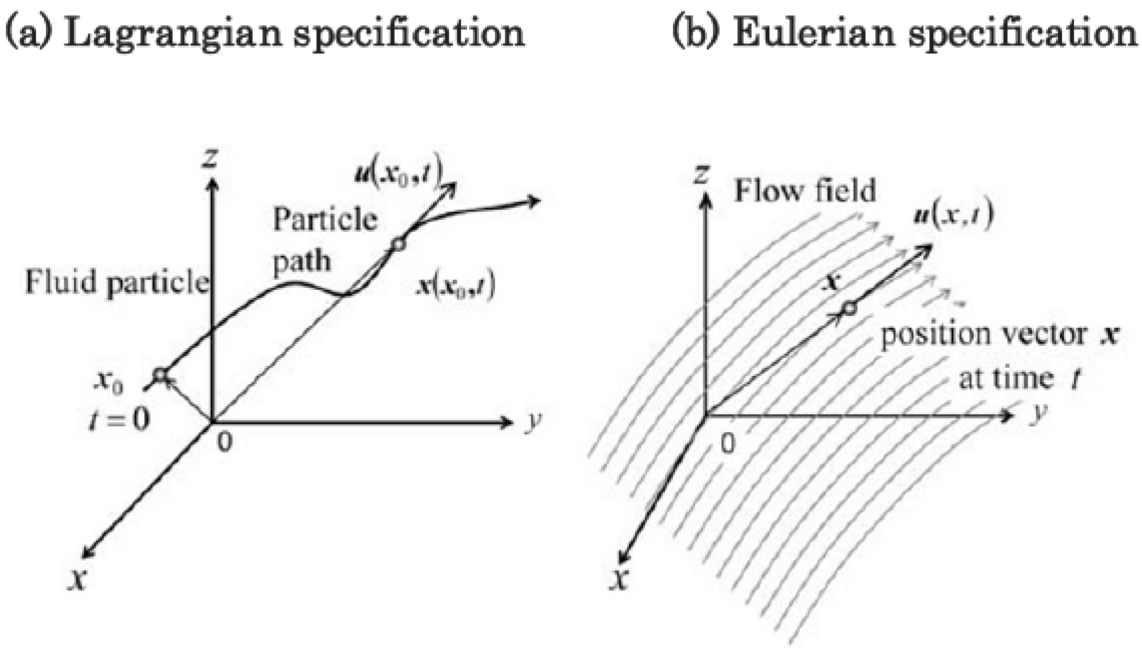
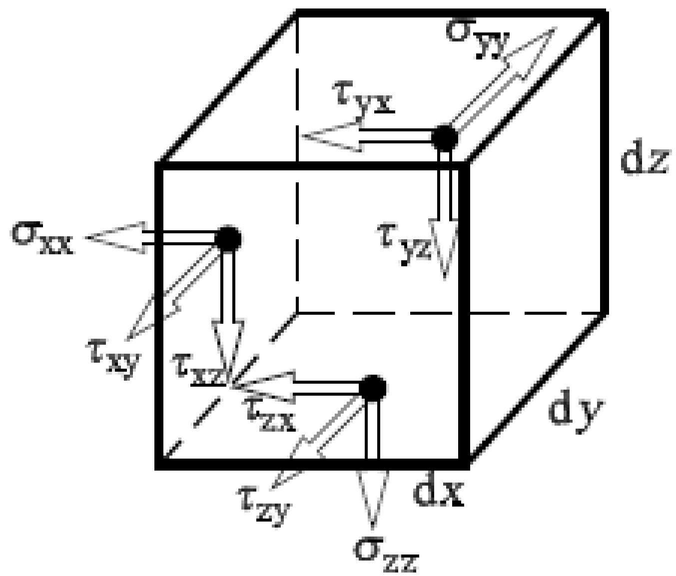
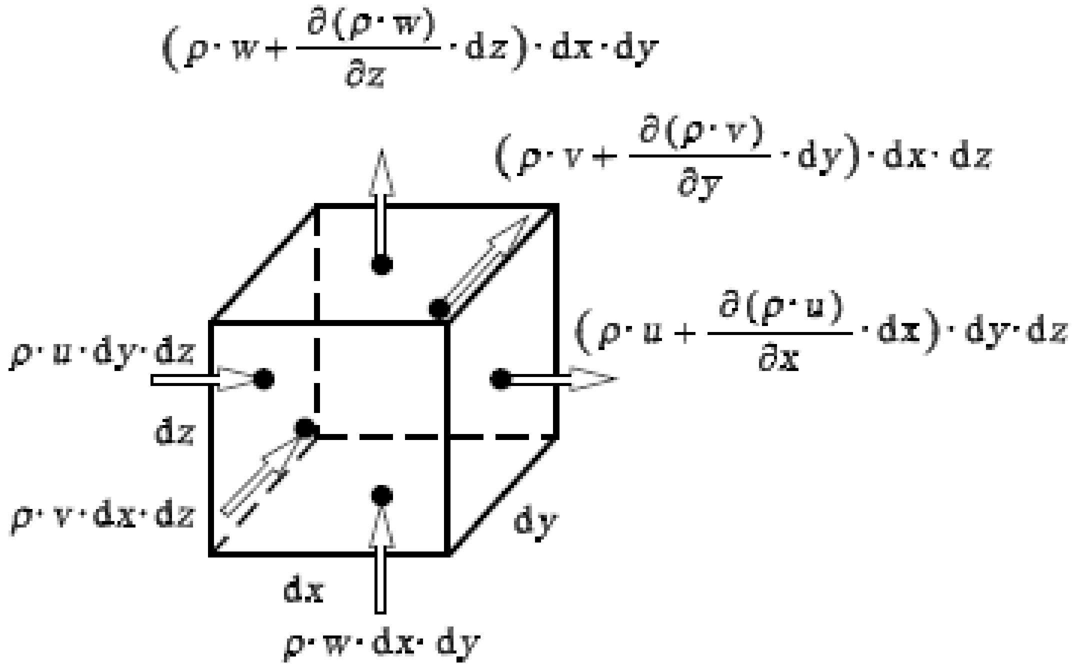


Fig. 1.2 Description of fluid motion



Normal and shear stress at volume element dV = dx·dy·dz



Mass fluxes entering and exiting the volume element dV