We are in pursuit of truth, goodness and beauty.

Engineering Fluid Mechanics

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Course Logistics

- Instructor
  - Prof. *Jun Zou*
- Teaching assistant
- Where can you get the latest updates?
  - https://pan.zju.edu.cn/share/b8945af0bae578d3a40e6bde8e, verified code:6730

Learning Resources

- Lecture
  - Presentation of new material
  - Example problems
- Homework
  - Problem solving skills
- Interaction in class and right after class
- Course notes
  - from white board
- World Wide Web
  - supplemental materials on the web

Roll call + Homework + Exam

Roll call will be taken during class irregularly. Homework will be assigned after the finish of each chapter. Unless you have a university excuse (see Absences in the syllabus), *late assignments will not be accepted for credit.*

One two-hour final examination are scheduled (see the course calendar given in the syllabus). *Unexcused absences will result in a grade of zero for missed examinations.* The exam are closed book. You are allowed to bring in one A4 size paper with your own notes and formulas . No other resources are permitted in the exams.

Grade

Grading Policy:

Roll call 10%

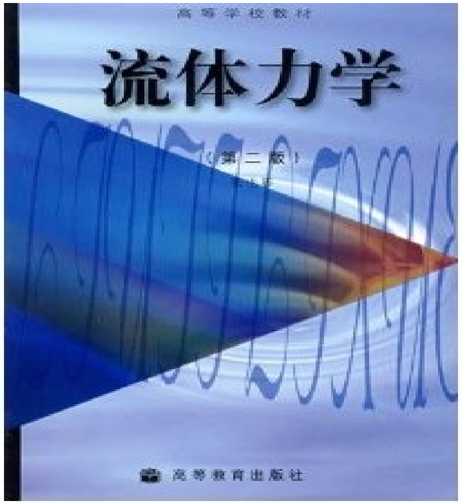
Homework 20%

Final Exam 70%

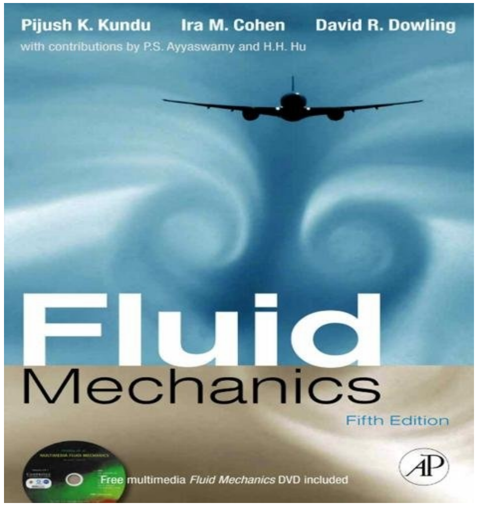
** Please note that homework and class participation are 30% of your total grade – please do not neglect this work.

Course Text

- **Fluid Mechanics (2th edition)**
  - By Yeying Zhang(张也影)
  - Publisher: Higher Education Press
  - Published year: 1989



- **Reference**
  - By Kundu, Cohen, Dowling
  - Published year: 2011



Course Topics

1. Introduction
2. Properties of fluids
3. Hydrostatics
4. Hydrodynamics
5. Dimensional analysis

Course Topics

6	**Pipe flow**
7	**Orifice discharge**
8	**Gap flow**
9	**Review**
10	**Q & A**

My Goals for Course

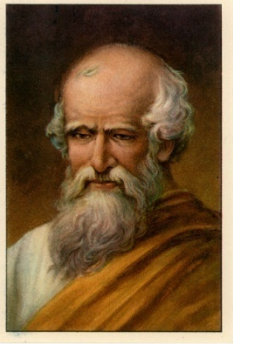
- You develop an intuition for the fundamental principles of fluid mechanics
- After this course, you say “Fluids makes sense” and “I can deal with fluid problems.”
- Wish we have an happy learning together

Chapter One

Introduction

Archimedes

B.C.287-B.C.212



Introduction

Why do we care about fluids?

Fluids support life

- Why do we care about fluids?
  - Fluids essential to life
    - Every living things are mainly composed of water
    - Earth's surface is 2/3 water
    - Atmosphere extends 17km above the earth's surface

Fluids support life

We can’t live without fluids

Fluids improve life

- Why do we care about fluids?
  - Fluids make our life better
    - Tap water
    - Airplane
    - Vehicle
    - Dam
    - …

Fluids improve life

Fluids beautify life

- Why do we care about fluids?
  - Fluids art up our life
    - Fountain
    - Soap bubble
    - Lake, River, Brook
    - …

Fluids beautify life

History

SOME FAMOUS NAMES OF FLUID MECHANICS

Archimedes (阿基米德)

Newton (牛顿)

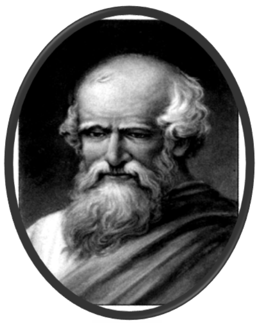
Pascal (帕斯卡)

Bernoulli (伯努利)

。。。

Express our high respects to them

History



Archimedes

(287-212 BC)

- Archimedes' principle——"Any floating object displaces its own weight of fluid" stated in the treatise *On Floating Bodies*

Newton

(1642-1727)

- The effects of friction and viscosity in diminishing the velocity of running water were noticed in the *Principia of Sir Isaac Newton*
- The first to investigate the difficult subject of the motion of waves

History

Pascal

(1623-1662)

- The hydrostatic pressure does not depend on the weight of the fluid but on the elevation difference.

Bernoulli

(1700-1782)

- A moving fluid exchanges its kinetic energy for pressure.

History

Navier

(1785-1836)

Stokes

(1819-1903)

- Navier–Stokes equations——the equations arise from applying Newton's second law to fluid motion, together with the assumption that the fluid stress is the sum of a diffusing viscous term (proportional to the gradient of velocity), plus a pressure term.

- Mathematicians have not yet proven that in three dimensions solutions always exist (existence), or that if they do exist, then they do not contain any singularity (smoothness). These are called the Navier–Stokes existence and smoothness problems.

History

Reynolds

(1842-1912)

- The famous experiment: the flow of fluid in pipes transitioned from laminar flow to turbulent flow. Reynolds number for dynamic similarity — the ratio of inertial forces to viscous forces.

Prandtl

(1875-1953)

- Flow separation as a result of the boundary layer. He is often referred to as the father of modern aerodynamics

Method

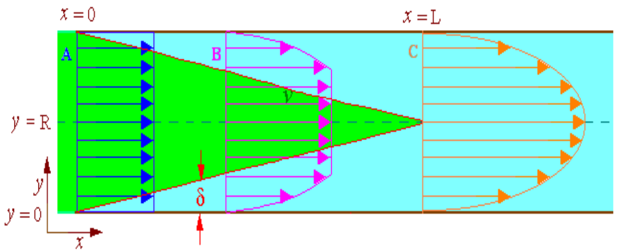
How to study fluid phenomena?

Method

AFD

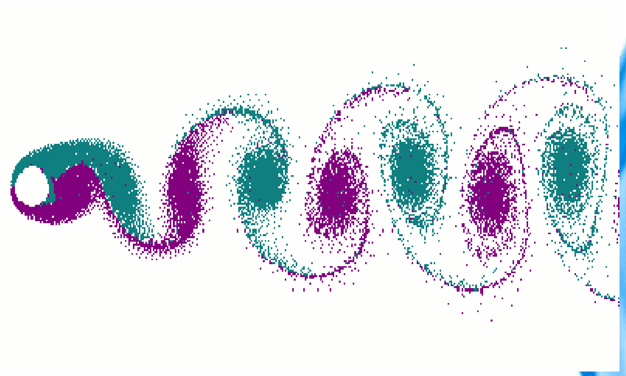
EFD

CFD



$$\nabla \bullet \mathbf{U} = 0$$

$$\frac{D\mathbf{U}}{Dt} = -\nabla p + \frac{1}{\mathrm{Re}}\nabla^2\mathbf{U} + \nabla \bullet \overline{u_i u_j}$$



Analytical Fluid Dynamics

Experimental Fluid Dynamic

Computational Fluid Dynamics

Solving Fluid Engieering Problems

Analytical Fluid Dynamics

- The theory of mathematical physics problem formulation
- Control volume & differential analysis
- Exact solutions only exist for simple geometry and conditions
- Approximate solutions for practical applications
  - Linear
  - Empirical relations using EFD data

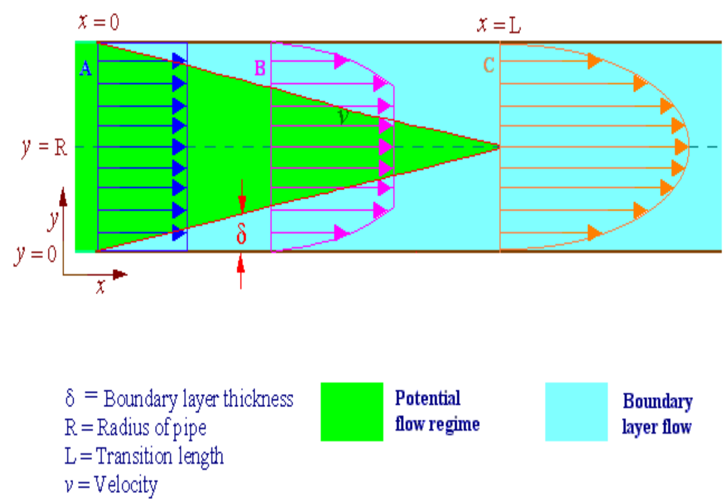
Analytical Fluid Dynamics

Example: laminar pipe flow

- **Assumptions:** Fully developed, Low $\mathrm{Re}=\dfrac{\rho UD}{\mu}<2000$
- **Approach**: Simplify momentum equation, integrate, apply boundary conditions to determine integration constants and use energy equation to calculate head loss

$$\cancelto{0}{\frac{Du}{Dt}}=-\frac{\partial p}{\partial x}+\mu\left[\cancelto{0}{\frac{\partial^2 u}{\partial x^2}}+\frac{\partial^2 u}{\partial y^2}\right]+\cancelto{0}{g_x}$$

- Schematic



Development of boundary-layer flow in pipe

- **Exact solution** :

$$u(r)=\frac{1}{4\mu}\left(-\frac{\partial p}{\partial x}\right)(R^2-r^2)$$

- Friction factor: $f=\dfrac{8\tau_w}{\rho\bar{V}^2}=\dfrac{8\mu\left.\dfrac{du}{dy}\right|_w}{\rho\bar{V}^2}=\dfrac{64}{\mathrm{Re}}$

- Head loss: $\dfrac{p_1}{\gamma}+z_1=\dfrac{p_2}{\gamma}+z_2+h_f \qquad h_f=f\dfrac{L}{D}\dfrac{V^2}{2g}=\dfrac{32\mu LV}{\gamma D^2}$

Experimental Fluid Dynamics

Definition:

Use of experimental methodology and procedures for solving fluids engineering systems, including full and model scales, large and table top facilities, measurement systems (instrumentation, data acquisition and data reduction), uncertainty analysis, and dimensional analysis and similarity.

Note:

- Test is governed within allowable uncertainties
- Integration of uncertainty analysis into all test phases
  - Test design
  - Determination of error sources
  - Estimation of uncertainty
  - Documentation of the results

Goal

- Science & Technology: understand and investigate a phenomenon/process, substantiate and validate a theory (hypothesis)
- Research & Development: document a process/system, provide benchmark data (standard procedures, validations), calibrate instruments, equipment, and facilities
- Industry: design optimization and analysis, provide data for direct use, product liability, and acceptance
- Teaching: instruction/demonstration

Application of EFD

Products test

Car design optimization and analysis

Scientific study

Investigation of a phenomenon/process

Computational Fluid Dynamics

- Computational methods for solving fluid engineering systems, including modeling (mathematical & Physics) and numerical methods (solvers, finite differences, and grid generations, etc.)
- Rapid growth in CFD technology since advent of computer

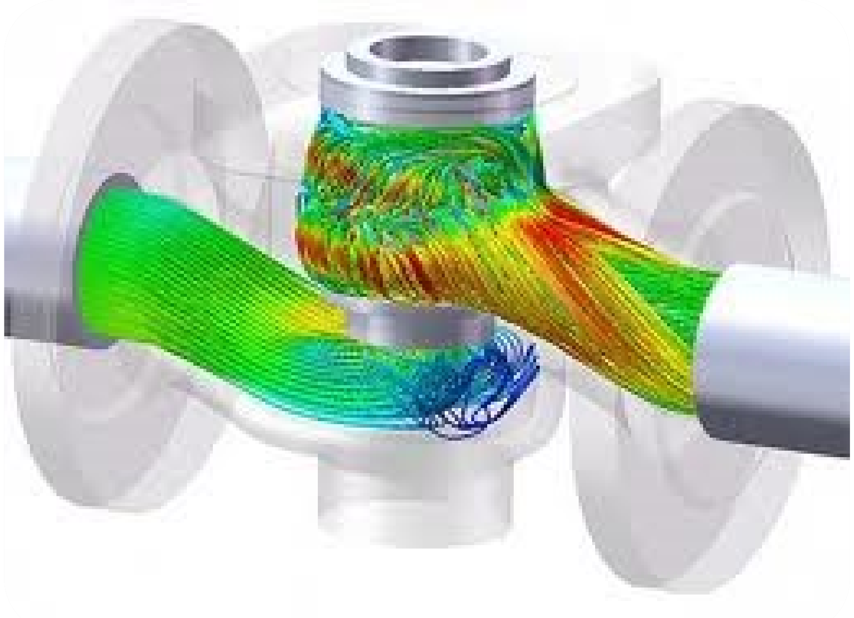
Super computer

Personal computer

Goal

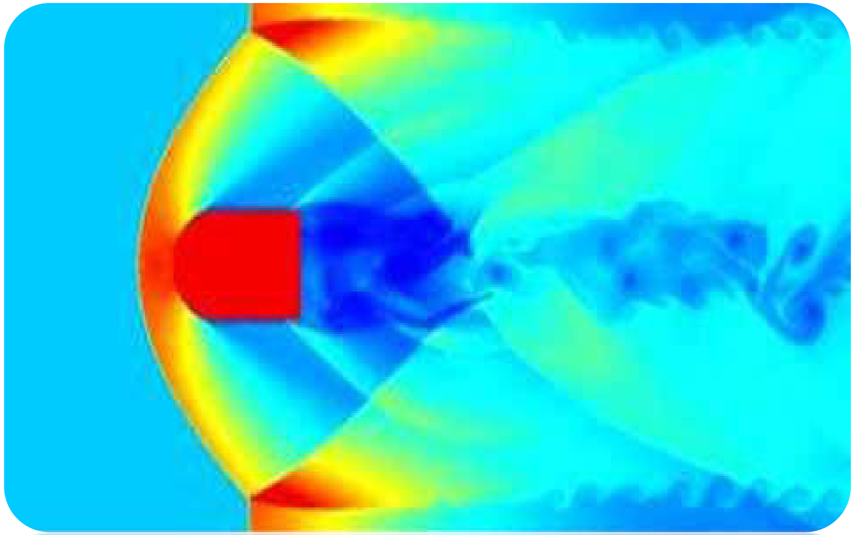
- Model fluids into an algebra problem through Discretized Partial Differential Equations (DPDEs, solve it, validate it and achieve simulation based design instead of "build then test"
- Simulation of physical fluid phenomena that are difficult to be measured by experiments: scale simulations (full-scale ships, airplanes), hazards (explosions, radiations, pollution), physics (weather prediction, planetary boundary layer, stellar evolution)

Application of CFD



Design and test

Valve design and test based on simulation



Scientific study

Investigation of bullet in pipe