Computational Fluid Dynamics: Lecture 1 (ME EN 6720)

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CFD Motivation

Computational Fluid Dynamics (CFD)

Motivations:

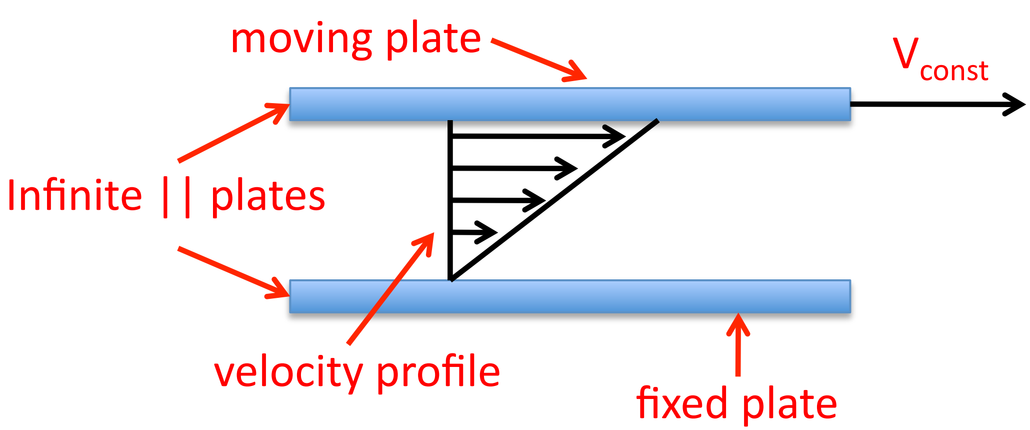
There are 3 basic approaches to study fluid dynamics

1. Theoretical (analytical approaches)
2. Experimental approaches
3. Numerical approaches

Examples:

We can solve the following problems analytically

• Couette flow

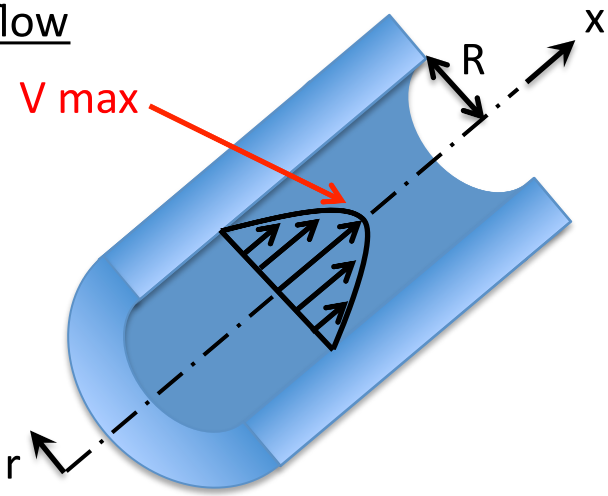


• For incompressible viscous flow between 2 infinite | | plates (small separation distance) the velocity distribution can be found analytically.

CFD Motivation

Motivations (cont.):

- Laminar pipe flow



- It can be shown analytically that fully-developed laminar flow in a section of straight pipe is given by:

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

[More examples including engineering problems that use CFD can be found in Anderson chapter 1]

What about complex geometry or more complex physics (e.g., **turbulence**)?

Turbulence has the following problematic properties:

- highly unsteady
- unpredictable
- chaotic behavior

CFD Pros/Cons

Pros and Cons of using different methods to study **Fluid Mechanics**

Method	Advantages	Disadvantages
Theoretical	• clean and exact • solution in formula form	• Restricted to simple geometries and physics • usually only linear problems
Experimental	• very realistic!!!	• can be costly • quantities of interest can be hard to measure • measurement errors • scaling problems
Numerical	• can solve complex nonlinear problems • complex physics • Time evolution and spatial distributions	• truncation errors • boundary conditions • computational cost • subgrid-scale models

CFD goals

- **Goal of CFD**: (or any exploration of a physical process)

  Create useful descriptions of physical processes for engineering, scientific and environmental applications

- **How is this accomplished**?

Identify physical process or system of interest → Develop a math-ematical model (typ. P.D.E.s, e.g. Navier-Stokes eqns.) → Solve model to gain insight into process

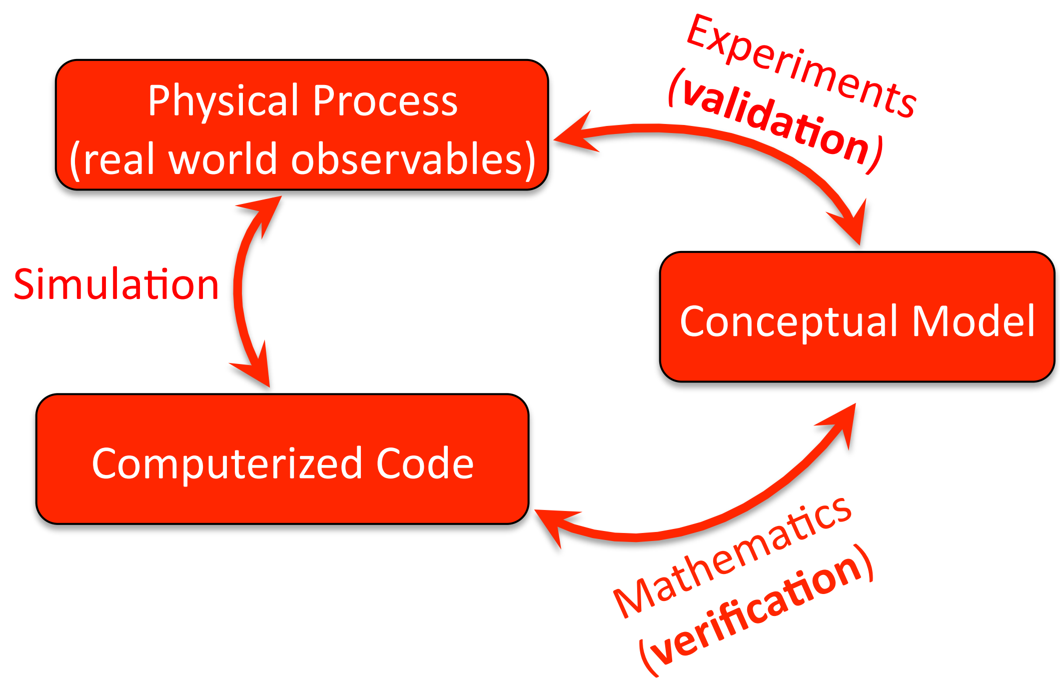
Many P.D.E.s can't be solved analytically → **Numerical approximations (CFD)!**

Verification and Validation

- Note that our numerical solution can't be isolated from theory and experiments.
- We can think of the link between theoretical, experimental and numerical approaches as a cycle:

Verification: The process of determining that a model implementation accurately represents the conceptual model and the solution to the model

Validation: The process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model



Developmental cycle

- When we develop a numerical code, we can view these components as part of a development cycle
- When we use **validation and verification** we need to balance two competing issues:

  - go to fast: trying to gain physical insight from numerical noise
  - go to slow: spend time and resources on misguided ideas