Fluid Mechanics - MTF053

Lecture 10

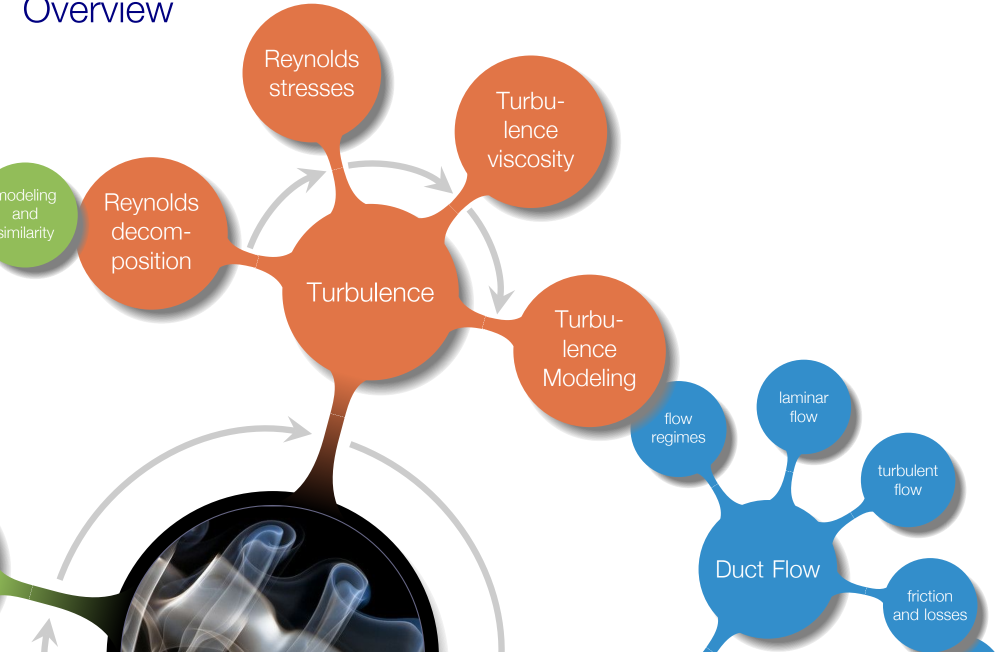
Niklas Andersson

Chalmers University of Technology
Department of Mechanics and Maritime Sciences
Division of Fluid Mechanics
Gothenburg, Sweden

niklas.andersson@chalmers.se

Chapter 6 - Viscous Flow in Ducts

Overview


Reynolds stresses
Turbu-lence viscosity
modeling and similarity
Reynolds decom-position
Turbulence
Turbu-lence Modeling
flow regimes
laminar flow
turbulent flow
Duct Flow
friction and losses

Learning Outcomes

3 **Define** the Reynolds number

4 Be **able to categorize** a flow and **have knowledge about** how to select applicable methods for the analysis of a specific flow based on category

6 **Explain** what a boundary layer is and when/where/why it appears

8 **Understand** and be able to **explain** the concept shear stress

18 **Explain** losses appearing in pipe flows

19 **Explain** the difference between laminar and turbulent pipe flow

20 **Solve** pipe flow problems using Moody charts

24 **Explain** what is characteristic for a turbulent flow

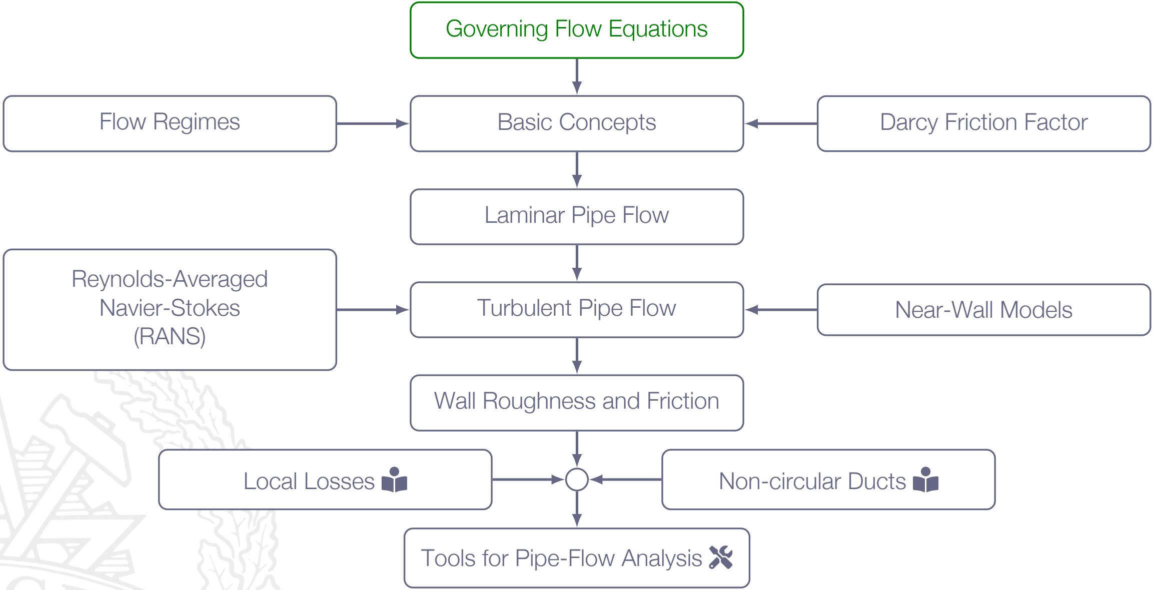
25 **Explain** Reynolds decomposition and derive the RANS equations

26 **Understand** and **explain** the Boussinesq assumption and turbulent viscosity

27 **Explain** the difference between the regions in a boundary layer and what is characteristic for each of the regions (viscous sub layer, buffer region, log region)

if you think about it, pipe flows are everywhere (a pipe flow is not a flow of pipes)

Roadmap - Viscous Flow in Ducts

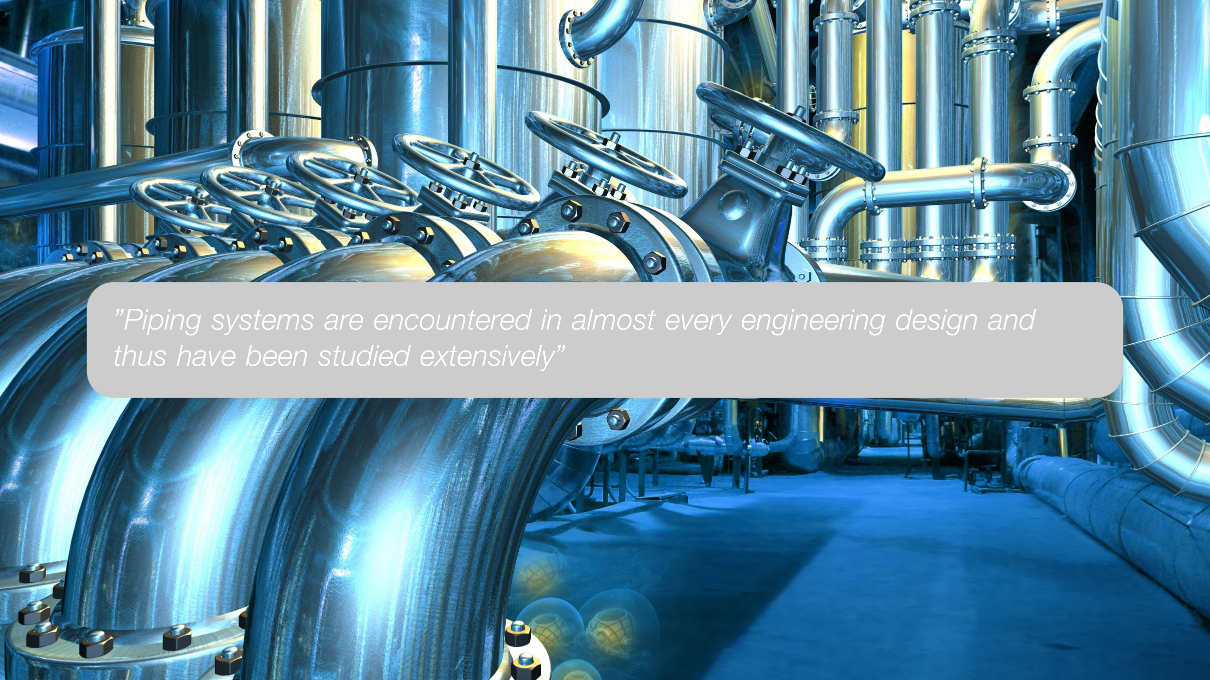


Complementary Course Material

These lecture notes covers chapter 6 in the course book and additional course material that you can find in the following documents

MTF053_Equation-for-Boundary-Layer-Flows.pdf

MTF053_Turbulence.pdf



”Piping systems are encountered in almost every engineering design and thus have been studied extensively”

Typical Pipe-Flow Problems

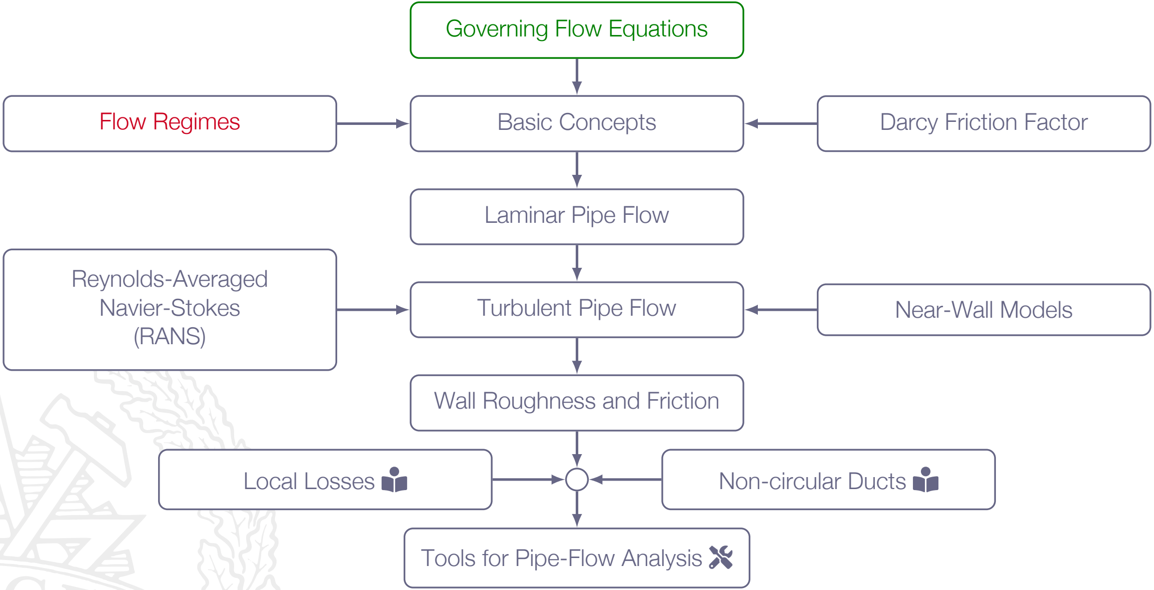
Example I:

Given pipe geometry, fluid properties, flow rate, and locations of valves, bends, diffusers etc - estimate the pressure drop needed to drive the flow

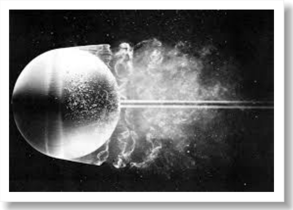
Example II:

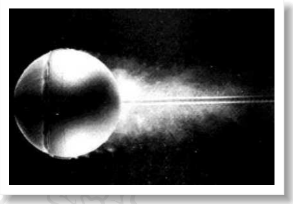
Given the pressure drop available from a pump - what flow rate can be expected

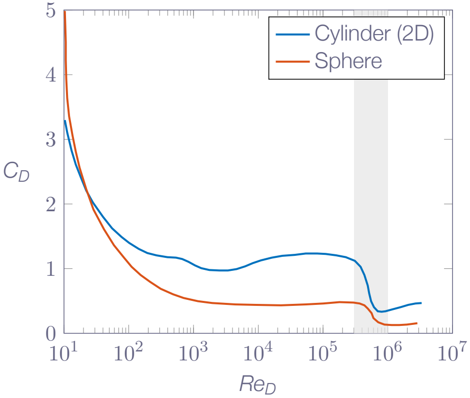
Roadmap - Viscous Flow in Ducts



Transition to Turbulence







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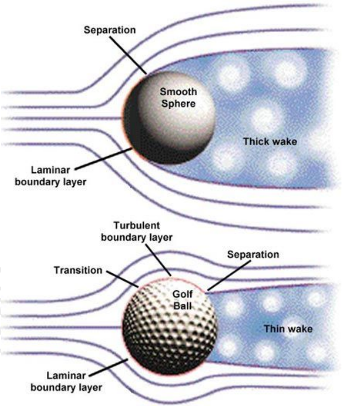
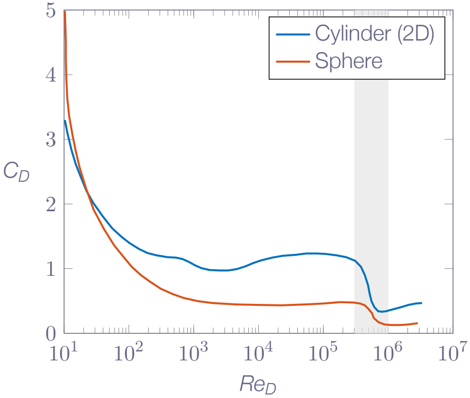


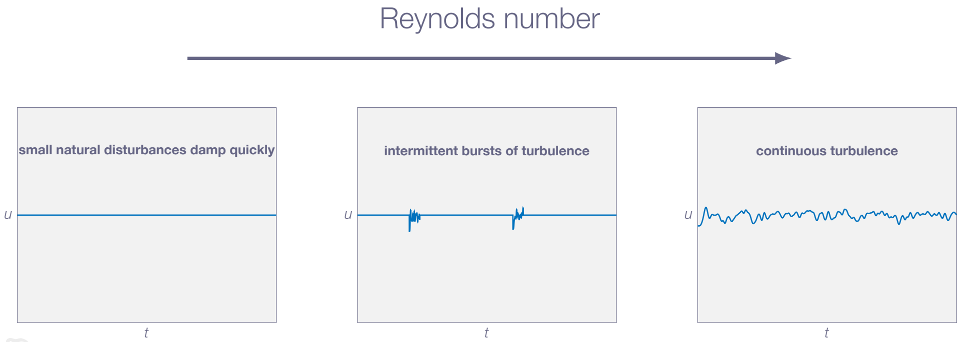


Transition to Turbulence

Factors that affects the transition to turbulent flow:

1. Wall roughness
2. Fluctuations in incoming flow
3. Reynolds number

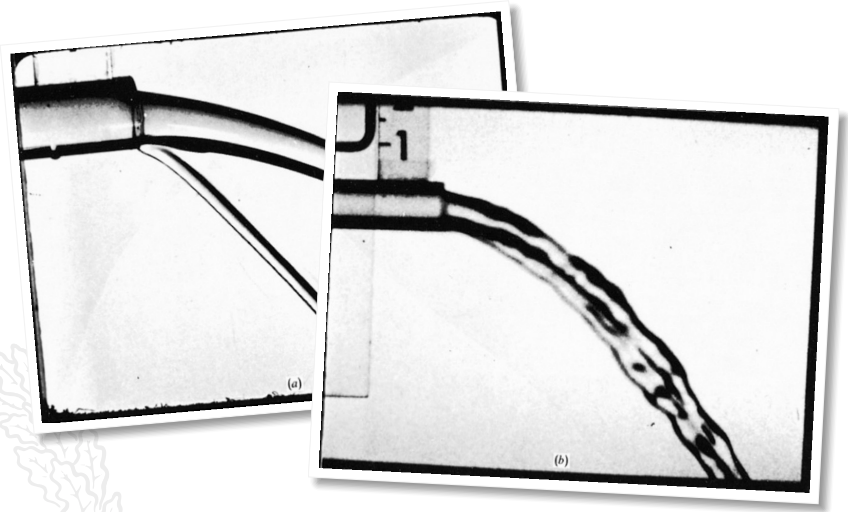
Transition to Turbulence



Fluctuations in the fully turbulent flow velocity signal:

- typically 1% to 20% of the average velocity
- not periodic
- random
- continuous range (spectrum) of frequencies

Transition to Turbulence



Transition to Turbulence - Viscous Flow in Ducts

0	$< Re <$	1	highly viscous laminar ”creeping” motion
1	$< Re <$	100	laminar, strong Reynolds number dependence
100	$< Re <$	10^3	laminar, boundary layer theory useful
10^3	$< Re <$	10^4	transition to turbulence
10^4	$< Re <$	10^6	turbulent, moderate Reynolds number dependence
10^6	$< Re <$	∞	turbulent, slight Reynolds number dependence

Note! The ranges will vary somewhat with geometry and surface roughness

Transition to Turbulence - Viscous Flow in Ducts

An accepted design value for **pipe flow transition** is

$$Re_{d,crit} \approx 2300$$

Note!

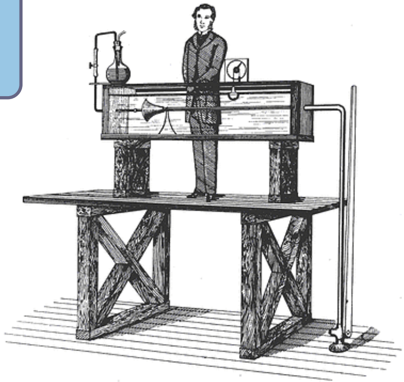
1. this value is **for pipe flows**, other applications have different transition Reynolds numbers
2. by careful design the Reynolds number can be pushed to higher values

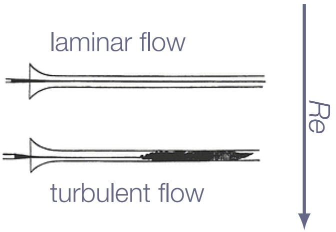
Transition to Turbulence - Viscous Flow in Ducts

The great majority of our analyses are concerned with laminar flow or with turbulent flow, and one should not normally design a flow operation in the transition region.

Transition to Turbulence - Osborne Reynolds (1842-1912)

$$Re = \frac{\rho U D}{\mu}$$



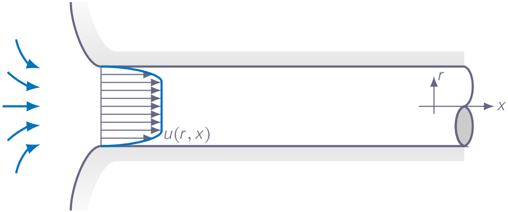


Internal Flows

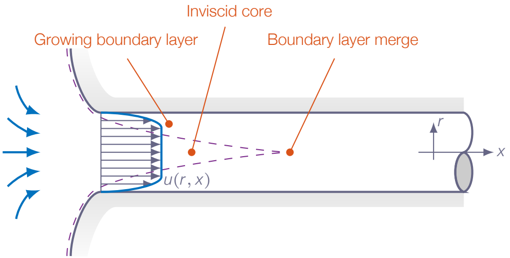
Wall-bounded flows - constrained by bounding walls

Boundary layers grows and meet at the center

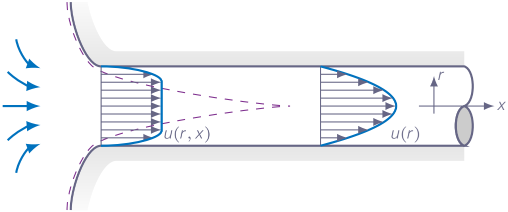
Velocity Profile Development



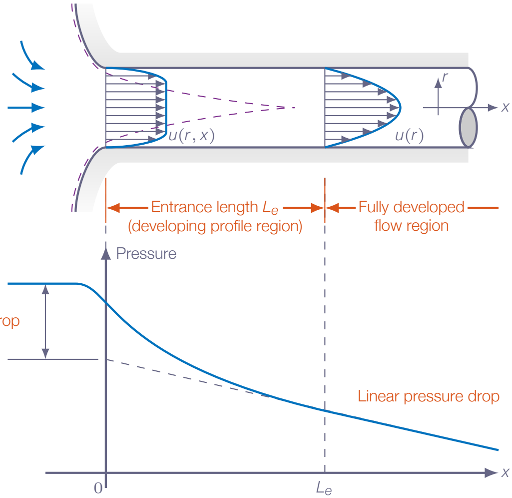
Velocity Profile Development



Velocity Profile Development



Velocity Profile Development



Velocity Profile Development

$$L_e = f(d, V, \rho, \mu)$$

where

$$V = \frac{Q}{A} = \frac{4Q}{\pi d^2}$$

and

$$Q = \int u dA = const$$

Dimensional analysis gives:

$$\frac{L_e}{d} = g\left(\frac{\rho V d}{\mu}\right) = g(Re_d)$$

Velocity Profile Development

Laminar flow:

$$\frac{L_e}{d} \approx 0.06 Re_d$$

The maximum laminar entrance length, at $Re_d = Re_{d,crit} = 2300$, is $L_e = 138d$, which is the longest development length possible

Velocity Profile Development

Turbulent flow ($Re_d \leq 10^7$):

$$\frac{L_e}{d} \approx 1.6 Re_d^{1/4}$$

Re_d	4.0×10^3	1.0×10^4	1.0×10^5	1.0×10^6	1.0×10^7
L_e/d	13	16	28	51	90