Fluid Mechanics MTF053

Study Guide

Division of Fluid Dynamics
Department of Mechanics and Maritime Sciences
Chalmers University of Technology

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Chapter Summaries and Quizzes

Chapter 1 – Introduction
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Complementary Documents

1. MTF053_Formulas-Tables-and-Graphs.pdf

2. MTF053_Equation-for-Boundary-Layer-Flows.pdf

4. MTF053_Turbulence.pdf

6. MTF053_Recommended_Problems.pdf

1 Introduction (Basic Concepts)

The course covers most parts of the book *F. M. White Fluid Mechanics 9th ed.* but the following parts of Chapter 1 are **not** included:

- The following subsections and figures of section 1.6
  - Figure 1.4
  - State Relations for Liquids
- The following subsections and figures of section 1.7
  - Figure 1.7
- Section 1.10 - The Fundamentals of Engineering (FE) Examination

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9th ed.*) and in the following complementary course material:

MTF053_C01.pdf

Summary of chapter 1 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

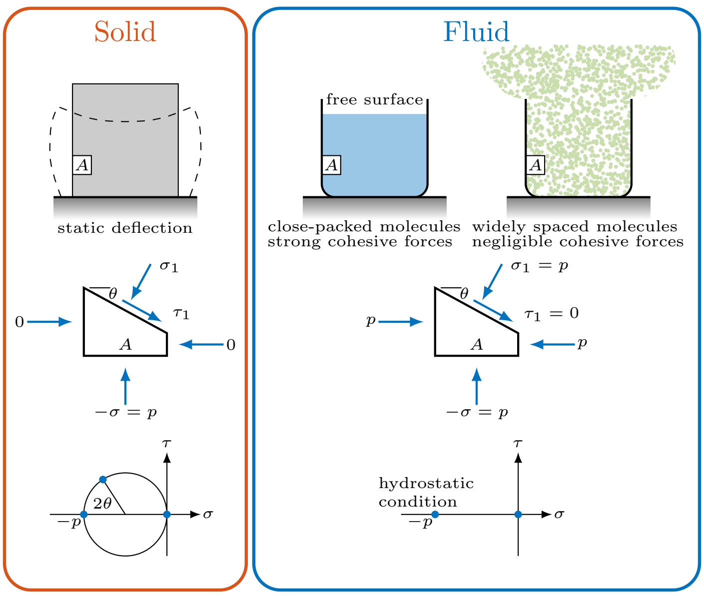

Figure 1.1: Fluid versus solid

1.1 Explain how a fluid differs from a solid (see Fig. 1.1). How does a fluid element and solid element react under the presence of shear forces?

Fluid Mechanics:
Chapter 1.2: The Concept of a Fluid

MTF053_C01.pdf:
The Concept of a Fluid

1.2 The continuum concept is very central in fluid mechanics - explain this concept.

Fluid Mechanics:
Chapter 1.3: The Fluid as a Continuum

MTF053_C01.pdf:
The Fluid as a Continuum

1.3 Primary and secondary dimensions:

(a) What does *primary dimension* mean?

(b) Which are the primary dimensions used in fluid mechanics?

(c) Give examples of secondary dimensions.

(d) What does a *dimensional homogeneous equation* imply?

Fluid Mechanics:
Chapter 1.4: Dimensions and Units

1.4 Explain the difference between Eulerian and Lagrangian frame of reference

Fluid Mechanics:
Chapter 1.5: System and Control Volume / Methods of Description

MTF053_C01.pdf:
Frame of Reference

1.5 Show that if the shear stress is proportional to the fluid element strain rate $\delta\theta/\delta t$, it is also proportional to the velocity gradient du/dy

Fluid Mechanics:
Chapter 1.7: Viscosity and Other Secondary Properties

MTF053_C01.pdf:
Viscosity

1.6 What is the viscosity of a fluid?

Fluid Mechanics:
Chapter 1.7: Viscosity and Other Secondary Properties

MTF053_C01.pdf:
Viscosity

1.7 For a viscous flow, what is the fluid velocity at a wall? What is this boundary condition called?

Fluid Mechanics
Chapter 1.7: Viscosity and Other Secondary Properties / Viscosity
Chapter 1.7: Viscosity and Other Secondary Properties / No-Slip and No-Temperature-Jump Conditions

MTF053_C01.pdf:
No Slip / No Temperature Jump

1.8 What does it mean that a fluid is Newtonian?

Fluid Mechanics
Chapter 1.7: Viscosity and Other Secondary Properties / Viscosity
Chapter 1.7: Viscosity and Other Secondary Properties / NonNewtonian Fluids

MTF053_C01.pdf:
Non-Newtonian Fluids

1.9 How is the Reynolds number defined? Explain in words what the Reynolds number is.

Fluid Mechanics
Chapter 1.7: Viscosity and Other Secondary Properties / The Reynolds Number

MTF053_C01.pdf:
Reynolds Number

1.10 Explain the following concepts:

(a) Steady-state flow

(b) Unsteady flow

(c) Incompressible flow

(d) Inviscid flow

(e) Turbulent flow

MTF053_C01.pdf:
Flow Categories

1.11 What is the vapor pressure of a fluid? Explain why cavitation may occur if the pressure becomes low enough in a fluid flow

Fluid Mechanics:
Chapter 1.7: Viscosity and Other Secondary Properties / Vapor Pressure

MTF053_C01.pdf:
Vapor Pressure

1.12 Explain the difference between *streamline*, *pathline*, and *streakline*. Under what circumstances do these three line types coincide in a fluid flow?

Fluid Mechanics:
Chapter 1.8: Flow Patterns: Streamlines, Pathlines, and Streaklines

MTF053_C01.pdf:
Flow Visualization

1.13 The energy per unit mass e can be expressed as follows:

$$e = \hat{u} + \frac{1}{2}V^2 + gz$$

The three components on the right-hand side represents different forms of energy. What does each of the terms represent physically?

Fluid Mechanics:
Chapter 1.6: Thermodynamic Properties of a Fluid

MTF053_C01.pdf:
Potential and Kinetic Energy

1.14 How does the fluid viscosity vary with temperature in liquids and gases, respectively.

Fluid Mechanics:
Chapter 1.7: Viscosity and Other Secondary Properties / Variation of Viscosity with Temperature

MTF053_C01.pdf:
Viscosity

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	**Recommended home problems**
1.1, 1.2, 1.3, 1.4	1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11

2 Pressure Distribution in a Fluid

The course covers most parts of the book *F. M. White Fluid Mechanics 9^{th} ed.* but the following parts of Chapter 2 are **not** included:

- The following subsections of section 2.3
  - Is the Linear Formula Adequate for Gases?
- Sections 2.5-2.7
- The following subsections of section 2.8
  - Stability Related to Waterline Area
- Section 2.9

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9^{th} ed.*) and in the following complementary course material:

MTF053_C02.pdf

Summary of chapter 2 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

2.1 If you would hold your thumb tightly over the upper end of straw filled with water and held vertically, would the water not pour out - explain why. Is there a limit for how high a water pillar can be without pouring out? If so, how high can it be?

Fluid Mechanics:
Chapter 2.3: Hydrostatic Pressure Distribution (the section on the mercury barometer can give a hint)

2.2 Show that the pressure difference in a fluid can be calculated as $\Delta p = -\rho g \Delta z$ starting from Newton's second law ($F = ma$), the fluid density can be assumed to be constant.

MTF053_C02.pdf:
Equilibrium of a Fluid Element
Hydrostatic Pressure in Liquids

2.3 Show that the force balancing gravity in a fluid at rest is caused by the pressure gradient.

Fluid Mechanics:
Chapter 2.2: Equilibrium of a Fluid Element
Chapter 2.3: Hydrostatic Pressure Distribution

MTF053_C02.pdf:
Pressure Forces on a Fluid Element

2.4 Show that the normal of a constant-pressure surface must be aligned with the gravity vector in a fluid at rest.

MTF053_C02.pdf:
Equilibrium of a Fluid Element

2.5 How does the hydrostatic pressure distribution differ in liquids and gases?

Fluid Mechanics:
Chapter 2.3: Hydrostatic Pressure Distribution / Hydrostatic Pressure in Liquids
Chapter 2.3: Hydrostatic Pressure Distribution / Hydrostatic Pressure in Gases

MTF053_C02.pdf:
Hydrostatic Pressure in Liquids
Hydrostatic Pressure in Gases

2.6 How can we make use of Pascal's law when analyzing manometer tubes?

Fluid Mechanics:
Chapter 2.4: Application to Manometry

MTF053_C02.pdf:
Manometry

2.7 Describe the implication of buoyancy for immersed bodies and floating bodies, respectively.

Fluid Mechanics:
Chapter 2.8: Buoyancy and Stability

MTF053_C02.pdf:
Buoyancy

2.8 How is the buoyancy of a body immersed in a fluid calculated? Show how this relation is obtained.

Fluid Mechanics:
Chapter 2.8: Buoyancy and Stability

MTF053_C02.pdf:
Buoyancy

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	**Recommended home problems**
2.1, 2.2, 2.3, 2.4	2.5, 2.6, 2.7, 2.8

3 Integral Relations for a Control Volume

The course covers most parts of the book *F. M. White Fluid Mechanics 9th ed.* but the following parts of Chapter 3 are **not** included:

- The following subsections of section 3.4
  - Noninterial Reference Frame

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9th ed.*) and in the following complementary course material:

MTF053_C03.pdf

Summary of chapter 3 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

3.1 Volume flow and mass flow:

(a) Show how the volume flow Q and mass flow $\dot{m}$ over a control volume surface can be calculated in a general way

(b) How are volume flow Q and mass flow $\dot{m}$ related if the density is constant

(c) How is the volume-averaged mean velocity over a surface defined for a fluid with constant density?

Fluid Mechanics:
Chapter 3.1: Basic Physical Laws of Fluid Mechanics / Volume and Mass Rate of Flow
MTF053_C03.pdf:
Control Volume - Volume and Mass Flow Rate

3.2 Give examples of when it is appropriate to use fixed control volume, moving control volume, and deformable control volume, respectively.

Fluid Mechanics:
Chapter 3.2: The Reynolds Transport Theorem
MTF053_C03.pdf:
Control Volume - Classification

3.3 Reynolds transport theorem:

(a) In Reynolds transport theorem, B and β denotes extensive and intensive properties respectively. Explain the difference between B and β.

(b) If an intensive property, β, is known, how is the corresponding extensive property, B, calculated?

(c) Give two examples of intensive and extensive properties

(d) Explain the physical meaning of each of the terms in Reynolds transport theorem:

$$\frac{d}{dt}\left(B_{syst}\right)=\frac{d}{dt}\left(\int_{cv}\beta\rho d\mathcal{V}\right)+\int_{cs}\beta\rho\left(\mathbf{V}_r\cdot\mathbf{n}\right)dA \qquad (3.16)$$

(e) How can the generic form of Reynolds transport theorem (above) be be simplified for a fix control volume?

(f) What does it mean that inlets and outlets are one-dimensional?

(g) How can we simplify Reynolds transport theorem for one-dimensional inlets and outlets?

Fluid Mechanics:
Chapter 3.2: The Reynolds Transport Theorem
MTF053_C03.pdf:
Reynolds Transport Theorem

3.4 The continuity equation:

(a) Derive the continuity equation on integral form for a fixed control volume using Reynolds transport theorem

(b) Explain the physical meaning of each of the terms in the continuity equation on integral form

(c) How can we simplify the continuity equation on integral form under the following circumstances (assuming that the control volume is fixed)?

$$\int_{cv} \frac{\partial \rho}{\partial t} d\mathcal{V} + \int_{cs} \rho \left(\mathbf{V} \cdot \mathbf{n} \right) dA \tag{3.21}$$

i. inlets and outlets can be assumed to be one-dimensional
ii. steady-state flow
iii. incompressible unsteady flow

Fluid Mechanics:
Chapter 3.3: Conservation of Mass
MTF053_C03.pdf:
Conservation of Mass

3.5 The momentum equation:

(a) Derive the momentum equation on integral form starting from Reynolds transport theorem

(b) Explain the physical meaning of each of the terms in the momentum equation on integral form

(c) How can we simplify the momentum equation on integral form under the following circumstances?

$$\frac{d}{dt} \left(m\mathbf{V} \right)_{syst} = \sum \mathbf{F} = \frac{d}{dt} \left(\int_{cv} \mathbf{V} \rho d\mathcal{V} \right) + \int_{cs} \mathbf{V} \rho \left(\mathbf{V}_r \cdot \mathbf{n} \right) dA \tag{3.35}$$

i. fixed control volume
ii. fixed control volume and one-dimensional inlets and outlets
iii. fixed control volume, one-dimensional inlets and outlets, and steady-state flow

Fluid Mechanics:
Chapter 3.4: The Linear Momentum Equation
MTF053_C03.pdf:
Conservation of Linear Momentum

3.6 What is gauge pressure?

Fluid Mechanics:
Chapter 3.4: The Linear Momentum Equation / Net Pressure Force on a Closed Control Surface
MTF053_C03.pdf:
Surface Pressure Forces

3.7 The Bernoulli equation:

(a) Derive the Bernoulli equation for steady-state, incompressible flow along a streamline

$$\frac{p_1}{\rho} + \frac{1}{2}V_1^2 + gz_1 = \frac{p_2}{\rho} + \frac{1}{2}V_2^2 + gz_2 = const \tag{3.54}$$

(b) What assumptions are made in the derivation of the Bernoulli equation?

Fluid Mechanics:
Chapter 3.5: Frictionless Flow: The Bernoulli Equation
MTF053_C03.pdf:
The Bernoulli Equation

3.8 The energy equation:

(a) What does Q and W in the energy equation represent?

(b) The energy per unit mass, e, and the work are both divided into parts, what parts are the terms divided into?

(c) The Bernoulli equation is a simplified form of the energy equation.

$$\frac{p_1}{\rho} + \frac{1}{2}V_1^2 + gz_1 = \frac{p_2}{\rho} + \frac{1}{2}V_2^2 + gz_2 = const \tag{3.54}$$

In what ways are the Bernoulli equation above more limited than the energy equation on the form given below?

$$\left(\frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1\right) = \left(\frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2\right) + \frac{\hat{u}_2 - \hat{u}_1 - q}{g} \tag{3.72}$$

(d) Why is the kinetic energy correction factor introduced?

(e) Show that the kinetic energy correction factor is $\alpha = 2.0$ for laminar, incompressible pipe flow.

Fluid Mechanics:
Chapter 3.7: The Energy Equation
MTF053_C03.pdf:
The Energy Equation

3.9 Explain how to measure velocity using a Prandtl tube (Pitot-static tube) and derive the relation needed to estimate the velocity

Fluid Mechanics:
Chapter 3.5: Frictionless Flow: The Bernoulli Equation / Stagnation, Static, and Dynamic Pressure
MTF053_C03.pdf:
Pitot Static Tube

3.10 Explain how a venturi meter works and derive the relation needed to estimate the velocity

Fluid Mechanics:
Chapter 3.5: Frictionless Flow: The Bernoulli Equation / Stagnation, Static, and Dynamic Pressure
Chapter 3.5: Frictionless Flow: The Bernoulli Equation / Example 3.15
MTF053_C03.pdf:
Venturi Tube

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	**Recommended home problems**
3.1, 3.2, 3.3, 3.4, 3.12, 3.13, 3.17, 3.21, 3.23, 3.24	3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.14, 3.15, 3.16, 3.18, 3.19, 3.20, 3.22, 3.25, 3.26, 3.27*

4 Differential Relations for Fluid Flow

The course covers most parts of the book *F. M. White Fluid Mechanics 9th ed.* but the following parts of Chapter 4 are **not** included:

- Section 4.7 (stream functions are mentioned in the lecture notes but the stream function theory covered in section 4.7 is not included)
- The following subsections of section 4.9
  - Velocity Potential
  - Orthogonality of Streamlines and Potential Lines
  - Generation of Rotationality
- The following subsections of section 4.10
  - Instability of Rotating Inner Cylinder Flow

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9th ed.*) and in the following complementary course material:

MTF053_C04.pdf

Summary of chapter 4 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

4.1 What is the difference between the control volumes used when applying the integral formulation of the governing equations to a problem and the ones used when deriving the differential formulation of the governing equations?

Fluid Mechanics:
Chapter 4.2: The Differential Equation of Mass Conservation
MTF053_C04.pdf:
Differential Relations

4.2 Flow acceleration:

(a) Rewrite the acceleration using the chain rule and group the terms into local acceleration terms and convective acceleration terms

(b) Explain the physical meaning of the local acceleration term and the convective acceleration term

Fluid Mechanics:
Chapter 4.1: The Acceleration Field of a Fluid
MTF053_C04.pdf:
Acceleration Field

4.3 The continuity equation on differential form:

(a) Derive the continuity equation on differential form starting from the integral form for a fixed control volume

$$\int_{cv} \frac{\partial \rho}{\partial t} d\mathcal{V} + \sum_i (\rho_i A_i V_i)_{out} - \sum_i (\rho_i A_i V_i)_{in} = 0 \tag{3.22}$$

and let the size of the control volume reduce to infinitesimal size

(b) How can we simplify the continuity equation on differential form under the following circumstances?

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \tag{4.4}$$

i. steady-state flow

ii. incompressible flow

Fluid Mechanics:
Chapter 4.2: The Differential Equation of Mass Conservation
MTF053_C04.pdf:
Mass Conservation

4.4 The momentum equation on differential form:

(a) Derive the momentum equation on differential form starting from the integral form

$$\sum \mathbf{F} = \frac{d}{dt}\left(\int_{cv} \mathbf{V} \rho d\mathcal{V}\right) + \sum (\dot{m}_i \mathbf{V}_i)_{out} - \sum (\dot{m}_i \mathbf{V}_i)_{in} \tag{3.40}$$

and let the size of the control volume reduce to infinitesimal size

(b) A fluid element is subjected to both body forces and surface forces. Give an example of a body force and name the two surface forces.

(c) Make a sketch of a control volume used for the derivation of the governing equations on differential form and indicate the stresses acting on the surfaces of the cube in one selected direction. Write down the resulting surface force in the selected direction.

(d) What generates the stresses denoted τ_{ij}. What is the difference between τ_{ij} and σ_{ij}.

Fluid Mechanics:
Chapter 4.3: The Differential Equation of Linear Momentum
MTF053_C04.pdf:
Linear Momentum

4.5 The x-component of the Navier-Sokes equations reads:

$$\rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) = \rho \frac{Du}{Dt} \tag{4.38}$$

where Du/Dt is the substantial derivative

$$\frac{Du}{Dt} = \frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}$$

What is the physical meaning of each of the terms in the equation?

Fluid Mechanics:
Chapter 4.3: The Differential Equation of Linear Momentum
MTF053_C04.pdf:
Linear Momentum

4.6 Under what circumstances can the general formulation of the momentum equation be reduced to the Navier-Stokes equation?

Fluid Mechanics:
Chapter 4.3: The Differential Equation of Linear Momentum
MTF053_C04.pdf:
Linear Momentum - Viscous Stresses in a Newtonian Fluid

4.7 If the integral angular momentum equation is applied to a control volume and the control volume is reduced to infinitesimal size, one will see a special feature of the stress tensor τ_{ij}. What feature is that?

Fluid Mechanics:
Chapter 4.4: The Differential Equation of Angular Momentum
MTF053_C04.pdf:
Angular Momentum

4.8 What is the physical meaning of the terms in the simplified energy equation?

$$\rho C_v \frac{dT}{dt} = k\nabla^2 T + \Phi \tag{4.53}$$

Fluid Mechanics:
Chapter 4.5: The Differential Equation of Energy
MTF053_C04.pdf:
The Energy Equation

4.9 Simplify the following system of equations for incompressible flow. Use the relation between the stress tensor and velocity derivatives applicable for Newtonian fluids.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \tag{4.56}$$

$$\rho \frac{d\mathbf{V}}{dt} = \rho \mathbf{g} - \nabla p + \nabla \cdot \tau_{ij} \tag{4.57}$$

$$\rho \frac{d\hat{u}}{dt} + p\,(\nabla \cdot \mathbf{V}) = \nabla \cdot (k\nabla T) + \Phi \tag{4.58}$$

What unknown properties can be calculated and how many equations do we have?

Fluid Mechanics:
Chapter 4.2: The Differential Equation of Mass Conservation
Chapter 4.3: The Differential Equation of Linear Momentum
Chapter 4.5: The Differential Equation of Energy
MTF053_C04.pdf:
Mass Conservation
Linear Momentum
The Energy Equation

4.10 What boundary conditions are often used for velocity and temperature at a solid wall?

Fluid Mechanics:
Chapter 4.6: Boundary Conditions for the Basic Equations
MTF053_C04.pdf:
Flow Equations on Differential Form

4.11 2D incompressible duct flow:

(a) Simplify the continuity equation and Navier-Stokes equations without pressure gradient driven by a moving upper wall, i.e., Couette flows.

(b) Simplify the continuity equation and Navier-Stokes equations for pressure-driven flow, i.e., Poiseuille flows.

(c) Show that the Couette flow is rotational by analyzing a small fluid element.

Fluid Mechanics:
Chapter 4.10: Some Illustrative Incompressible Viscous Flows

MTF053_C04.pdf:
Example - Couette Flow
Example - Poiseulle Flow

4.12 How is vorticity defined?

Fluid Mechanics:
Chapter 4.8: Vorticity and Irrotationality

MTF053_C04.pdf:
Flow Rotataion

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	**Recommended home problems**
4.1, 4.6, 4.7, 4.11, 4.13	4.2, 4.3, 4.4, 4.5, 4.8, 4.9, 4.10, 4.12, 4.14

5 Dimensional Analysis and Similarity

The course covers most parts of the book *F. M. White Fluid Mechanics 9th ed.* but the following parts of Chapter 5 are **not** included:

- The following examples in section 5.5
  - Exemples 5.9-5.11

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9th ed.*) and in the following complementary course material:

MTF053_C05.pdf

Summary of chapter 5 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

5.1 If you are going to do an experimental investigation of a problem including a number of important physical variables, why is it beneficial to divide the variables into non-dimensional groups?

Fluid Mechanics:
Chapter 5.1: Introduction
MTF053_C05.pdf:
Motivation
Dimensional Analysis - What is it?

5.2 Explain Buckinghams Π-theorem.

Fluid Mechanics:
Chapter 5.3: The Π-Theorem
MTF053_C05.pdf:
The Buckingham Π-Theorem

5.3 Rewrite the continuity equation and the x-component of the momentum equation in non-dimensional form

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{4.12}$$

$$\rho\left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{4.38}$$

Fluid Mechanics:
Chapter 5.4: Nondimensionalisation of the Basic Equations
MTF053_C05.pdf:
Non-Dimensionalized Equations

5.4 Explain the concepts *geometric similarity*, *kinematic similarity*, and *dynamic similarity*

Fluid Mechanics:
Chapter 5.5: Modeling and Similarity
MTF053_C05.pdf:
Geometric Similarity
Kinematic Similarity
Dynamic Similarity

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	Recommended home problems
5.1, 5.2, 5.4	5.3, 5.5, 5.6

6 Viscous Flow In Ducts

The course covers most parts of the book *F. M. White Fluid Mechanics 9th ed.* but the following parts of Chapter 6 are **not** included:

- Section 6.8: Replaced by lecture notes
- The following subsections of section 6.9
  - Gradual Expansion - The Diffuser
- Sections 6.10-6.11
- Most parts of section 6.12 (the subsections *Pitot-Static Tube*, *Bernoulli Obstruction Theory*, and *Venturi Meter* are **included**)

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9th ed.*) and in the following complementary course material:

MTF053_C06.pdf

MTF053_Equation-for-Boundary-Layer-Flows.pdf

MTF053_Turbulence.pdf

Summary of chapter 6 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

6.1 How do we usually define the Reynolds number for pipe flows?

Fluid Mechanics:
Chapter 6.1: Reynolds Number Regimes
MTF053_C06.pdf:
Transition to Turbulence - Osborne Reynolds (1842-1912)

6.2 What does critical Reynolds number mean for a pipe flow?

Fluid Mechanics:
Chapter 6.1: Reynolds Number Regimes
MTF053_C06.pdf:
Transition to Turbulence - Viscous Flow in Ducts

6.3 What does the concept *entrance length* mean? How does the flow velocity profile change over the entrance length?

Fluid Mechanics:
Chapter 6.2: Internal Viscous Flows
MTF053_C06.pdf:
Velocity Profile Development

6.4 What do we mean when we say that a pipe flow is *fully developed*?

Fluid Mechanics:
Chapter 6.2: Internal Viscous Flows
MTF053_C06.pdf:
Velocity Profile Development

6.5 Give three examples of sources of local losses in a pipe system

Fluid Mechanics:
Chapter 6.9: Minor or Local Losses in Pipe Systems
MTF053_C06.pdf:
Local Losses

6.6 Start from Bernoulli's extended equation and the momentum equation for a horizontal pipe with the length L and diameter $D = 2R$ and show that

$$\Delta p_f = 2\tau_w \frac{L}{R}$$

where Δp_f is the pressure drop due to friction

Fluid Mechanics:
Chapter 6.3: Head Loss - The Friction Factor
MTF053_C06.pdf:
Head Loss

6.7 The Darcy friction factor is defined as

$$f = \frac{8\tau_w}{\rho V^2} \tag{6.11}$$

Rewrite the friction loss from the previous question using the Darcy friction factor

Fluid Mechanics:
Chapter 6.3: Head Loss - The Friction Factor
MTF053_C06.pdf:
Head Loss
Friction Factor

6.8 For laminar pipe flows, show that:

$$f = \frac{64}{Re_D} \tag{6.13}$$

Fluid Mechanics:
Chapter 6.4: Laminar Fully Developed Pipe Flow
MTF053_C06.pdf:
Fully-Developed Laminar Pipe Flow

6.9 What parameters effects the magnitude of the friction factor f?

Fluid Mechanics:
Chapter 6.3: Head Loss - The Friction Factor
MTF053_C06.pdf:
Friction Factor

6.10 For fully developed laminar pipe flow, the velocity profile can be expressed as

$$u = u_{max}\left(1 - \frac{r^2}{R^2}\right)$$

Show that the average velocity in fully developed laminar pipe flow is half the maximum velocity.

MTF053_C04.pdf:
Conservation of Mass - Example 2

6.11 Compare the velocity profiles for fully developed laminar and turbulent flow, which of the flows gives the highest wall shear stress for a given mass flow?

MTF053_C06.pdf:
Turbulent Pipe Flow

6.12 For fully developed turbulent pipe flow, the mean velocity profile can be approximated using the 1/7-rule

$$u = u_{max} \left(\frac{r}{R}\right)^{1/7}$$

Why should this not be used directly for the calculation of wall shear stress?

MTF053_C06.pdf:
Example - Pipe Flow Boundary Layer

6.13 Give three characteristics of turbulent flow

MTF053_Turbulence.pdf:
Chapter 1.1: Turbulence Characteristics

6.14 Turbulent flow is dissipative. What does that mean?

MTF053_Turbulence.pdf:
Chapter 1.1: Turbulence Characteristics

6.15 What defines the largest and smallest length scales in a turbulent flow?

MTF053_Turbulence.pdf:
Chapter 1.3: Length Scales in Turbulent Flows

6.16 Explain the concept of Reynolds decomposition

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 2.1: Reynolds Decomposition

MTF053_C06.pdf:
Reynolds Decomposition

6.17 Why do one often want to use time-averaged equations when studying turbulent flow while that is not the case for laminar flows?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

6.18 Explain the closure problem related to the Reynolds-averaged flow equations

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 2.3: Turbulent Stresses

MTF053_C06.pdf:
Reynolds-Averaged Navier Stokes (RANS)

6.19 In the Reynolds decomposition, the velocity components and pressure are divided into an average part and a fluctuating part as for example

$$u = \bar{u} + u' \tag{6.16}$$

Define the time average and show that the time average of the fluctuating component is identically equal to zero.

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling / Reynold's Time Averaging Concept

MTF053_Turbulence.pdf:
Chapter 2.1: Reynolds Decomposition

MTF053_C06.pdf:
Reynolds Decomposition

6.20 How is the intensity of the fluctuating velocity component specified?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling / Reynold's Time Averaging Concept

MTF053_Turbulence.pdf:
Chapter 2.1: Reynolds Decomposition

MTF053_C06.pdf:
Reynolds Decomposition

6.21 Derive the continuity equation for the time-averaged velocity field for incompressible turbulent flow starting from the general continuity equation on differential form

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} \tag{4.4}$$

MTF053_Turbulence.pdf:
Chapter 2.2.1: The Continuity Equation

MTF053_C06.pdf:
Reynolds-Averaged Navier Stokes (RANS)

6.22 Derive the x-component of the Navier-Stokes equation for turbulent flow. Explain the physical meaning of each of the terms in the equation.

MTF053_Turbulence.pdf:
Chapter 2.2.2: The Navier-Stokes Equation

MTF053_C06.pdf:
Reynolds-Averaged Navier Stokes (RANS)

6.23 Show that the term $-\rho\overline{u'v'}$ can be interpreted as a shear stress

MTF053_Turbulence.pdf:
Chapter 2.3: Turbulent Stresses

MTF053_C06.pdf:
Reynolds Stresses

6.24 How can the turbulent shear stress be related to the mean flow using the turbulence viscosity μ_t? What is this assumption called?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 2.5: Turbulent Viscosity

MTF053_C06.pdf:
Reynolds Stresses

6.25 Define the friction velocity u^*

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.1: The Viscous Sublayer

MTF053_C06.pdf:
Viscous Sublayer

6.26 Derive the average velocity distribution in the viscous sublayer starting from

$$\overline{u}\frac{\partial \overline{u}}{\partial x} + \overline{v}\frac{\partial \overline{v}}{\partial y} = \frac{1}{\rho}\frac{\partial \tau}{\partial y}$$

MTF053_Turbulence.pdf:
Chapter 3.1: The Viscous Sublayer

MTF053_C06.pdf:
Viscous Sublayer

6.27 How does the turbulence viscosity μ_t compare to the fluid viscosity μ in the viscous sublayer and in the log region, respectively?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.1: The Viscous Sublayer
Chapter 3.2: The Log-Region

MTF053_C06.pdf:
Laminar vs Turbulent Shear Stress

6.28 How does the total shear stress vary with distance from the wall in the viscous sublayer and in the log region, respectively?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.1: The Viscous Sublayer
Chapter 3.2: The Log-Region

MTF053_C06.pdf:
Viscous Sublayer
Log Region

6.29 How are the velocity profiles characterized mathematically in the viscous sublayer and in the log region, respectively?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.1: The Viscous Sublayer
Chapter 3.2: The Log-Region

MTF053_C06.pdf:
Viscous Sublayer
Log Region

6.30 Make a schematic representation of the non-dimensional velocity u^+ as a function of the non-dimensional wall distance y^+ for a turbulent boundary layer. The velocity profile can be divided into different regions. Name these regions.

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.3: The Other Regions in a Turbulent Boundary Layer

MTF053_C06.pdf:
Regions in a Turbulent Boundary Layer

6.31 What relation for the local average velocity is used for the derivation of the friction factor f for turbulent pipe flow?

Fluid Mechanics:
Chapter 6.5: Turbulence Modeling

MTF053_Turbulence.pdf:
Chapter 3.5: The Skin Friction Coefficient for Turbulent Pipe Flow

MTF053_C06.pdf:
Turbulent Pipe Flow

6.32 The Moody chart is an engineering tool that can be used for estimation of pressure losses in a pipe flow

(a) Why does the Moody chart not give reliable values in the Reynolds number range $2000 < Re < 4000$?

(b) How does f vary with the Reynolds number in the fully turbulent regime?

(c) What is the effect of surface roughness on the friction factor?

(d) What can we say about the Moody chart when it comes to accuracy?

Fluid Mechanics:
Chapter 6.6: Turbulent Pipe Flow

MTF053_Turbulence.pdf:
Chapter 3.6: Surface Roughness

MTF053_C06.pdf:
Wall Roughness
Moody Chart

6.33 How is the hydraulic diameter defined and how can it be used for calculation of the friction factor f for laminar and turbulent flow in non-circular ducts?

Fluid Mechanics:
Chapter 6.8: Flow in Non-Circular Ducts

MTF053_C06.pdf:
Non-Circular Ducts

6.34 Define the loss coefficient K

Fluid Mechanics:
Chapter 6.9: Minor or Local Losses in Pipe Systems

Recommended Problems

Problem numbering according to `MTF053_Recommended_Problems.pdf`

Problems solved in class	**Recommended home problems**
6.5, 6.10, 6.11, 6.13, 6.14, 6.16	6.1, 6.2, 6.3, 6.4, 6.6, 6.7, 6.8, 6.9, 6.12, 6.15

7 Flow Past Immersed Bodies

The course covers most parts of the book *F. M. White Fluid Mechanics 9^{th} ed.* but the following parts of Chapter 7 are **not** included:

- The following subsections of section 7.5
  - Laminar Integral Theory
- The following subsections of section 7.6
  - Buoyant Rising Light Spheres
  - Drag of Surface Ships
  - Body Drag at High Mach Numbers
  - Biological Drag Reduction
- The following subsections of section 7.7
  - The Kline Fogelman Airfoil
  - A Wing Inspired by the Humpback Whale
  - A combination Car and Airplan

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9^{th} ed.*) and in the following complementary course material:

MTF053_C07.pdf

MTF053_Equation-for-Boundary-Layer-Flows.pdf

MTF053_Turbulence.pdf

Summary of chapter 7 (and quiz)

MTF053_Formulas-Tables-and-Graphs.pdf

MTF053_Recommended_Problems.pdf

7.1 Make a schematic sketch of the velocity profile in a flat-plate boundary layer showing the extent of the viscous region at $Re_L = 10$ and $Re_L = 10^7$, respectively. How does the extent of the viscous region δ relate to the characteristic length, L, for the two Reynolds numbers? Indicate what parts of the boundary layer that is laminar and turbulent respectively as well as the transition region.

Fluid Mechanics:
Chapter 7.1: Reynolds Number and Geometry Effects
MTF053_C07.pdf:
Reynolds Number Effects

7.2 Make a schematic sketch of the flow over a cylinder at $Re_D = 10^5$. Indicate the stagnation point, separation points and the wake region.

Fluid Mechanics:
Chapter 7.1: Reynolds Number and Geometry Effects

MTF053_C07.pdf:
Pressure Gradient

7.3 The boundary layer equations are derived from the continuity equation and the Navier-Stokes equation on non-dimensional form

(a) Define the non-dimensional properties x^*, u^*, and p^* and explain the included properties.

(b) Give the order of magnitude of x^*, u^*, and p^* that holds for larger part of the boundary layer. The estimation of magnitude is made using the following terms $\partial u^*/\partial x^*$, $\partial u^*/\partial y^*$, $\partial^2 u^*/\partial {x^*}^2$, and ν^*. Use relevant figures to justify the estimation of the derivatives.

(c) What assumption is made to be able to derive the boundary layer equations?

(d) Show that the static pressure is independent of the distance from the wall in a laminar two-dimensional boundary layer. Use the non-dimensional form of the y-component of the Navier-Stokes equations

$$u^* \frac{\partial v^*}{\partial x^*} + v^* \frac{\partial v^*}{\partial y^*} = -\frac{\partial p^*}{\partial y^*} + \frac{1}{Re} \left(\frac{\partial^2 v^*}{\partial {x^*}^2} + \frac{\partial^2 v^*}{\partial {y^*}^2} \right)$$

The following size estimates can be assumed to hold (does not need to be proved): $u^* \sim 1$, $v^* \sim \delta^*$, and $Re \sim {\delta^*}^{-2}$

note: here δ^* is the non-dimensional boundary layer thickness, not the displacement thickness

(e) How do the boundary layer equations for laminar boundary-layer flow and turbulent boundary-layer flow differ? How does this difference affect the possibility to solve the equations?

MTF053_Equation-for-Boundary-Layer-Flows.pdf:
Chapter 2: The Boundary-Layer Equations

MTF053_C07.pdf:
Boundary Layer Equations

7.4 Show using the Bernoulli equation (with small differences in elevation) that the pressure gradient for the flow over a flat plate depends on the density, the derivative of the freestream velocity, and the freestream velocity. Justify the use of the Bernoulli equation for this purpose.

MTF053_Equation-for-Boundary-Layer-Flows.pdf:
Chapter 2: The Boundary-Layer Equations

MTF053_C07.pdf:
Boundary Layer Equations

7.5 Describe in words the steps taken in Blasius solution of the boundary layer equations for laminar flow over a flat plate.

Fluid Mechanics:
Chapter 7.4: The Flat-Plate Boundary Layer

MTF053_C07.pdf:
The Blasius Velocity Profile

7.6 For laminar flow over a flat plate, the velocity profile is self-similar - what does that mean?

Fluid Mechanics:
Chapter 7.4: The Flat-Plate Boundary Layer

MTF053_C07.pdf:
The Blasius Velocity Profile - Self Similarity

7.7 For a laminar boundary layer over a flat plate, the local wall shear stress coefficient c_f can be obtained as

$$c_f = \frac{0.664}{\sqrt{Re_x}} \tag{7.25}$$

The wall shear stress coefficient, c_f, is related to the wall shear stress, τ_w, and the free stream velocity, U, as

$$c_f = \frac{2\tau_w}{\rho U^2} \tag{7.10}$$

Show how to obtain the total friction force (the flat plate drag), D, for one side of a flat plate with the length L. Derive an expression for the drag force on non-dimensional form using the drag coefficient C_D.

Fluid Mechanics:
Chapter 7.4: The Flat-Plate Boundary Layer
MTF053_C07.pdf:
Laminar Boundary Layer - Blasius

7.8 Name two alternative ways to measure the boundary layer thickness other than δ. How can these measures be interpreted physically?

Fluid Mechanics:
Chapter 7.2: Momentum Integral Estimates
MTF053_Equation-for-Boundary-Layer-Flows.pdf:
Chapter 3: Integral Estimates
MTF053_C07.pdf:
Momentum Integral Estimates

7.9 Derive von Kármán's momentum integral relation

$$\tau_w = \rho U^2 \frac{d\theta}{dx} \tag{7.5}$$

starting from

$$D(x) = \rho b U^2 \theta \tag{7.3}$$

where

$$\theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$$

Describe how to derive an approximate solution for the boundary layer thickness and the wall shear stress for laminar flow over a flat plate using the von Kármán momentum integral relation.

Fluid Mechanics:
Chapter 7.2: Momentum Integral Estimates
MTF053_Equation-for-Boundary-Layer-Flows.pdf:
Chapter 3: Integral Estimates
MTF053_C07.pdf:
The Von Kármán Integral Relation

7.10 In what way is the transition location effected by (assume other properties to be constant)

(a) increased freestream velocity U for a given $Re_{x,tr}$
(b) surface roughness ε
(c) freestream turbulence

(d) positive pressure gradient

Fluid Mechanics:
Chapter 7.4: The Flat-Plate Boundary Layer
MTF053_C07.pdf:
Boundary Layer Transition

7.11 Show how the velocity profile as well as its first and second derivative and the pressure gradient change in a boundary layer when the flow separates

Fluid Mechanics:
Chapter 7.5: Boundary Layers with Pressure Gradient
MTF053_C07.pdf:
Pressure Gradient

7.12 The drag coefficient, C_D, for cylinder flow is drastically changed as the boundary layer becomes turbulent (before separating). Show schematically how C_D varies with the Reynolds number, Re_D, and indicate the location transition to turbulence and separation.

Fluid Mechanics:
Chapter 7.6: Drag of Two- and Three-Dimensional Bodies
MTF053_C07.pdf:
Cylinder Surface Pressure
Cylinder Drag

7.13 The drag coefficient, C_D, can be divided into two components, which two components? What phenomena are associated with each of the two components?

Fluid Mechanics:
Chapter 7.6: Drag of Two- and Three-Dimensional Bodies
MTF053_C07.pdf:
Drag of Immersed Bodies

7.14 Make a schematic representation of the pressure distribution around a cylinder for inviscid flow (potential flow), viscous flow with laminar and turbulent separation respectively. Explain why the pressure varies the way it does. Which of the three cases will give the lowest and highest pressure drag?

Fluid Mechanics:
Chapter 7.6: Drag of Two- and Three-Dimensional Bodies
MTF053_C07.pdf:
Cylinder Surface Pressure

7.15 Why do dimpled golf balls have lower pressure drag than golf balls with smooth surfaces?

Fluid Mechanics:
Chapter 7.6: Drag of Two- and Three-Dimensional Bodies
MTF053_C07.pdf:
Cylinder Surface Pressure

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	**Recommended home problems**
7.2, 7.4, 7.6*, 7.10, 7.11, 7.14, 7.17, 7.21	7.1, 7.3, 7.5, 7.7, 7.8, 7.9, 7.12, 7.13, 7.15, 7.16, 7.18, 7.19, 7.20, 7.22

8 Potential Flow and Computational Fluid Dynamics

Chapter 8 is **not** included in the course

9 Compressible Flow

The course covers most parts of the book *F. M. White Fluid Mechanics 9^{th} ed.* but the following parts of Chapter 9 are **not** included:

- Sections 9.7-9.8
- The following subsections of section 9.10
  - Thin Airfoil Theory

Theory Questions

Answers to the theory questions listed below can be found in the course book (*F. M. White Fluid Mechanics 9^{th} ed.*) and in the following complementary course material:

`MTF053_C09.pdf`

Summary of chapter 9 (and quiz)

`MTF053_Equation-for-Boundary-Layer-Flows.pdf`

9.1 How is the Mach number defined?

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics
`MTF053_C09.pdf`:
Mach Number Regimes

9.2 Show by estimation of the density variation in a fluid flow that the criteria for incompressible flow is $M \ll 1$
hint: see Eqn 4.13 - 4.17 in F. M. White Fluid Mechanics 9^{th} ed.

Fluid Mechanics:
Chapter 4.2: The Differential Equation of Mass Conservation

9.3 What is the upper Mach number often used as the limit for incompressible flow?

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics

9.4 Name the different Mach number regimes in compressible flow and specify the corresponding Mach number ranges

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics
`MTF053_C09.pdf`:
Mach Number Regimes

9.5 What is an adiabatic process?

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics
Chapter 9.3: Adiabatic and Isentropic Steady Flow

9.6 What is required for a process to be isentropic?

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics
Chapter 9.3: Adiabatic and Isentropic Steady Flow

9.7 Write down the relation between internal energy and temperature and between enthalpy and temperature for

(a) an ideal gas with constant specific heats (calorically perfect gas)

(b) an ideal gas with specific heats that are functions of temperature (thermally perfect gas)

Fluid Mechanics:
Chapter 9.1: Introduction: Review of Thermodynamics
Chapter 9.3: Adiabatic and Isentropic Steady Flow
MTF053_C09.pdf:
Internal Energy and Enthalpy

9.8 Derive an expression for the speed of sound for a generic fluid. In the derivation, an assumption regarding the pressure derivative is made – what is the assumption?

Fluid Mechanics:
Chapter 9.2: The Speed of Sound
MTF053_C09.pdf:
Speed of Sound

9.9 The speed of sound in a generic fluid is given by

$$a = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s} \quad (9.15)$$

From the relation above, derive an expression for the speed of sound in a calorically perfect gas (perfect gas with constant specific heats) as a function of temperature. Use the isentropic relation

$$\frac{p_2}{p_1} = \left(\frac{\rho_2}{\rho_1}\right)^{\gamma} \quad (9.9)$$

Fluid Mechanics:
Chapter 9.2: The Speed of Sound
MTF053_C09.pdf:
Speed of Sound

9.10 The adiabatic energy equation

(a) Write down the energy equation for steady-state adiabatic compressible flow without potential energy changes and no viscous work. The equation should be written out using enthalpy.

(b) Rewrite the energy equation from the previous question but now expressed in terms of temperature

(c) Now, derive the following relation:

$$\frac{T_o}{T} = 1 + \frac{\gamma - 1}{2} M^2 \quad (9.26)$$

Fluid Mechanics:
Chapter 9.3: Adiabatic and Isentropic Flow
MTF053_C09.pdf:
Stagnation Enthalpy
Stagnation Temperature
Mach Number Relations

9.11 Which of the properties h_o, T_o, a_o, p_o, and ρ_o are constants in a flow if the flow is adiabatic and isentropic, respectively?

Fluid Mechanics:
Chapter 9.3: Adiabatic and Isentropic Flow
MTF053_C09.pdf:
Stagnation Properties

9.12 What is a critical property (such as for example the critical temperature T^*)?

Fluid Mechanics:
Chapter 9.3: Adiabatic and Isentropic Flow

MTF053_C09.pdf:
Critical Properties

9.13 Using the continuity equation and energy equation on differential form together with the definition of speed of sound, the following relation can be derived

$$\frac{dV}{V} = \frac{dA}{A}\frac{1}{M^2-1} = -\frac{dp}{\rho V^2} \tag{9.40}$$

Show, using the relation given above, how the velocity and pressure changes in a flow through a divergent or convergent duct for initially subsonic flow or initially supersonic flow

Fluid Mechanics:
Chapter 9.4: Isentropic Flow with Area Changes
MTF053_C09.pdf:
The Area-Velocity Relation

9.14 Explain the concept of choking

Fluid Mechanics:
Chapter 9.4: Isentropic Flow with Area Changes / Choking
MTF053_C09.pdf:
The Area-Mach-Number Relation
Choking

9.15 Normal shocks:

(a) Explain what a normal shock is. What happens with the velocity, pressure and total temperature over a normal shock? How is the critical area, A^* affected?

(b) The normal shock equation system has two solutions. How do we know which solution that is the correct one?

(c) How is the Hugoniot relation derived?

(d) Derive a relation for the pressure ratio over a normal shock

(e) How does pressure (p), temperature (T), density (ρ), Mach number (M), total pressure (p_o), and total temperature (T_o) change over a normal shock?

Fluid Mechanics:
Chapter 9.5: The Normal Shock Wave
MTF053_C09.pdf:
Normal Shocks

9.16 Explain, using a schematic figure, how pressure and velocity varies in a nozzle (the two types of nozzles specified below) as the downstream pressures (back pressures) changes. The upstream end of the nozzle is connected to a large reservoir (tank) with the pressure p_o and temperature T_o. What happens with the mass flow when the downstream pressure changes?

(a) convergent nozzle

(b) convergent-divergent nozzle

Fluid Mechanics:
Chapter 9.6: Operation of Converging and Diverging Nozzles
MTF053_C09.pdf:
Convergent-Divergent Nozzles

9.17 Make a schematic sketch showing how pressure waves expands around an object moving at

(a) subsonic speed

(b) sonic speed

(c) supersonic speed

Show the location of object at the time t and the time $t + \Delta t$. In your sketch, show features such as Mach waves and the Mach angle

Fluid Mechanics:
Chapter 9.9: Mach Waves and Oblique Shock Waves
MTF053_C09.pdf:
Mach Wave

9.18 Oblique shocks:

(a) Show schematically how the velocity (normal velocity component, tangential velocity component, and the total velocity) changes over an oblique shock. Indicate the shock angle, β, and the deflection angle, θ.

(b) Show schematically how the oblique shock formed ahead of a wedge traveling at supersonic speed if

i. $\theta < \theta_{max}$

ii. $\theta > \theta_{max}$

(c) Can the relations for total quantities for a normal shock be used for an oblique shock? Explain why/why not.

Fluid Mechanics:
Chapter 9.9: Mach Waves and Oblique Shock Waves
MTF053_C09.pdf:
Oblique Shock Relations
Flow Deflection

9.19 Prandtl-Meyer expansions:

(a) What is a Prandtl-Meyer expansion. Show with a figure.

(b) How does pressure (p), temperature (T), density (ρ), Mach number (M), total pressure (p_o), and total temperature (T_o) change over an expansion region?

Fluid Mechanics:
Chapter 9.10: Prandtl-Meyer Expansion Waves
MTF053_C09.pdf:
Prandtl-Meyer Expansion Waves

Recommended Problems

Problem numbering according to MTF053_Recommended_Problems.pdf

Problems solved in class	Recommended home problems
9.2, 9.4, 9.7, 9.9, 9.15, 9.17, 9.20	9.1, 9.3, 9.5, 9.6, 9.8, 9.10, 9.11, 9.12, 9.13, 9.14, 9.16, 9.18, 9.19

10 Open-Channel Flow

Chapter 10 is **not** included in the course

11 Turbomachinery

Chapter 11 is **not** included in the course