Nanyang Technological University
Division of Physics and Applied Physics

Academic Year	2020/21	**Semester**	1
Course Coordinator	A/P Cheong Siew Ann		
Course Code	PH3501		
Course Title	Fluid Mechanics		
Pre-requisites	PH2104 or PH2201		
No of AUs	4 AU		
Contact Hours	Lecture: 39 hours (3 hours per week); Tutorial: 12 hours (1 hour per week)		
Proposal Date	3 June 2020		

Course Aims

This course introduces the laws governing fluid motion. Starting from Pascal's Principle and Archimedes' Principle for hydrostatics, you will learn the Lagrangian and Eulerian descriptions of fluid flow, and how to combine the mass continuity equation and Newton's Second Law to derive the Navier-Stokes Equation (and Euler's Equation, its linearized approximation), or to combine mass continuity with energy conservation to derive Bernoulli's equation. After learning about stream functions and vorticity, you will solve for laminar flows of incompressible inviscid fluids in simple geometries, before moving on to consider compressible fluids with and without viscosity. Finally, you will learn how to construct the dimensionless scaling variable known as the Reynolds number, and how it determines whether a flow is laminar or turbulent. When possible, you will also learn how to apply your understanding of fluid mechanics to surface waves in shallow waters.

Intended Learning Outcomes (ILO)

Upon the successful completion of this course, you (as a student) would be able to:

1. Apply Pascal's and Archimedes' Principles to hydrostatic problems;
2. Describe the differences between the Lagrangian and Eulerian descriptions of fluid flow;
3. Derive the differential form of the mass continuity equation;
4. Combine the mass continuity equation and the differential form of Newton's Second Law to derive the Navier-Stokes Equation;
5. Combine the mass continuity equation and the conservation of mechanical energy to derive Bernoulli's equation;
6. Describe the linear momentum density and angular momentum density of a fluid in terms of stream functions and vorticity for laminar flow;
7. Recognise how the physics of fluid flow changes when it is viscous;
8. Recognise how fluid flow can be characterized by the dimensionless scaling variable known as Reynolds number, and determine whether the flow is laminar or turbulent;
9. Apply your understanding of the Navier-Stokes Equation to derive the equation governing surface waves in shallow waters.

Course Content

Hydrostatics

Pascal's Principle $p = \rho g h$
Archimedes' Principle $F_B = \rho_f V_s g$

Conservation of Mass, Momentum, and Energy

Mass continuity equation $\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$

Navier-Stokes Equation $\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \nabla \vec{u} = -\nabla p + \nabla \cdot \vec{\tau} + \rho \vec{g}$
Bernoulli's Equation $\frac{u^2}{2} + gz + \frac{p}{\rho} =$ constant

Laminar Flow

Stream function and vorticity
Two-dimensional flow around a cylindrical obstacle
Two-dimensional flow across a step
Flow between two parallel plates
Couette flow

Reynolds Number and Turbulent Flow

Reynolds Number
Dimensionless Navier-Stokes Equation
Linear instability of Dimensionless Navier-Stokes Equation

Surface and Interfacial Waves

Linear instability of Water-Air Interface
Waves in shallow waters

Assessment (includes both continuous and summative assessment)

Component	Course LO Tested	Related Programme LO or Graduate Attributes	Weighting	Team / Individual	Assessment Rubrics
1. Final Examination	All	Competence (1,3,4)	60%	Individual	Point-based marking (not rubric-based)
2. CA1: Quiz 1	1-5	Competence (1,3,4)	15%	Individual	Point-based marking (not rubric-based)
3. CA2: Quiz 2	6-9	Competence (1,3,4)	15%	Individual	Point-based marking (not rubric-based)
4. CA3: Assignments	All	Competence (1,3,4) Creativity (1) Communication (3) Character (3)	10%	Individual	Point-based marking (not rubric-based) You are encouraged to discuss with your course mates, but

					please write up for submission on your own
Total			100%		

Formative feedback

You are encouraged to ask questions during lectures and tutorials, to clear doubts quickly. Homework will be graded and feedback given, and you are encouraged to check against the homework solutions provided. Feedback on the common mistakes is also given after each quiz. Past exam questions and examiner's report will be made available to students.

Learning and Teaching approach

Approach	How does this approach support students in achieving the learning outcomes?
Lectures	Reviews of previous materials will be done first. We will focus on developing physical intuition before going in to the mathematics. After a problem has been solved mathematically, we will then interpret the physics of the solution.
Tutorial	We will attempt additional problems during tutorials to supplement the physical understanding and mathematical competence developed in the lectures. You will learn how to justify physically and mathematically every step of your solution.
Homework	Homeworks will serve two purposes. First, tedious mathematical derivations outlined in lectures will be assigned as homework exercises, to help students acquire mathematical competence. Second, variations of problems solved in lectures and tutorials will also be assigned, to help students broaden their physical intuition on fluids.

Reading and References

Primary

1. T. E. Faber, *Fluid Dynamics for Physicists, 1st Edition*. Cambridge University Press (1995). ISBN-13: 978-0521429696
2. P. S. Bernard, *Fluid Dynamics, 1st Edition*. Cambridge University Press (2015). ISBN-13: 978-1107071575

Supplementary

3. C. Pozrikidis, *Fluid Dynamics: Theory, Computation, and Numerical Simulation, 3rd Edition*. Springer (2016). ISBN-13: 978-1489979902
4. G. K. Batchelor, *An Introduction to Fluid Dynamics*. Cambridge University Press (2000). ISBN-13: 978-0521663960

5. A. Feldmeier, *Theoretical Fluid Dynamics*. Springer (2019). ISBN-13: 978-3030310219
6. D. J. Tritton, *Physical Fluid Dynamics, 2nd Edition*. Clarendon Press (1988). ISBN-13: 978-0198544937

Course Policies and Student Responsibilities

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class / Mid-term quizzes, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class and make-up mid-term quizzes.
2. Submit the original Medical Certificate* or official letter of excuse to administrator.
3. Attend the assigned replacement class (*subject to availability*) and make-up mid-term quizzes.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Academic Integrity

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructor

Instructor	Office Location	Phone	Email
A/P Cheong Siew Ann	SPMS-PAP-04-03	65138084	cheongsa@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course LO	Readings/ Activities
1	Forces in a fluid at rest	1	Textbook, Lecture notes
2	Lagrangian and Eulerian description; Continuum approximation	2	Textbook, Lecture notes, Tutorial
3	Conservation of mass; continuity equation; conservation of linear	3, 4, 5	Textbook, Lecture notes

	momentum; conservation of energy		
4	Derivation of Navier-Stokes Equation; Derivation of Bernoulli's Equation	4, 5	Textbook, Lecture notes, Tutorial
5	Stream function and vorticity	6	Textbook, Lecture notes
6	Laminar flow in simple geometries	6	Textbook, Lecture notes, Tutorial
7	Laminar flow in simple geometries; Viscosity	6, 7	Textbook, Lecture notes, Quiz 1
8	Viscous flow in simple geometries	7	Textbook, Lecture notes, Tutorial
9	Viscous flow in simple geometries; Reynolds number	7, 8	Textbook, Lecture notes
10	Dimensionless Navier-Stokes equation; Linear stability; Turbulence	8	Textbook, Lecture notes, Tutorial
11	Water-air interface; linear stability	9	Textbook, Lecture notes
12	Shallow water equation	9	Textbook, Lecture notes, Tutorial
13	Review	All	Textbook, Lecture notes, Quiz 2

Graduate Attributes

What we want our graduates from Physics and Applied Physics to be able to do:

Upon the successful completion of the PHY, APHY and PHMA programs, graduates should be able to:

Competency	1	demonstrate a rigorous understanding of the core theories and principles of physics involving (but not limited to) areas such as classical mechanics, electromagnetism, thermal physics and quantum mechanics;
		[PHMA only] demonstrate a rigorous understanding of the core theories and principles of mathematical sciences involving (but not limited to) areas such as analysis, algebra and statistical analysis;
	2	read and understand undergraduate level physics content independently;
	3	make educated guesses / estimations of physical quantities in general;
	4	apply fundamental physics knowledge, logical reasoning, mathematical and computational skills to analyse, model and solve problems;
	5	develop theoretical descriptions of physical phenomena with an understanding of the underlying assumptions and limitations;
	6	critically evaluate and distinguish sources of scientific/non-scientific information and to recommend appropriate decisions and choices when needed;
	7	demonstrate the ability to design and conduct experiments in a Physics laboratory, to make measurements, analyse and interpret data to draw valid conclusions.

Creativity	1	propose valid approaches to tackle open-ended problems in unexplored domains;
	2	offer valid alternative perspectives/approaches to a given situation or problem.

Communication	1	describe physical phenomena with scientifically sound principles;
	2	communicate (in writing and speaking) scientific and non-scientific ideas effectively to professional scientists and to the general public;
	3	communicate effectively with team members when working in a group.

Character	1	uphold absolute integrity when conducting scientific experiments, reporting and using the scientific results;
	2	readily pick up new skills, particularly technology related ones, to tackle new problems;
	3	contribute as a valued team member when working in a group.

Civic Mindedness	1	put together the skills and knowledge into their work in an effective, responsible and ethical manner for the benefits of society.