Fluid Mechanics
EML 5709
Syllabus

Dr. Leon van Dommelen

Fall 2014

Contents

1 Credit Hours

3

2 Course Type

Core Graduate.

3 Terms Offered

Fall.

4 Catalog Description

Introductory conceps,description, and kinematical concepts of fluid motion, basic field equations, thermodynamics of fluid flow, Navier-Stokes equations, elements of the effects of friction and heat flow, unsteady one-dimensional motion, selected nonlinear steady flows.

5 Prerequisites

Graduate standing in Mechanical Engineering. (Knowledge of undergraduate fluid mechanics, calculus, and ordinary differential equations.)

6 Instructor

Dr. Leon Van Dommelen:

Office hours MWR 2–3 pm, or by appointment, in A242 CEB

Phone (850) 410-6324. I tend to forget to check my voice mail.

E-mail `mailto:dommelen@eng.fsu.edu`

Web page `http://www.eng.fsu.edu/~dommelen/index.html`

Contact information `http://www.eng.fsu.edu/~dommelen/contact`

7 Teaching Assistant

None

8 Class Schedule

Class times: MWF 11:00-11:50 in B214 CEB (B building).

Homeworks will be posted as soon as possible after Friday's class and will be due the next Friday.

The below tentative schedule was taken from the 2011 class taught by Dr. Tiara and is likely to be modified as we go along. K stands for the Kundu & Cohen class textbook, and other initials stand for the corresponding other references.

- 08/25/14 M First day of class. Syllabus. Fundamental concepts. [K: Chap 1.1-3; P: 1.2-3] Continuum hypothesis. [K: Chap 1.4; P: 1.1,4] Viscous stress. [K: Chap 1.5; P: 6.2]
- 08/27/14 W Stress tensor. [K: Chap 2.1,3-4,6,8,10; P: 3.1-2,5-6 5.3-6]. Please have a look at these book sections before class.
- 08/29/14 F Tensor calculus. [K: Chap 2.2,11; P: 3.4,7,10]. Please have a look at these book sections before class.

- 09/01/14 M LABOR DAY ==========
- 09/03/14 W Rate of deformation tensor. [K: Chap 2.9, 3.4; P: 4.4-5]. Before class, you must watch the video Deformation of Continuous Media from `http://web.mit.edu/hml/ncfmf.html`. One version is at YouTube[1]
- 09/05/14 F Due HW 1. Constitutive relation. Asymmetric stress tensor. [K: Chap 2.7, 4.5; P: 6.1]

[1] `https://www.youtube.com/watch?v=pqWwHxn6LNo&list=PL0EC6527BE871ABA3&index=2&feature=plpp_video`

- 09/08/14 M Control masses. Conservation laws. Control Volumes. [K: 2.12-14, 3.6, 4.1-2,4; P: 3.12-13, 5.1-3,13-14]. Before class, please study the Fluids DVD / Control Volumes / Introduction and Basic Concepts, 866-880.
- 09/10/14 W Control volumes, simple and non simple. Reynold transport theorem = Leibniz. [KC 2.12-14, 3.6, 4.1-2,4; P: 3.12-13, 5.1-3,13-14].
- 09/12/14 F Due HW 2. Control volumes. CV analysis of drag. Momentum thickness. [KC 2.12-14, 3.6, 4.1-2,4; P: 3.12-13, 5.1-3,13-14].

- 09/15/14 M Finite volume method. [P: 5.7].
- 09/17/14 W Boundary conditions [K: 4.10; P: 6,4]. Differential continuity equation from a zero-size finite volume. [K: 4.1-2; P: 5.1].
- 09/19/14 F Due HW 3. Reynolds transport theorem $\neq$ Leibniz. Differential continuity equation. [K: 4.1-2; P: 5.1]. Differential momentum conservation. [K: 4.4; P: 5.7]. Differential energy equation. [K: 4.8; P: 5.9].

- 09/22/14 M Lagrangian/Eulerian descriptions. [K: 3.1-2; P: 4.1-2]. Material/ Lagrangian/substantial derivative. [K: 3.2; P: 4.3]. Path/stream/streak lines. [K: 3.3; P: 4.2]
- 09/24/14 W Nonconservative continuity equation. Incompressible flow. [K: 4.2; P: 5.1]. Nonconservative momentum equations. Navier-Stokes equations. [K: 4.4-6; P: 5.7, 6.6 16.2]. Hydrostatics. Kinetic pressure. [K: 1.7, 4.9; P: 10.5].
- 09/26/14 F Due HW 4. Nonconservative energy equation. Mechanical and thermal energy equations. Entropy equation. The 2nd law. [K: 4.8; P: 5.10-12].

- 09/29/14 M Compressible Euler equations. "Incompressible" Navier-Stokes equations. Dynamic similarity. [K: 4.11; P: 10.2-4].
- 10/01/14 W Non-dimensional parameters. [K: 1.11; P: 8.1-4,8].
- 10/03/14 F Due HW 5. Buckingham Π theorem. Low-Reynolds number flow past a sphere. [K: 8.6, P: Chap 21.8].

- 10/06/14 M FE revisited. Exact solutions (laminar, steady): Plane Poiseuille flow. [K: 8.2; P: 7.1,3].
- 10/08/14 W Exact solutions (laminar, steady): Plane Poiseuille flow. Couette Flow. [K: 8.2; P: 11.1].
- 10/10/14 F Due HW 6. Exact solutions (laminar, unsteady): Poiseuille pipe flow. Elliptic and triangular pipes. [K: 8.4; P: 7.7, 11.8]

- 10/13/14 M Midterm Review I. Cylindrical and spherical coordinates.
- 10/15/14 W Centripetal acceleration. Bernoulli's equation. Major head loss [K: 4.9; P: 7.2]
- 10/17/14 F Due HW 7. Minor head losses. Entrance effects. Normal pressure gradients. [P: 7.2]

- 10/20/14 M Midterm Review II.
- 10/22/14 W Midterm.

- 10/24/14 F Due none. Midterm discussion Stokes' 1st problem (AKA Rayleigh's problem). [K: 8.4; P: 7.7]

- 10/27/14 M Stokes' 1st problem (AKA Rayleigh's problem). Similarity. (Lamb-)Oseen vortex. [K: 8.4; P: 7.7, 11.8]
- 10/29/14 W Midterm II
- 10/31/14 F Due HW 8 and 9. Kelvin's theorem: vortex strenghtening. [K: 5.2; P:13.10] Kutta-Joukowski law. [K: 6.5; P: 18.8] Stokes theorem: boundary layer vorticity and lift; persistence of irrotational flow. [K: 2.13; P: 3.12]

- 11/03/14 M Helmholtz laws. [K: 5.3; P:13.9] Vortex system of a wing.
- 11/05/14 W Biot-Savart law. [K: 5.5; P: 17.2] Line vortices. [K: 5.7; P: 13.11] Induced drag. [K: 14.6]
- 11/07/14 F Due HW 10. Ideal flows. Potential. Streamfunction. [K: 6.1-6; P: 18.1-13]

- 11/10/14 M Ideal flows. Circular cylinder potential. Interpretation of the streamfunction. Potential flow Bernoulli law. [K: 6.1-6; P: 18.1-13]
- 11/12/14 W Ideal flows. Complex potential. Complex numbers. Uniform flow. Source/Sink. [K: 6.1-6; P: 18.1-13]
- 11/14/14 F Due HW 11. Ideal flows. More complex manipulations. Vortex flow. Shifting sources and vortices. Superposition and Magnus effect. Corners. [K: 6.1-6; P: 18.1-13]

- 11/17/14 M Ideal flows. 2D Rankine half body, oval. Conformal mapping. Plates and ellipses. Joukowski airfoils. Kutta condition. [K: 6.1-6; P: 18.1-13]
- 11/19/14 W Boundary layer variables, equations, boundary conditions. [K: 9.1; P: 16.1-5, 20.11]
- 11/21/14 F Due HW 12. Blasius boundary layer for a semi-infinite flush plate. [K: 9.3; P: 20.1]

- 11/24/14 M (APS DFD) Boundary layer thicknesses, displacement effect, separation. [K: 9.2,7-9; P: 20.2,11,16, 14.6]
- 11/26/14 W THANKSGIVING ==========
- 11/28/14 F THANKSGIVING ==========

- 12/01/14 M Review. Hydrodynamic instability. Kelvin-Helmholtz instability. [K: 11.1,3; P: 25.1-2] Turbulence: historical notes. [K: 12.1-3; P: 26.1-2]
- 12/03/14 W RETURN DVD TO INSTRUCTOR. Reynolds decomposition. Reynolds stress. Mixing length. Energy cascade. Kolmogorov scales. [K: 12.5; P: 26.3,4]
- 12/05/14 F Due HW 13. Inertial range. Free turbulence. (Wall bounded turbulence in the lecture notes). [K: 12.8,9; P: 26.5,6,11,12]

- 12/10/14 Wednesday 12:30-2:30 pm FINAL EXAM (in the usual classroom)

- 12/16/14 Grades due FAMU/FSU 5:00/4:00 pm
- 12/17/14 Grades available online

9 Textbooks

Required:

1. Kundu, Pijush K, Cohen, Ira M, & Dowling, David R, *Fluid Mechanics.* Academic Press, Fifth Edition, 2012. ISBN 978-0-12-382100-3. (This book includes the Homsy DVD mentioned below.)

The following references are useful:

1. ? Aris, R, *Vectors, tensors and the basic equations of fluid mechanics.*

2. Batchelor, G. K, *An Introduction to Fluid Mechanics.* Cambridge University Press 1988.

3. Currie, I. G, *Fundamental Mechanics of Fluids.* McGraw-Hill Second Edition 1993. ISBN 0-07-015000-1.

4. Karamcheti, Krishnamurty *Principles of Ideal–Fluid Aerodynamics.* Robert E. Krieger Publishing Co, 1980.

5. ? Granger, Robert A, *Fluid Mechanics.* Holt, Rinehart, and Winston, 1985. ISBN 0-03-062951-9.

6. Homsey, G.M., *Multimedia Fluid Mechanics DVD-ROM* Cambridge University Press[2] (Included for free in the required text book.)

7. Liepmann, H. W, and Roshko, A, *Elements of Gasdynamics.* John Wiley & Sons, 1957.

8. Panton, Ronald L, *Incompressible Flow.* John Wiley & Sons, Inc, Third Edition, 2005. ISBN-10 0-471-26122-X; ISBN-13 978-0-471-26122-3. (Typically considered a very helpful book by many students.)

9. Schlichting, H, *Boundary Layer Theory.* McGraw-Hill, 1968.

10. Spiegel, Murray R, *Complex Variables.* Schaum's Outline Series, McGraw-Hill, 1964. ISBN 07-060230-1.

11. White, Frank M, *Viscous Fluid Flow.* McGraw-Hill, Second Edition, 1991. ISBN 0-07-069712-4. Third Edition, 2006. ISBN 0-07-240231-8.

10 Science/Design

Engineering Science: 100%

[2] `http://www.cambridge.org/us/catalogue/catalogue.asp?isbn=9780521721691`

11 Course Topics

- *Introduction:* mathematical preliminaries, continuum hypothesis, kinematics, Eulerian and Lagrangian description.
- *Basic laws:* Reynolds transport theorem, equations of motion (mass/momentum/energy balance), integral and differential forms, Navier-Stokes equations, Euler equations, Bernoulli's equation, constitutive relations, vorticity, dimensional analysis.
- *Potential flow:* complex analysis, velocity potential and streamfunction, circulation, airfoil.
- *Viscous flow:* exact solutions to the Navier-Stokes equations, low-Reynolds number flow, vortex dynamics, boundary layer theory
- *Other topics:* turbulence, hydrodynamic stability. (As time permits.)

12 Assessment Tools

The course grade will be computed as:

- Homework and short quizes: 20%
- Midterm: 40%
- Final: 40%

Historically, the B/B– boundary has been at 75%.

Short quizes will be given at random at the start of class and require that you know the material up to and including the previous class.

Grading is at the discretion of the instructor.

Homework and quiz questions will be graded on a scale from 0 to 3: 0=incomplete, 1=serious errors, 2=mostly right, 3=perfect. Reasoning I cannot follow while grading, or writing I cannot read, count as wrong.

You can miss two homeworks, their grades will be taken from the average of your other grades. You still need to know the material for the final, but you can study the posted solutions.

13 Course Objectives

This course has several objectives, including:

1. Teach how real-life engineering problems involving fluids can be modeled mathematically [A,E].
2. Teach how mathematical techniques can be used to solve real-life engineering problems involving fluids [A,E].

Capitals in square brackets refer to the departmental student program outcomes: `http://www.eng.fsu.edu/me/undergrad/ed_objective.html`

14 Student Learning Outcomes

The specific desired outcomes for any undergraduate students are:

1. Distill a mechanical engineering problem involving fluids into a mathematical one [1].
2. Solve the problem mathematically [2].

Samples of specific problems are in the lecture notes, old exams, and in homework assignments.

Numbers in square brackets refer to the Course Objectives above.

15 Methods of Instruction

Lectures, problem solving sessions, examinations, web-based information.

16 Computer Requirements

Students must have an E-mail address and daily check their E-mail. Students must be able to use a Web browser such as Firefox. The class web page can be accessed at:

`http://www.eng.fsu.edu/~dommelen/courses/flm`

If you are taking this class remotely, contact the FEEDS office[3] for requirements.

17 Important Regulations

17.1 Must Check Dates Immediately

Immediately check all dates listed in this syllabus for any conflicts.

17.2 Homework

Homework should be neat. Questions must be answered in the order asked or 0 will be assigned.

Homework must be handed in at the *start* of the lecture at which it is due. It may *not* be handed in at the departmental office or at the end of class. Homework that is not received at the start of class on the due date listed above cannot be made up unless permission to hand in late has been given *before* the homework is due, or it was not humanly possible to ask for such permission before the class. If there is a chance you may be late in class, hand the homework in to the instructor the day before it is due. (Shove it under his door if necessary.) This also applies to Web students: they must E-mail the homework before the time the class starts.

[3] `http://www.eng.fsu.edu/feeds`

17.3 Copying is Never Allowed

You must write *your own* homework solution *all by yourself*. You may not allow anyone else to see your solution. You must compute your own results. In case of evidence of copying, of homework all parties involved will receive 0 for the homework.

However, working together with other students on homework, to figure out *how* to solve the problems is encouraged, as you will learn more with more points of view. But afterwards, you must apply the procedures yourself, in your own way, and determine the answers and any numerical values individually.

Exams should be made by each student separately. In case of evidence of copying in an exam, a zero grade will be assigned for the exam. It will in addition be pursued as a violation of your university honor policy. This may lead to other actions, such as expulsion from the program. Please see the separate section on your honor code below.

Students should take care during exams that other students cannot get visual or other access to their work. This too is required by your university honor policy, and violations will be pursued.

17.4 Attendance Policy

17.4.1 Initial attendence

FSU students are dropped if not present the first day of classes. FAMU students are dropped if not attending at the end of the first week.

17.4.2 Excused absences

You should contact the instructor as soon as possible when the need for an excused absence arrives.

Excused absences include documented illness, deaths in the immediate family and other documented crises, call to active military duty or jury duty, religious holy days, and official University activities. Accommodations for these excused absences will be made and will do so in a way that does not penalize students who have a valid excuse. Consideration will also be given to students whose dependent children experience serious illness. See however the notification requirements below.

Please note that the College of Engineering has a restrictive interpretation of what is considered a valid excuse for an absence. See:
`http://www.eng.fsu.edu/current/undergraduate/guide.html`
If an absence is to be excused, make sure you check beforehand. In case of excused absence, the instructor will work with you to help you make up for missed time and catch up, subject to the notification requirements below.

Classes are not suspended at the College of Engineering unless they are suspended at both institutions. If you are required to attend a university event, you can receive an excused absence. Otherwise, your absence is considered unexcused.

You must notify me in the first week of the semester if you will need an excused absence during a scheduled examination for observance of a religious holy day. If you will need such an absence for a planned event, you must notify me at the start of the semester, or the day

that the event is scheduled if later. If an emergency prevents you from attending a scheduled examination, you must notified me at your earliest opportunity, by e-mail (check that you get a timely response from me), phone, or in person. Please provide official documentation of event or emergency. In case the notification procedures are not followed, no make up examination will be given and a zero will be assigned.

17.4.3 Unexcused absences

A student having more than four unexcused absences will be dropped from the course and assigned the grade F. No exceptions. Tests and exams missed because of unexcused absence receive the grade 0. No exceptions.

Other projects and activities missed completely receive the grade 0 for those projects or activities. No exceptions except as may be noted elsewhere in this syllabus. Homework handed in after the due date and time will receive a zero or greatly reduced credit depending on circumstances and any regulations elsewhere in this syllabus.

17.4.4 Initial and daily e-mail checks required

Students must daily check their e-mail at the address they provided at the start of class. They must ensure that they receive an welcome e-mail at the beginning of the semester, or contact the instructor to correct their recorded e-mail address immediately.

17.4.5 Consequential loss of credit

Failure to properly complete homework, tests, assignments, etcetera due to changes in date, assignment, etcetera, that you did not know about due to failure to check e-mail, unexcused absence, lateness, or inattentiveness will not be excused and cannot be made up.

17.5 Extract of ME Departmental Policy

An undergraduate student may continue in the B.S. in ME degree program unless one or more of the following conditions arise;

1. A grade below C in the second attempt of the same engineering course.
   `http://www.eng.fsu.edu/me/resources/pdf/ME_Prerequisite_Policy.pdf`
2. More than three (3) repeat attempts in engineering courses.
   `http://www.eng.fsu.edu/me/resources/pdf/ME_Excessive_Repeat_Policy.pdf`
3. Violation of academic honor code as defined in university bulletin or catalog
4. Use of grade forgiveness (currently available for FAMU students only) in more than two (2) courses.

Non-ME undergraduate students should contact their home department for corresponding regulations.

17.6 Extract of College Policy

It is the policy of the College not to assign "plus and minus (+/-)" grades for undergraduate engineering courses.

http://www.eng.fsu.edu/current/undergraduate/guide.html

Any student who has repeated attempts in one or more engineering courses may be subject to academic sanctions including but not limited to warning, probation, suspension, or dismissal from their engineering program. Students should contact the department of their engineering major for more information regarding this policy.

17.7 Learning outcomes/compacts

Mechanical engineering student outcomes:
http://www.eng.fsu.edu/me/undergrad/ed_objective.html

Engineering program outcomes/student learning outcomes:
http://www.eng.fsu.edu/outcomes

Engineering academic learning compact:
http://www.eng.fsu.edu/about/accreditation/outcomes.html

Florida State University academic learning compact:
http://learningforlife.fsu.edu/smalcs/learningCompact.cfm?smalcId=57339

17.8 Honor Policy

Students are expected to uphold their University Student Code of Conduct and/or Academic Honor Code. You must read this code if you have not yet done so.

- Florida A&M University is committed to academic honesty and its core values which include scholarship, excellence, accountability, integrity, fairness, respect, and ethics. These core values are integrated into its academic honesty policy. Being unaware of the Academic Honesty Policy is not a defense to violations of academic honesty. Academic Honesty Policy violations shall be reported and appropriate actions taken by the department chair and associate dean for student affairs and curriculum. The complete Florida A&M Student Code of Conduct - Regulation 2.012 (10) (s) can be found at
  http://www.famu.edu/index.cfm?judicialAffairs&StudentCodeofConduct
- The Florida State University Academic Honor Policy outlines the University's expectations for the integrity of students' academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process. Students are responsible for reading the Academic Honor Policy and for living up to their pledge to "... be honest and truthful and ... [to] strive for personal and institutional integrity at Florida State University."The complete Florida State University Academic Honor Policy can be found at
  http://fda.fsu.edu/Academics/Academic-Honor-Policy

Possible sanction for violations of your code of conduct and/or honor code include but are not limited to:

1. a failing grade on an exam or assignment,
2. a failing grade in the course,
3. dismissal from the academic program,
4. dismissal from the university.

17.9 Americans with Disabilities Act

Students with disabilities needing academic accommodation should:

- Register with and provide documentation to the appropriate university office. For FAMU students, this is the Learning Development and Evaluation Center (LEDC). For FSU students this is the Student Disability Resource Center (SDRC);
- Bring a letter to the instructor indicating the need for accommodation and what type.

This should be done during the first week of class.

For more information about services available to students with disabilities:

- FAMU Students should contact:

  Learning Development and Evaluation Center (LDEC)
  677 Ardelia Court
  Florida A&M University
  Nathaniel Holmes, Director
  Donna Shell, Asst. Director
  (850) 599-3180 (voice)
  (850) 561-2512 (fax)
  (850) 561-2783 (TDD)
  `http://www.famu.edu/index.cfm?a=EOP&p=ADA`

- FSU Students should contact:

  Student Disability Resource Center (SDRC)
  874 Traditions Way
  108 Student Services Building
  Florida State University
  Tallahassee, FL 32306-4167
  (850) 644-9566 (voice)
  (850) 644-8504 (TDD)
  sdrc@admin.fsu.edu
  `http://www.disabilitycenter.fsu.edu/`

17.10 Non-Discrimination Policy Statement

- The Florida A&M University statement can be found at:
  `http://www.famu.edu/index.cfm?EOP&NON-DISCRIMINATIONPOLICYSTATEMENT`
- The Florida State University statement can be found at:
  `http://www.hr.fsu.edu/PDF/Publications/diversity/EEO_Statement.pdf`

17.11 Exceptions

The instructor might wave some regulation on a case-by-case basis depending on his subjective determination of fairness and appropriateness. This will occur only under exceptional circumstances and should not be assumed. Especially, never assume that a seemingly minor

regulation will be waived because the instructor has waived it in the past. A second appeal to waive a minor regulation will probably indicate to the instructor that the regulation is not being taken seriously and most likely refused. Any appeal to the instructor will further be refused a priori unless it is made at the earliest possible moment by phone and/or by E-mail. Do not wait until you are back in town, say.

17.12 Syllabus Change Policy

Except for changes that substantially affect implementation of the evaluation (grading) statement, this syllabus is a guide for the course and is subject to change with advance notice.