Fluid Mechanics
EML 5709
Syllabus

Dr. Leon van Dommelen

Fall 2018

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1 Credit Hours

3

2 Course Type

EML 5709: Core Graduate Course.

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. (Assumes undergraduate fluid mechanics.)

6 Instructor

Dr. Leon Van Dommelen:

Office hours MW 5–6:15 pm or by appointment, in A242 CEB. I also give a help session MW 9:30–10:30 in A337 CEB, which is open to all my classes.

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

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

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

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

7 Teaching Assistant

None

8 Class Schedule

Class times: MWF 11:00-11:50 in A125 CEB (A building).

Normally, homeworks cover last week's material and are due on Wednesdays. Exceptions occur.

The below schedule is subject to change. Coverage shown is that of an earlier year, not necessarily this year.

- 08/27/18 M
  Syllabus. DVDs. Definition of a continuum. Density and velocity. Velocity and pressure fields.
- 08/29/18 W
  [Kinematics: Flowlines . . . , to Onera 59-78]
  Knudsen number. Pressure. Pressure force per unit volume. Coefficient of viscosity.
- 08/31/18 F
  [Kinematics: The material derivative, to Stokes 37-49]
  Lagrangian stagnation point flow. Material derivative. Particle paths. Eulerian stagnation point flow.

- 09/03/18 M LABOR DAY ==========
- 09/05/18 W Due: HW 1.
  [Kinematics: Kinematics of point . . . , to jelly fish 2-16]
  Streamlines and streaklines. Euler equations.

- 09/07/18 F
  [The "Deformation of Continuous Media" movie on the class movie page[1]]
  Particle deformation. Solid body rotation.

- 09/10/18 M
  [Kinematics: Compressible and incompressible flow, to Newton 50-58]
  Strain rate picture.
- 09/12/18 W Due HW 2.
  [Dynamics: Newton's second law of motion 142-153]
  Finding principal strains and principal directions as eigenvalues and eigenvectors of the strain rate tensor. Rate of relative volume expansion. Continuity for incompressible fluids.
- 09/14/18 F
  [Dynamics: Navier-Stokes equations 154-167]
  Continuity equation for compressible fluids. Molecular basis of stresses. Viscosity. Stress tensor.

- 09/17/18 M
  [Dynamics: Boundary conditions 173-190]
  Newtonian stress tensor. Navier Stokes equations.
- 09/19/18 W Due HW 3.
  [Dynamics: Reynolds Number: 191-199]
  Navier Stokes equations. Boundary conditions.
- 09/21/18 F
  [Control volumes: intro 866-877]
  No slip boundary condition. Kinetic pressure. Heat conduction. Fourier law. Energy equation. Second law form. Dissipation.

- 09/24/18 M
  [Control Volumes: Conservation of mass 881-893]
  Hydrostatics. Kinetic pressure. Boundary conditions. Fourier's law.
- 09/26/18 W Due: HW 4.
  [Control Volumes: Balance of momentum 894-904]
  Material regions. Surface and body forces. Start of control volumes. Mass conservation and mass fluxes. Momentum conservation and momentum fluxes.
- 09/28/18 F
  [Control Volumes: Pressure jet 932-935 (list drag coefficients) and cylinder wake virtual jets 936-938 (explain the error in the drag coefficients)]
  Control volumes. Complete equations. Surface forces. Pipe nozzle.

- 10/01/18 M
  [Control Volumes: Conservation of energy 939-946]
  Control volume analysis of drag in an infinite fluid. Momentum thickness.

[1] `http://www.eng.famu.fsu.edu/~dommelen/courses/flm/movies/`

- 10/03/18 W Due: HW 5.
  [Dynamics: Low Reynolds number 219-228]
  Displacement thickness. Finite volume example: mass.
- 10/05/18 F
  [Dynamics: Forces: 245-251]
  Finite volume example: momentum. Example incompressible flow field involving a duct.

- 10/08/18 M
  [Dynamics: Reynolds number Gallery 200-218]
  Streamline curvature and pressure. Unidirectional flow: plane Poiseuille flow.
- 10/10/18 W Michael. Not Due: HW 6.

- 10/12/18 F Michael.

- 10/15/18 M
  [Dynamics: Forces: 252-260]
  Plane Poiseuille flow.
- 10/17/18 W Due: HW 7.
  [Dynamics: 168-172 (CFD) and 261-269 (drag)]
  Head loss. Major head loss.
- 10/19/18 F
  [Dynamics: Stokes flow 229-244]
  Review of exam material. Minor head loss.

- 10/22/18 M
  [Similarity: Dimensionless numbers: 521-533]
  Stokes 2nd problem.
- 10/24/18 W Due: HW 8.
  [Similarity: Forces: 495-508]
  Review. Stokes 2nd problem.
- 10/26/18 F
  Midterm Exam

- 10/29/18 M
  [Similarity: Forces: 509-520]
  Stokes 2nd problem finished. Kelvin theorem. Bathtub vortices.
- 10/31/18 W Due: HW 9.
  [Dynamics: Potential flow: 270-281]
  Kutta-Joukowski law. Stokes theorem. Persistence of irrotational flow. Vortex tubes.
- 11/02/18 F
  [Dynamics: Potential flow: 282-287]

Biot-Savart law. Straight line vortices. Trailing vorticity system of wings. Trailing vortices. Induced drag. Ground effect. Mirror vortices.

- 11/05/18 M
  [Boundary Layers: 612-621]
  Potential flow and its Bernoulli law. Ideal flow around a cylinder.
- 11/07/18 W Due HW 10.
  [Boundary Layers: 603-611]
  Streamfunction. Complex variables.
- 11/09/18 F
  [Boundary Layers: 622-624, 628-637]
  Overview of complex variable solutions. Basic ideal flows. Superposition. Rankine bodies. Cylinder. Overview of conformal mappings: Joukowski mapping.

- 11/12/18 M VETERANS DAY ==========
- 11/14/18 W Due: HW 11.
  [Boundary Layers: 638-650]
  Ellipses. Flat plate airfoils. Kutta condition. Lift coefficient. Joukowski airfoils.
- 11/16/18 F
  [Boundary Layers: 651-661]
  Straight surfaces and the Schwarz-Cristoffel mapping. Hodograph plane. Free streamlines in separated flows. Boundary layer coordinates.

- 11/19/18 M
  [Boundary Layers: 662-675]
  Boundary layer separation. Boundary layer equations.
- 11/21/18 W THANKSGIVING
- 11/23/18 F THANKSGIVING ==========

- 11/26/18 M
  [Boundary Layers: 676-686]
  Boundary layers. Blasius boundary layer.
- 11/28/18 W Due: HW 12.
  [Turbulence: 697-709]
  Blasius solution. Wall shear.
- 11/30/18 F
  [Turbulence: 710-715, 720-726]
  Displacement thickness. Transition.

- 12/03/18 M
  [Turbulence: 727-739]
  Turbulence. Reynolds decomposition. Mixing length.
- 12/05/18 W Due HW 13.
  [Turbulence: 799-806]
  Shear layers, jets, and [wakes].

- 12/07/18 F Due: HW 14.
  Review. Kolmogorov scales? Inertial range? Wall bounded flows?

- 12/12/18 Wednesday 12:30-2:30 pm; FINAL (in the usual classroom).
- 12/18/18 4:00 pm: Grades due online FSU (Available next day)

9 Textbooks

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

The following references are useful:

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

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

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

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

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

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

7. Homsey, G.M., *Multimedia Fluid Mechanics DVD-ROM* Cambridge University Press[2]

10 Science/Design

Engineering Science: 100%

11 Course Topics

The course will likely cover:

- *Definitions.* Fluids, material regions, control volumes.

- *Continuum Mechanics.* The continuum approximation and its limitations. Free path length. Density and velocity.

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

- *Kinematics* Lagrangian and Eulerian derivatives. Particle paths, streamlines, steady flows. Lagrangian and Eulerian time derivatives. Decomposition of particle evolution in strain and rotation. Vorticity. Linear shear flow. Circulation.

- *Basic Laws.* Integral conservation of mass, momentum, and energy and the second law in integral and differential forms. Reynolds transport/Leibnitz theorem. Divergence theorem. Relationships to computational fluid dynamics. Stress tensor. Inviscid flow. Expansion coefficient. Integral conservation laws for arbitrary regions.

- *Newtonian Fluids.* Newtonian and inviscid stress tensors, Stokes' hypothesis. Fourier's law. Navier-Stokes equations.

- *Example Incompressible Flows.* Duct flow, Bernoulli law, effects of viscosity, entrance length, friction factor, critical Reynold number, head loss. Stokes' second problem, similarity.

- *Vorticity Dynamics* Vorticity and circulation. Kelvin's theorem. Boundary layers and wakes. Starting vortices.

- *2D Ideal Flows* Velocity potential and streamfunction. Boundary conditions. Bernoulli law for unsteady potential flows.

- *Boundary Layers.* The limit of small viscosity: boundary layer equations. Boundary layer along a flat plate and similarity. Boundary layer thickness, wall shear, displacement thickness.

- *Turbulent Flows.* Reynolds decomposition, Reynolds stresses, mixing length and dimensional analysis models.

12 Assessment Tools

The course grade will be computed as:

- Movie summaries: 7%

- Homework: 13%

- Midterm: 40%

- Final: 40%

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

Grading is at the discretion of the instructor.

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

- Refresh the students' memory about undergraduate fluid mechanics.
- Introduce students to the fundamentals of graduate Fluid Mechanics.
- Introduce techniques of dealing with the partial differential equations of fields.
- Help students prepare for the Ph.D. Preliminary exam.

14 Methods of Instruction

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

15 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.famu.fsu.edu/~dommelen/courses/flm`

16 Important Regulations

16.1 Must Check Dates Immediately

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

16.2 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.

16.3 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.

16.4 Attendance Policy

16.4.1 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.

16.4.2 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.

16.4.3 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.

16.4.4 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.

16.4.5 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.

16.5 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/~dommelen/short/deppolp.html`
2. More than three (3) repeat attempts in engineering courses.
   `http://www.eng.fsu.edu/~dommelen/short/deppolr.html`
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.

16.6 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.

16.7 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

16.8 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.

16.9 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 Cen-

ter (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/`

16.10 Non-Discrimination Policy Statement

- The Florida A&M University statement can be found at:
  `http://www.eng.fsu.edu/~dommelen/short/fameeo.html`
- The Florida State University statement can be found at:
  `http://www.eng.fsu.edu/~dommelen/short/fsueeo.html`

16.11 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.

16.12 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.