EML 5709 **Spring 2004**

Fluid Mechanics

Van Dommelen

1 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.

2 Credit Hours

3

3 Prerequisites

EML 5060 and graduate standing in Mechanical Engineering.

4 Textbooks

Panton, Ronald L, *Incompressible Flow.* John Wiley & Sons, Inc, Second Edition. ISBN 0-471-59358-3.

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.

5 Instructor

Dr. Leon Van Dommelen:

Office hours M 2-3 pm, T 5:15-6:15 pm, in A 242 CEB

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

E-mail dommelen@eng.fsu.edu

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

Contact information See web page

6 Teaching Assistant

None

7 Schedule

Class times: MWF 9:40-10:30 in A 226 CEB or as announced.
Tentative outline (keep checking for changes):

- 01/07/03 W: Lecture.
- 01/09/03 F: Lecture.

- 01/12/03 M: Lecture.
- 01/14/03 W: Lecture. [1.2, 1.3, 1.7 due.]
- 01/16/03 F: Lecture. [2.1, 2.2, 2.5 due.]

- 01/19/03 M: Martin Luther King, Jr. day
- 01/21/03 W: Lecture.
- 01/23/03 F: Lecture.

- 01/26/03 M: Lecture. [Due: 4.1, 1.1, 4.4 (functions $T(x_1, x_2), b_1(t), b_2(t)$ are given), 4.2 (do not guess, use the appendices!), 4.7 (integrate around a circle around the origin in (c), but around an arbitrarily shaped contour in (b)) (comment on the error in the Stokes' result in (b)), 4.9.]
- 01/28/03 W: Lecture.
- 01/30/03 F: Lecture.

- 02/02/03 M: Lecture. [5.11, 12, 14 due. In question 5.11, d is much larger than D, not the other way around. In question 5.14 (13), the pressure is 700 kPa at the nozzle entrance.]
- 02/04/03 W: Lecture. [5.16, 17 due In 5.16, it can be assumed that no computer is available and that the flow over the cone is quasi-steady *relative to the cone.* In question 5.17, the book means that a part with diameter D/4 of the incoming stream enters the cone, while the remainder between D/4 and D continues to pass around the outside of the cone.]
- 02/06/03 F: Lecture.

- 02/09/03 M: Lecture. [5.1, 5.3 due.]
- 02/11/03 W: Lecture.
- 02/13/03 F: Lecture.

- 02/16/03 M: Exam 1.
- 02/18/03 W: Lecture. [Spherical finite volume due.]
- 02/20/03 F: Lecture. [5.2 due.]

- 02/23/03 M: Lecture. [5.6 and 5.8 due. In question 5.6, take the curl of the differential momentum equation. The book's Z is the height h. Also, assume that it is a Newtonian fluid: there are no viscous stresses if a Newtonian fluid is at rest.]
- 02/25/03 W: Lecture.

- 02/27/03 F: Lecture.

- 03/01/03 M: Lecture. [6.3 and 6.5 due. In 6.3, explain why this flow is *not* called inviscid but does have an inviscid velocity field. In 6.5, look up the incompressible continuity equation and momentum equations in cylindrical coordinates (Appendix C, constant viscosity and density,) substitute in the given velocities, ($v_\vartheta = 0$), verify that the continuity equation is already satisfied, and find the single scalar pressure field that ensures that the three momentum equations are also all satisfied. The pressure must of course be the same pressure in all three equations.]

- 03/03/03 W: Lecture.

- 03/05/03 F: Lecture.

- 03/08/03 M: Spring Break.

- 03/10/03 W: Spring Break.

- 03/12/03 F: Spring Break.

- 03/15/03 M: Lecture.

  [Due: (A) Find the continuity equation and momentum equations in cylindrical coordinates for an incompressible fluid when $v_r = v_z = 0$ and neither velocity nor pressure depends on z. Work these equations out as far as possible, finding the most precise expression for the pressure and partial differential equation for v_ϑ. (B) Now assume that the flow is steady. Also, assume that that the streamlines are complete circles; this will allow you to say something more about the integration constants of the pressure field, since the pressure must return to the same value when ϑ increases by 2π. Solve the resulting ordinary differential equation for ϑ. (C) Put in the boundary condition that at $r = R_i$, the fluid ends at a cylinder rotating with an angular speed Ω_i, giving the boundary condition $v_\vartheta = \Omega_i R_i$ at $r = R_i$. Also put in the boundary condition that at a larger $r = R_o$, the fluid meets an outer rotating cylinder: $v_\vartheta = \Omega_o R_o$ at $r = R_o$. Use these boundary conditions to find the integration constants in the expression for v_ϑ. (D) Identify the special flow fields that arise when (a) $R_o = \infty$ and $\Omega_o = 0$, and (b) $R_i = 0$. You can find these derivations in graduate fluid books like Curry's, but try to do it from scratch.]

- 03/17/03 W: Lecture.

- 03/19/03 F: Lecture.

- 03/22/03 M: Exam II.

- 03/24/03 W: Lecture. [18.8 due. In 18.8, write the problem for either the streamfunction ψ or the potential ϕ and solve using an appropriate method. The boundary conditions are that (a) $u = U_0 + U(y)$ at $x = 0, 0 < y < h$, (b) the flow remains finite at $x = \infty, 0 < y < h$, and (c,d) the duct walls $y = 0, 0 < x < \infty$ and $y = h, 0 < x < \infty$ are streamlines (the vertical velocity component is zero at walls.) Compare the properties of this inviscid "entrance" flow with the viscous developed duct flow of chapter 7.]

- 03/26/03 F: Lecture.

- 03/29/03 M: Lecture. [18.1, 18.2, and the first part of 18.3 due. In 18.3, use the trig addition formulae on page 44 of the math handbook and the relationships with hyperbolic functions on page 58 to write the sine in terms of real functions and i only.]

- 03/31/03 W: Lecture. [Due:

1. Find the real and imaginary parts of: $(1+i)^2$, $(1+i)(1-i)$, $1/(1+i)$, $\ln(1+i)$, $\exp(1+i)$. Plot the results in the complex plane and find their magnitude and argument.
2. For the following complex potentials, find the velocity potential ϕ and the streamfunction ψ, and sketch the streamlines: z, iz, z^2, $\ln(z)$, $i\ln(z)$.
3. For the same velocity potentials, find the complex conjugate velocity W in terms of z, the Cartesian velocity components u and v in terms of x and y, and the polar velocity components u_r and u_θ in terms of r and θ.

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- 04/02/03 F: Lecture.

- 04/05/03 M: Lecture. [18.6 due.]
- 04/07/03 W: Lecture.
- 04/09/03 F: Lecture. [18.4, 18.5, 18.9 due.]

- 04/12/03 M: Lecture. [18.7, 18.19 due. Also integrate the pressure distribution on the surface of a cylinder with circulation in a cross flow to find the force on the cylinder.]
- 04/14/03 W: Lecture. [Due: (1) Compute the Reynolds number of your car (based on driving velocity and height, and of a plane of characteristic size 20 m flying at Mach 0.8 in standard conditions.

  (2) What is the flow velocity of water in a pipe of diameter 0.1 m if the Reynolds number based on diameter and average velocity is 1.

  (3) List other nondimensional numbers than the Reynolds number that need to be the same for flows that look similar to be really similar. Think of high-speed planes, ships, etcetera.]
- 04/16/03 F: Lecture. [Due: (1) Identify the boundary layer coordinates and velocity components for the boundary layer around a circular cylinder in terms of more usual coordinates.

  (2) For the same case, identify the boundary velocity u_e just above the boundary layer and the pressure p_e just above the boundary layer from the potential flow solution.]

- 04/19/03 M: Lecture. [Due: (1) Using the results of the previous homework, formulate the boundary layer problem for the impulsively started cylinder.

  (2) Rewrite the Navier Stokes equations for the exact problem in terms of the boundary layer variables and compare them to the boundary layer approximation. What terms are lost in the boundary layer approximation?]
- 04/21/03 W: Lecture.
- 04/23/03 F: Lecture. [Due: (1) Find the shear force on a plate of length 0.5 m moving flush through air at a speed of 0.5 m/sec

  (2) Derive the steady boundary layer problem along a semi-infinite plate if instead of a uniform flow, there is a sink sitting at the nose of the plate. In other words, the potential flow just above the boundary layer is $u_e = -m/(2\pi x)$.

  (3) Solve the previous boundary layer problem. The boundary layer solution is again similar, but the boundary layer thickness is now linear in x. In other words, $u(x,y) = u_e(x)f'(y/x)$, where $Re = m/\nu$]

- 04/27/03: Tuesday final 3:00-5:00 pm (ignore FSU schedule).

8 Goals

Introduce students to the fundamentals of Fluid Mechanics.

9 Course Outline

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.
- *Thermodynamics* Simple systems, extensive and intensive properties. Second law. Ideal gasses.
- *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. Complex variable theory, complex conjugate, polar form. Uniform flow, point source, point vortex, doublet, corner, Rankine body, Finite bodies. Cylinder. Unsteady boundary layer separation. Circulation, lift, and drag: Kutta-Joukowski and D'Alembert results. Conformal transformations. Flat plate and Joukowski airfoils. Contour integrals. Blasius' formulas.
- *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.

10 Methods of Instruction

Lectures, problem solving sessions, examinations.

11 Student Evaluation

The course grade will be computed as:

- Homework: 25%
- Exams: 50%
- Final: 25%

Grading is at the discretion of the instructor.

12 Important Regulations

1. Immediately check the dates listed above for any conflicts.
2. 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 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. Homework should be neat.
4. Students are bound by the rules and regulations in their University bulletin, as well as by those specified in this syllabus, and by the usual standards applied by the College of Engineering. Read your academic bulletin. Violations of the rules and regulations in your bulletin may result in reduced grades and/or other actions.
5. Students are bound by the honor code of their university. It requires you to uphold academic integrity and combat academic dishonesty. Please see your student handbook. Violations of your honor code may result in reduced grades and/or other actions.
6. *Copying* of homework, assignments, or tests is never allowed and will result in a failing or zero grade for the copied work. It will also result in a failing or zero grade of the person whose work is being copied if that person could reasonably have prevented the copying. However, *working together* is typically allowed and encouraged for most homeworks, (and sometimes for other take-home assignments,) as long as you present the final results in your own words and using your own line of reasoning. Since close similarities between solutions will reduce credit, it is better not to formally put down anything until you have figured out the problem, and then let each person write their own solution. If it is unclear whether working together is allowed on any assignment, check with the instructor beforehand.
7. Attendance is required. Exams missed, even when rescheduled from the original date and surprise tests, or homework not handed in on time due to unexcused absence or lateness will result in a zero grade for that exam and/or homework. Failure to properly complete homework, tests, assignments, etcetera due to changes in date, assignment, etcetera, that you did not know about due to unexcused absence, lateness, or inattentiveness will not be excused and cannot be made up.
8. For excused absences where the student has given advanced notice of the absence at the earliest opportunity, the instructor will work with the student to arrange for make-up work and tests.
9. The total grade is further reduced due to unexcused absences or lateness. See the instructor for details. Even a few absences will make it impossible to pass the class. Typically, four unexcused absences result in an F grade regardless of numerical performance. Conscientious attendance is required for a confident determination of your mastery of the subject matter to be made. In other words, this class cannot be taken like a DIS unless a faculty member will allow you to do so under formal DIS rules with appropriately modified grading and testing standards.
10. The College of Engineering has a restrictive interpretation of what is considered a valid excuse for an absence. If an absence is to be excused, make sure you at least get official confirmation by phone that it will be granted beforehand.
11. The instructor will make sure that make-up tests are no simpler than the original, but he will try to make them similarly difficult. However, he cannot make allowances for increased difficulty due to the small sample size.

12. The College of Engineering has a more restrictive drop-add period than you might think based on your bulletin. Check both your bulletin and the Dean's office to determine whether drop-add will be allowed.

13. Some of these rules may not apply if you fall under the Americans with Disabilities Act. FAMU students with disabilities needing academic accommodations should contact Student Health Services for confirmation of permanent physical disability, FSU students should register with and provide documentation to the Student Disability Resource Center. Next bring a letter to the instructor from the Services or Center indicating you need academic accommodations. This should be done during the first week of classes.

14. 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 waved because the instructor has waved it in the past. A second appeal to wave 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 apriori unless it is done at the earliest possible moment by phone and/or by E-mail. Do not wait until you are back in town, say.

13 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 Netscape. The class web page can be accessed at

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

If you are taking this class remotely, see the departmental web page for requirements.