EML 5709 **Fall 2005**

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

Graduate standing in Mechanical Engineering.

4 Textbooks

Panton, Ronald L, *Incompressible Flow.* John Wiley & Sons, Inc, Third Edition. 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.

5 Instructor

Dr. Leon Van Dommelen:

Office hours MF 2-3 in A242 CEB

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6 Teaching Assistant

None

7 Schedule

Class times: MWF 12:55-1:45 in A226 CEB (A building).

Tentative outline and homeworks (keep checking for changes):

- 08/29/05 M
- 08/31/05 W
- 09/02/05 F Due: 1.4
- 09/05/05 M LABOR DAY
- 09/07/05 W Due: 4.4
- 09/09/05 F Due: 4.1
- 09/12/05 M
- 09/14/05 W Due: 4.9
- 09/16/05 F Due: 4.8, 4.5 and explain, 4.2
- 09/19/05 M Due: 4.7 plus discrepancy with 4.2
- 09/21/05 W
- 09/23/05 F
- 09/26/05 M Due: Write the continuity equation for a Cartesian finite volume
- 09/28/05 W Due: 5.2
- 09/30/05 F Due: 5.3
- 10/03/05 M 5.1
- 10/05/05 W 5.11, 5.12
- 10/07/05 F Due: 5.6
- 10/10/05 M Mid Term Exam
- 10/12/05 W Due: 6.1
- 10/14/05 F Due: 6.5 (Last day to drop)
- 10/17/05 M Due:
- 10/19/05 W Due: 7.9. In particular, use equivalent steps as we used in class for a duct to find this flow. You can assume that the pipe wall can be approximated as a flat wall.
- 10/21/05 F Due: 7.10, 7.1 using the same steps as used in class to solve duct flow.
- 10/24/05 M Due: 7.6
- 10/26/05 W Due: 7.4

- 10/28/05 F Due: Consider the below graph for the minor head losses due to sudden changes in pipe diameter:

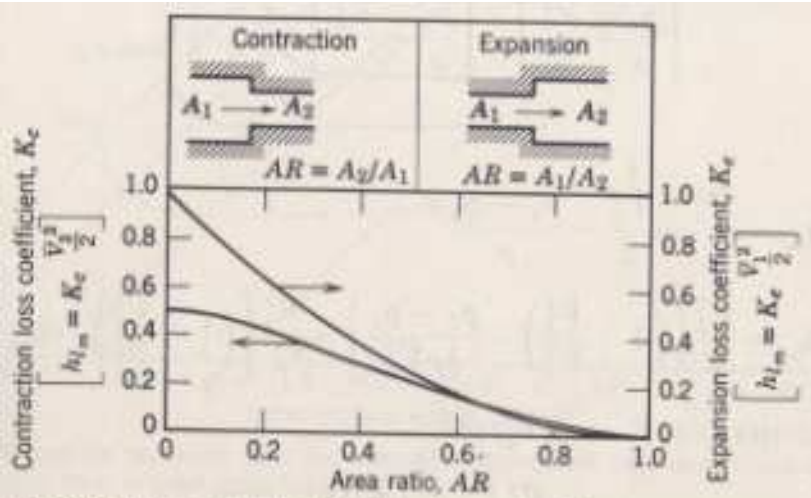

Fig. 8.16 Loss coefficients for flow through sudden area changes (Ref. 5).

Discus the following issues as well as possible from the sort of flow you would expect.

1. How come the head loss become zero for an area ratio equal to 1?
2. Why would the head loss be exactly one for a large expansion? Coincidence?
3. Why would the head loss be less than one if the expansion is less? If the expansion is less, is not the pipe wall in the expanded pipe closer to the flow, so should the friction with the wall not be more??
4. Why is there a head loss for a sudden contraction? The mechanism cannot be the same as for the sudden expansion, surely? Or can it?

(FSU Homecoming)

- 10/31/05 M Due: 7.18
- 11/02/05 W Due: 7.16
- 11/04/05 F Due: 7.14. Additionally, examine whether the *velocity profiles* are similar.
- 11/07/05 M Due: 13.7
- 11/09/05 W Due: Derive the streamfunction of ideal stagnation point flow. From it, determine the mathematical form of the streamlines. Also 18.1
- 11/11/05 F VETERANS DAY ==========
- 11/14/05 M Due: 18.8
- 11/16/05 W Due: Velocity and streamlines of vortex flow. What is the circulation and vorticity?
- 11/18/05 F Due: Find the velocity and pressure at the surface of a cylinder in an ideal flow.
- 11/21/05 M Due: 18.5, assuming $p \asymp p_{\text{ref}}$ at large y and $x = 0$, not the impossible $p + \frac{1}{2}\rho U_\infty^2 = \text{constant}$.

- 11/23/05 W Due: Compute the Reynolds number of your car and of a passenger plane flying somewhat below the speed of sound. List your assumptions. What is the flow velocity of water in a pipe of 10 cm diameter if the Reynolds number is one?
- 11/25/05 F THANKSGIVING ==========

- 11/28/05 M Due: 8.14. Also, identify the boundary layer variables x, y, u, v for the case of a circular cylinder with the cylindrical coordinates r, θ, v_r, v_θ. Write the exact Navier-Stokes equations for this example in terms of the boundary layer coordinates, and compare with the boundary layer approximation. Argue that in a thin boundary layer, the differences between the two can be ignored.
- 11/30/05 W Due: Write the full boundary layer problem to be solved for unsteady boundary layer flow around a circular cylinder (partial differential equations and boundary conditions), being specific about the values of all variables involved.
- 12/02/05 F Due: Find the drag force on a plate of length 0.5 m that is moving flush through air at a speed 0.5 m/s. Also determine what the viscous stress τ_{yy} normal to the plate surface is.

- 12/05/05 M Due: Find the pressure changes in the entrance flow of a two dimensional duct due to the thin wall boundary layers.
- 12/07/05 W Due:
- 12/09/05 F Due: Compare the value of speed of sound a time molecular mean free path λ for standard air with the kinematic viscosity ν.

- 12/16/03: Final Friday 7:30-9:30 am (ignore FAMU 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.
- *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.
- *Lubrication* Channel flow, Reynolds equation.
- *Microflows* Molecular dynamics, continuum description.

10 Methods of Instruction

Lectures, problem solving sessions, examinations.

11 Student Evaluation

The course grade will be computed as:

- Homework: 20%
- Midterm: 40%
- Final: 40%

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 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.

10. 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.

11. 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.

12. 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.

13. 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.