LEHIGH UNIVERSITY

Department of Mechanical Engineering & Mechanics (Spring 2013)

ME424 Unsteady and Turbulent Flows

Instructor:	Prof. Arindam Banerjee Email: arb612@lehigh.edu ; Phone: 610-75**8-4099**
Office:	453 Packard Laboratory
Class schedule:	**Tu-Th 9.20 am - 10.35 am**
Class Location:	**Packard 208**
Office hours :	**W 3.00 – 5.00 pm** (or by appointment)
Grading Outline:	Homework – 20%, 2 mid-term exams: 30% (15% each), Project: 25%, Final Exam: 25% (comprehensive exam).
Grading Policy:	**FINAL GRADES** will be curved. Tentative breakdown: A: Above 2 standard deviations from mean, B: Above 1 standard deviation from mean, C: Class mean score, D: Below 1 standard deviation from mean, F: Below 2 standard deviations from mean. Intermediate (+/-) letter grades will be calculated likewise. Letter grade will be given only after each exam.
Prerequisites:	Student should have taken ME331 or ME430 + a course in PDE
Textbook(s):	**Pope, S.B. Turbulent Flows – Cambridge University Press** **Turbulence Modeling for CFD – D. Wilcox-3rd Edition – DCW Industries** Note: Both books are available for 2 hour checkout at Fairchild Library
Supplements:	Notes/handouts by instructor
Course objectives:	**This course is designed to give the students an overview of various aspects of unsteady and turbulent flows – the course is mathematical and will involve rigorous derivations using PDEs**. The course is divided into 3 parts and will cover: (a) ***Turbulence theory*** (i.e. where does turbulence come from and what are its universal features, to what extent is it deterministic?) (b) ***Turbulence modeling*** (i.e. derive semi-empirical models to parameterize the influence of turbulence on various flows) (c) ***Turbulence measurements*** (discuss state of the art techniques to measure and quantify various parameters discussed in (a) and (b) above) The topics are meant to provide graduate students a sound theoretical foundation regarding analyzing turbulent flows.

Topics to be covered

Part 1: Fundamentals & Turbulence Theory

Introduction to Tensors, Statistical Properties, Origin and nature of turbulence, Basic equations of fluid motion (mean flow equations), Statistical description of turbulent flows, Averaging (time, space and ensemble), Scales of turbulent flows (phenomenology of Taylor, Richardson and Kolmogorov), Understanding canonical (simple) turbulent flows

Part 2: Modeling of Turbulent Flows

RANS models – algebraic models; half-, one- and two- equations models, applications and limitations (from the point of view of canonical flows); effects of compressibility – FAVRE averaging

Part 3: Turbulence Measurements

Advanced modeling techniques – DNS, LES; Data acquisition and analysis, Signal processing techniques, Anemometry techniques, Laser Velocimetry

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Policies:

Home-Work:

- Home-works will be assigned every week and will be due at the **start** of class on the date it is due– no late home-works will be accepted. You are expected to work on your own. If you have questions about the Home-Work, make every effort to come and see me. If that is not possible, send me an email with clear and concise question(s). A scanned copy of your work typically helps me to identify the problem faster. Home-Work solutions will be posted on Course-Site.
- In order to standardize the problem solution and presentation process for ME 424, it is expected that all homework will conform to certain standards. These are:

  a. Start each problem on a new sheet of paper. Your name should appear at the top right corner of the first page. All problem solutions are to be placed in numerical order in one packet and stapled (no paper clips) in the upper left corner only.

  b. Each problem solution should be organized and easy to follow. Start with a brief problem statement in the form:

  Given: A clear statement of given information, showing appropriate schematics.
  Find: A clear statement of what is required

  c. Solutions must include: (i) Basic equations employed, (ii) A clear list of simplifying assumptions, (iii) Organized solution procedure with clearly indicated results, and, (iv) Consistent use and listing of proper units.

  d. If the problem demands a graphical presentation, this should appear on separate pages, and should be done using a software (e.g. Excel, MatLab, Maple, etc.). Make sure that all axes are clearly titled, labeled, and that a legend is provided if more than one plot is presented on each graph.

Projects:

- A project report will be due at the end of the semester. A project proposal (in the form of an abstract) is due to Prof. Banerjee at the start of 3rd week of class (1/30/13). You will need to select a topic related to the class (see page 1 for general topics) and find a review paper within the last 10 years on that topic.
- Project reports must adhere to ASME paper writing standards, details can be found in: http://www.asme.org/kb/proceedings/proceedings/formatting-the-paper.
- Sharon Siegler (sls7@lehigh.edu), Engineering Librarian will be helping us with collection of all reference materials

Exams:

- Exams are open (text) book only. No class notes are allowed. No electronic devices (including e-books) are allowed during exams.
- The final exam is comprehensive (i.e. it will contain all topics covered in class).

Accommodation for Students with Disabilities: If you are requesting accommodations, please contact the Office of Academic Support Services at University Center (Phone: 610-758-4152) as early as possible during the semester. You need to bring in proper documentation for Academic Support Service Office before any request can be granted.

Academic Integrity: The work you submit with your name on it must be your own. The Lehigh community considers the promotion of academic integrity a fundamental responsibility. Statements issued by Undergraduate and Graduate Student Senates articulate the understanding of the importance of this responsibility by the student community. Academic integrity violations will be referred to the Office of Student Conduct. Some useful resources can be found at: http://www.lehigh.edu/~infdli/AcademicIntegrity.htm

ME-424-010-SP13-Unsteady and Turbulent Flow

home help

Home My courses Spring 2013 ME-424-010-SP13

Turn editing on

Academic Integrity

Academic Integrity Vignettes PPT

Provost's Academic Integrity Site

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Settings

Course administration
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Activities

Topic outline

Announcements
Course Syllabus
Supplemental Reading

1 Introduction & Review of Tensor Operations

Day 1: Tu (1/15)

- Course Policy and description (PPT slides)
- Definition & nature of turbulence (PPT slides)
- Cartesian Tensors: Notation rules, co-ordinate transformation & rules
- Reading Assignment: Pope - Chapter 1: pp 3-9; Appendix A: pp 643-647.

Day 2: Th (1/17)

- Second order tensors
- Operations: addition, products (inner and outer), gradients, divergence, laplacian, delta function & Levi-Civita (epsilon) symbol
- Properties of second order tensor
- Reading Assignment: Pope - Appendix A: pp 648-659; Appendix B: pp 661-665

In Class Problem Set 1
HW 1
HW1 solutions

2 Basic Equations of Fluid Motion

Day 3: Tu (1/22)

- Continuum Hypothesis, Eulerian & Lagrangian Fields
- Conservation Equations (Mass, Momentum)
- Role of pressure
- Conserved Passive Scalars
- Reading Assignment: Pope - Chapter 2: pp 10-22

* **Day 4: Th (1/24)**

- Vorticity Equation & Vorticity Dynamics
- Rates of Strain and rotation
- Transformation Properties: Similarity, Invariance (time, space, rotational, reflectional, Galilean, extended Galilean)
- Reading Assignment: Pope - Chapter 2: pp 23-33; Davidson: scanned copies.

3 Statistical Description of Turbulent Flows

Latest news

Add a new topic...

(No news has been posted yet)

Upcoming events

There are no upcoming events

Go to calendar...
New event...

Quickmail

- Compose New Email
- Signatures
- View Drafts
- View History
- Alternate Emails
- Configuration

Recent activity

Activity since Thursday, January 10, 2013, 10:06 AM

Full report of recent activity...

Nothing new since your last login

Forums
Resources

Day 5: Tu (1/29)

- Concepts and Tools to charecterize (statisticaly) random variable used in turbulent flows
- Sample Space, Probability, CDF, PDF, Mean & Moments, Standardization, Examples
- Reading Assignment: Pope - Chapter 3: pp 34-53

Day 6: Th (1/31)

- Joint Random Variables & Properties
- Joint PDF, Covariance, Correlation Coefficient
- Reading Assignment: Pope - Chapter 3: pp 54-63

Day 7: Tu (2/5)

- Random Process - characterization techniques
- Random Fields
- Reading Assignment: Pope - Chapter 3: pp 64-78

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Equations Governing Turbulent Flows

Day 8: Th (2/7)

- Averaging Techniques: Time-, Spatial- and Ensemble- averaging
- Correlations
- Reynolds Averaged Navier-Stokes(RANS) Equations
- Reynolds Stresses
- Reading Assignment: Wilcox - Chapter 2: pp 34-41, Pope: Chapter 4: 83-91

Day 9: Tu (2/12)

- Reynolds Stress Equation & Essence of the Closure Problem
- TKE and Mean Scalar Equations
- Gradient Diffusion Hypothesis
- Turbulence Modeling History (Overview) (PPT slides)
- Reading Assignment: Wilcox - Chapter 2: pp 41-45; Pope: Chapter 4: 92-95, Chapter 8: pp 335-343

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Scales of Turbulent Motion

Day 10: Th (2/14)

- Length Scales in Turbulent flow (Integral-, Taylor Micro-, Kolmogorov- and Batchelor Scales), Two point correlation (PPT slides)
- Concept of Energy Cascade & Spectral View (intro) (PPT slides)
- K41 Hypothesis, Structure functions (PPT slides)
- Reading Assignment: Wilcox - Chapter 1: pp 10-15; Chapter 2: pp 44-49; Pope: Chapter 6: 182-206

Day 11: Tuesday: 2/19 - Mid-term1

Day 12: Th (2/21)

- Fourier Modes
- Velocity Spectra
- Reading Assignment: Pope: Chapter 6: 207-249; Appendix E: 678-682

Day 13: Tu (2/26)

- Sepctral View of Energy Cascade
- Limitations, short-comings and refinement
- Reading Assignment: Pope: Chapter 6: 250-263

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Turbulence Modeling

Day 14: Th (2/28)

- Mixing Length Hypothesis (PPT slides)
- Modern Algebraic Models(PPT slides)
- Half Equation Models (PPT slides)
- Range of Applicability (PPT slides)
- Reading Assignment: Wilcox - Chapter 3: pp.53-59,74-84, 94-101; Pope: Chapter 10: pp 358-369

Day 15: Tu (3/5)

- TKE Equation, Closure Approximation
- One-Equation Models (PPT slides)
- Reading Assignment: Wilcox - Chapter 4: 101-122; Pope: Chapter 10: pp 385-386

Day 16: Th (3/7)

- Two-Equation Models (PPT slides)
- Reading Assignment: Wilcox: Chapter 4: 122-136; Pope: Chapter 10: pp 369-385

Spring Break : 3/11-3/15 (No Class)

Day 17: Tu (3/19)

- Two-Equation Models (continued) (PPT slides)
- Boundary conditions, roughness, application & transition (PPT slides)
- Reading Assignment: Wilcox - Chapter 4: 180-229; Pope: Chapter 10: pp 369-385

Day 18: Th (3/21)

- Effects of Compressibility (PPT slides)
- Favre averaging
- Reading Assignment: Wilcox: Chapter 5: 239-249

Day 19: Tu (3/26)

- Effects of Compressibility (continued) (PPT slides)
- Closure approximations for compressible flows (PPT slides)
- Compressible law of the wall (PPT slides)
- Reading Assignment: Wilcox - Chapter 5: 249-256, 262-269

Day 20: Th (3/28)

- Numerical considerations (PPT slides)
- Accuracy near boundaries (PPT slides)
- Marching Methods: Parabolic, Time-Marching, Block-Implicity
- Convergence & Stability (PPT slides)
- Reading Assignment: Wilcox - Chapter 7:

Day 21: Tuesday: 4/2 - Mid-term2

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Measurements of Turbulent Flows

Day 22: Th (4/4)

- Basic Measurements in Turbulent Flows (PPT slides)
- Pre-requisites for measurements (PPT slides)
- Relevant Flow Variables (PPT slides)
- Averaging Techniques in statistical domain, statistical quantities (PPT slides)

- Reading Assignment: Springer Handbook on Exp. Fluid Mechanics: Chapter 10: pp 745-788

Day 23: Tu (4/9)

- Particle Based Methods (PPT slides)
- Thermal Anemometry Methods (PPT slides)
- Reading Assignment: Journal Papers + scanned documents

Day 24: Th (4/11)

- Advanced measurement/modeling techniques
- Large Eddy Simulation (LES)
- Direct Numerical Simulation (DNS)
- Reading Assignment: Journal Papers + scanned documents

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Analysis of Turbulent Flows

Day 25: Tu (4/16)

- Free Shear Flows : Jets, Wakes, Mixing Layers
- Reading Assignment: Pope: Chapter 5

Day 26: Thu (4/18)

- Wall bounded flows
- Reading Assignment: Pope: Chapter 7

Day 27 & 28: Tu (4/23) & Thu (4/25)

- Any left over items from previous week
- Overview + Project Presentation

FINAL EXAM - TBD