ME 439 Turbulence Fall 2017

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Office Hours: MWF 10-11 am

Class: MW 2:00 – 3:15 pm Hopeman 204

Course Webpage:
http://www.complexflowgroup.com/courses/Fall 2017/ME439/

Teaching Assistant:

Dongxiao Zhao

Prerequisite Courses:
The following courses or their equivalent: ME 225, ME 201 or ME 400.

Recommended Courses:
It is recommended that you have taken ME 437 "Incompressible Flow."

Texts:

Turbulent Flows by Stephen B. Pope, Cambridge University Press

Turbulence: The Legacy of A. N. Kolmogorov by Uriel Frisch, Cambridge University Press

Course Outline:

While a considerable portion of the material will be based on the instructor's personal lecture notes, the course will also rely heavily on two of the standard books in the field: "Turbulent Flows" by Stephen Pope and "Turbulence: The Legacy of A. N. Kolmogorov" by Uriel Frisch. Two other books (by Davidson and Tennekes & Lumley) will also be on reserve at the Carslon library (see course's website for details).

Topics to be covered:

1) Preliminaries: equations of motion, symmetries and conservation laws, Eulerian and Lagrangian descriptions, basics of PDEs, roles of pressure, rotation and strain, material and global invariants, vorticity and angular momentum dynamics, Kelvin's Circulation Theorem.
2) Statistical versus deterministic approaches to understanding and modeling turbulence.

3) Scale decompositions: Reynolds averaging (mean-fluctuations), Fourier (or more generally, spectral) decompositions, Filtering (via convolutions in physical space)

4) Fundamental Turbulence:
    i. dynamics and kinematics of turbulent flows
    ii. the cascade of energy and invariants across scales
    iii. inertial range, dissipation range
    iv. self-similarity, power-law scaling, universality
    v. velocity correlations, spectrum, and structure functions.
    vi. Kolmogorov's 4/5-th law
    vii. range of scale-coupling
    viii. Kolmogorov's 1941 theory, scaling predictions
    ix. intermittency, extreme events, Refined Similarity Hypothesis
    x. probability distribution function of the velocity field
    xi. single-particle and two-particle dispersion, Richardson's law
5) Modeling and simulation approaches:
    a. Direct Numerical Simulations
        i. Pseudo-spectral method
        ii. Computational cost
        iii. Variations (hyperviscosity, sparse-mode, forcing)
    b. Reynolds Averaged Navier-Stokes (mixing length model, Reynolds-stress models)
    c. Large Eddy Simulation Modeling
        i. Filtering and coarse-grained (renormalized) dynamics
        ii. Smagorinsky and dynamic models,
        iii. Nonlinear model
        iv. Transport-equation models
6) Special topics:
    a. Effects of rotation and stratification
    b. Two-dimensional turbulence
    c. MHD turbulence and the effects of magnetic fields
    d. Effect of shocks and compressibility

<u>Grading:</u> There will be (i) assignments approximately every two to three weeks, (ii) an in-class exam toward the end of the semester, and (iii) a Term paper + presentation. Each will account for 1/3-rd of your final grade.

Homework: Assignments will typically include a combination of textbook problems and small computing projects. As part of assignments, you will need to learn how to access and query an online turbulence database at Johns Hopkins University (JHU): http://turbulence.pha.jhu.edu/ and use the data as a testbed for the concepts learned in class. The computational projects build upon each other such that you produce a spectral 1-dimensional code to simulate linear and nonlinear PDEs (heat equation, wave equation, Burgers equation).

Assignment reports have to be typed, so you should be familiar with typesetting software such as LaTeX, Lyx, or MS Word's Equations editor, and should be able to include figures and captions in your reports. Solutions to completed assignments will not be made available. However, you are encouraged to discuss your graded assignment with the instructor or TA. Although you may discuss homework problems with instructor, teaching assistants, or your classmates, you are expected to work out the problems independently (see Academic Honesty).