AME 651 - Statistical theories of turbulence

Spring 2016

Units: 3
Lecture hours: Mondays and Wednesdays 2:00-3:20pm
Location: VHE 214

Instructor: Prof. Iván Bermejo-Moreno (bermejom@usc.edu)
Office: RRB 215
Office Hours: Mondays and Thursdays 4-6pm

Teaching Assistant: TBA
Office: TBA
Office Hours: TBA

Course Description

This course intends to familiarize the student with some of the existing knowledge of turbulence in fluid flows. Starting from a phenomenological approach to the origin of turbulence, we will revisit the equations of fluid motion, identifying those aspects where turbulence is rooted. A close look at the dynamics of vorticity in three dimensions will follow, focusing on the importance of vortex stretching and vortex interactions as necessary ingredients of turbulence. The mathematical tools needed for the statistical description of turbulence will then be introduced and applied to the canonical case of isotropic homogeneous turbulence. Free and wall-bounded shear turbulent flows will be studied next. We will then address the interplay of turbulence with other physical phenomena such as the transport of passive scalars (which will lead to the introduction of the Lagrangian description of turbulence), compressibility, rotation, stratification and magnetic fields. The course will conclude with some considerations on the modeling of turbulent flows through numerical simulations of different degrees of fidelity.

Recommended Preparation: AME 530a

Textbooks:

The following books are suggested, but not required:

- S. B. Pope, *Turbulent flows*, Cambridge University Press, 2000.
- P. A. Davidson, *Turbulence, an introduction for scientists and engineers*, Oxford University Press, (2nd edition), 2015
- H. Tennekes and J. L Lumley *A First Course in Turbulence*, MIT Press, 1972.
- U. Frisch *Turbulence, the legacy of A. N. Kolmogorov*, Cambridge University Press, 1995
- A. S. Monin and A. M. Yaglom, *Statistical fluid mechanics*, vols. I & II, MIT Press, (1971,75)
- A. J. Chorin, *Vorticity and turbulence*, Springer, 1994

Grading Breakdown

Homework: 50% (6 assignments)
Final exam: 50% (take-home, open-books)

Assignment Submission Policy

Homework assignments will be due two weeks after they are posted. No late homeworks will be accepted.

Course schedule: Weekly breakdown

Week	Topics
1	Nature of turbulence. • Origins, instabilities and laminar to turbulent flow transition. • Dimensional analysis, introduction to length and time scales in turbulence. Equations of fluid motion. Navier-Stokes, energy and transport equations. • Symmetries and transformations.
2	Vortex dynamics and turbulence. • Helmholtz & Biot-Savart theorems. • Vorticity stretching • Vortex interactions
3	Mathematical tools for the statistical description of turbulence. • Time, space and ensemble averaging. Stationarity and ergodicity. • Probability theory, velocity correlations, structure functions. • Spectral representations of stationary processes and homogeneous fields. • Mean flow equations and Reynolds stresses. The closure problem.
4 & 5	Isotropic (and locally isotropic) homogeneous turbulence • Energy cascade. Kolmogorov hypotheses. • Karman-Howarth equation and Kolmogorov's four-fiths law. • Spectral representation. Autocorrelation function, power and energy spectra • Intermittency and the refined similarity hypothesis.
6 & 7	Turbulent free shear flows: jets, mixing layers, wakes.
8 & 9	Turbulent wall-bounded shear flows • Channels, pipes, boundary layers. • Structure of a turbulent boundary layer. • Log-law of the wall. • Turbulent coherent structures in wall-bounded flows. • Smooth and rough walls.
10	Conserved passive scalars in turbulent flows. • Relative roles and interaction of molecular and turbulent diffusion • Turbulent mixing, diffusion and dispersion. • Yaglom's four-thirds law • Taylor and Richardson diffusion
11	Lagrangian description of turbulence
12	Compressible turbulence. • Linear and quadratic effects. • Sound generation. • Turbulence in supersonic flows
13	Effects of rotation, stratification and magnetic fields on turbulence. Applications in geophysics and astrophysics.
14 & 15	Numerical simulation and modeling of turbulent flows • Direct Numerical Simulations (DNS) • Large-Eddy Simulations (LES) • Simulations based on Reynolds-Averaged Navier-Stokes equations (RANS)

Academic Conduct

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Section 11, Behavior Violating University Standards https://scampus.usc.edu/1100-behavior-violating-university-standards-and-appropriate-sanctions. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Discrimination, sexual assault, and harassment are not tolerated by the university. You are encouraged to report any incidents to the Office of Equity and Diversity http://equity.usc.edu or to the Department of Public Safety http://adminopsnet.usc.edu/department/department-public-safety. This is important for the safety of the whole USC community. Another member of the university community – such as a friend, classmate, advisor, or faculty member – can help initiate the report, or can initiate the report on behalf of another person. The Center for Women and Men http://www.usc.edu/student-affairs/cwm/ provides 24/7 confidential support, and the sexual assault resource center webpage http://sarc.usc.edu describes reporting options and other resources.

Support Systems

A number of USC's schools provide support for students who need help with scholarly writing. Check with your advisor or program staff to find out more. Students whose primary language is not English should check with the American Language Institute http://dornsife.usc.edu/ali, which sponsors courses and workshops specifically for international graduate students. The Office of Disability Services and Programs http://sait.usc.edu/academicsupport/centerprograms/dsp/home_index.html provides certification for students with disabilities and helps arrange the relevant accommodations. If an officially declared emergency makes travel to campus infeasible, USC Emergency Information http://emergency.usc.edu will provide safety and other updates, including ways in which instruction will be continued by means of blackboard, teleconferencing, and other technology.