Turbulence Modeling (ME 564)

by Sourabh V. Apte

1 Course Name: Turbulence Modeling

2 Course Number: ME 564

3 Course Credits: 3

4 Course Hours:

Total 3 hours per week per term (two 90 minute lectures per week is preferred format) for in class lectures.

5 Enforced Prerequisites:

ME560 (Intermediate Fluid Mechanics) AND [ME565 (Incompressible Flow) OR (ME566, Viscous Flow)]

6 Course Content

This course provides an overview of turbulence modeling techniques. Emphasis is placed on turbulence simulation techniques such as direct numerical simulation (DNS), large-eddy simulation (LES), and Reynolds-averaged Navier Stokes (RANS) models. This is not a programming intensive course, but rather based on the theory of turbulence modeling techniques. Students will gain understanding of turbulent flows and commonly used modeling techniques. Commonly used single and two-point statistics, energy spectra, and feature identification techniques will be summarized. Lectures will be designed to provide an overview of various topics and to introduce different concepts used in turbulence modeling. However, for deeper understanding of the presented concepts, this course requires extensive reading of assigned material including journal articles, handouts, book chapters, etc.

Details on the topics covered are given below.
7 Course Specific Measurable Student Learning Outcomes

After completion of the course, the students will be able to

1. Derive governing equations for turbulent flow based on temporal as well as spatial filtering and apply the governing equations to analyze simple free shear as well as wall-bounded flows,

2. Evaluate Reynolds averaged Navier Stokes equations and a suite of models used to close the Reynolds stresses using statistical correlations, realizability of the Reynolds stress tensor, and predictive capability,

3. Perform spatial and temporal filtering of DNS data for apriori and a posteriori analysis employed in large-eddy simulation,

4. Conduct independent reading of advanced research papers on assigned topics and analyze the findings based on the fundamental concepts of gradient diffusion hypothesis, scale-similarity, spatial and temporal scales, tensor manipulations, among others to individually complete a thorough research paper.

8 Contact Information and Office Hours

Email: sva@engr.orst.edu, Office: 308 Rogers Hall. Office hours: Wednesday 3-4pm; Friday 10:30-12pm. You may also send email for other available times

9 Evaluation of Student Performance

The assessment of your learning will be based upon assigned homework and reading materials (75%), and a final term paper (25%).

Periodic assignments may involve solving problems or reading of reference materials and submitting a brief summary. The final term paper will involve choosing an appropriate topic (of your interest) relevant to turbulence modeling, performing reading and analyzing the material from few published articles, writing a term paper in a prescribed format, and presenting your work to the class in the tenth week. You are encouraged to discuss your topics and reading material with the instructor.

10 Statement of Expectations for Student Conduct

Copying of any material, term paper, etc., and plagiarizing contents will be considered cheating and may result in a grade of zero on that piece of work. In addition, any instance in which a student is caught cheating will be handled in accordance to the policies mentioned in the Schedule of Classes and at the following web site:

http://oregonstate.edu/studentconduct/offenses-0
11 Statement Regarding Students with Disabilities

Oregon State University is committed to student success; however, we do not require students to use accommodations nor will we provide them unless they are requested by the student. The student, as a legal adult, is responsible to request appropriate accommodations. The student must take the lead in applying to Disability Access Services (DAS) and submit requests for accommodations each term through DAS Online. OSU students apply to DAS and request accommodations at our Getting Started with DAS page.
12 Expectations

This course is typically meant for advanced graduate students (in their second or later years). Fundamental understanding of advanced theory of fluid mechanics is necessary. It is expected that students taking this course are familiar with topics covered in basic fluid mechanics (e.g. ME560 (Intermediate Fluid Mechanics) and ME565 (Incompressible Flow) OR ME566 (Viscous Flow)). A general background on the theory of turbulence will be a plus. In addition, strong background in Advanced Calculus (Vector and Tensor notations, linear algebra, co-ordinate transformations etc.) and basic statistical theory are essential.

13 References

• Reference Books
  – Turbulence Modeling for CFD, by D. C. Wilcox, DCW Industries.

• Journals
  – Annual Review of Fluid Mechanics
  – Scientific American
  – Journal of Fluid Mechanics
  – Physics of Fluids
  – Physics Today
  – American Scientist

• Web resources: [http://www.efluids.com/](http://www.efluids.com/)

14 Topics

1. Introduction
   • Features of turbulent flows.
   • Conservation equations (incompressible/compressible), tensor notations.
   • Spatio-temporal scales, spectral description, non-linearity and instability, the Energy cascade.
   • Modeling challenges.

2. Conservation equations for turbulent flows
   • Reynolds and Favre Averaging
   • One-point and two-point correlations
   • Reynolds Averaged Navier Stokes equations
   • The Closure problem.
   • Turbulent kinetic energy and Reynolds Stress equations.
   • Kolmogorov’s $-5/3^\text{rd}$ law.
   • Effects of compressibility or variable density.

3. Direct Numerical Simulation (DNS)
   • Spatio-temporal scales and computing requirements.
   • DNS as a research tool.

4. Large Eddy Simulation (LES)
   • Resolved scales and unresolved subgrid scales
   • Spatial filtering in LES
   • Smagorinsky model
   • Dynamic modeling
   • Kinetic energy equation (resolved and subgrid scale) and interpretation of terms.

5. Reynolds Averaged Navier Stokes (RANS) Modeling
   • Algebraic Models (Boussinesq approximation, Prandtl’s mixing length hypothesis)
   • One and Two-equation models ($k-\epsilon$, $k-\omega$)
   • Wall functions
   • Second-order closure models.

6. Advanced topics, data analysis and vortex identification.
15 Important Landmark Reference Papers (in random order)

1. Stewart, R.W., Turbulence, MM Sound Films.
2. Liepmann, H.W., 1979, The rise and fall of ideas in turbulence, American Scientist, pp. 221.