Turbulence and CFD models:
Theory and applications

Course presentation – Syllabus

Aim of the course

The main objective of the course is to give the students a thorough knowledge of turbulence modeling in CFD from the theoretical and practical points of view. During the course, we will cover RANS models and scale-resolving simulations (DES and LES). We will also address accuracy and reliability of CFD turbulent simulations, as well as discretization techniques, solution strategies, and best standard practices when conducting CFD simulations. At the end of the course, the student should be able to choose the best turbulence model for her/his applications and give a critical assessment of the influence of turbulence models on the outcome of CFD simulations, independently of the software used. Hands-on sessions will be delivered to reinforce the knowledge acquired.

Course content - Syllabus

1. Transition to turbulence in shear flows.

2. Introduction to turbulence. Turbulence, does it matter? The nature of turbulence. Wall bounded flows and free shear flows.

3. Length scales in turbulent flows. From Kolmogorov scales to Taylor microscales, to integral scales. Energy cascade. Law of the wall. Near wall treatment.

4. Practical turbulence estimates.

5. Governing equations. Reynolds averaging. The Boussinesq hypothesis.

6. Closure problem. Algebraic models. One equation models. Two equation models. Reynolds stress models (RSM). Unsteady RANS simulations. Wall modeling and wall resolving simulations.

7. Statistical description of turbulence. Descriptive statistics. Joint statistics. One-point correlation. Two-point correlations. Time series. Turbulent kinetic energy spectrum. Power spectrum.

8. Post-processing turbulent simulations. Quantitative and qualitative post-processing. Dealing with steady and unsteady simulations.

9. Beyond the Boussinesq hypothesis, compressibility effects and multiphase flows. Effect of roughness on the law of the wall.

10. Scale-resolving simulations (SRS). DES, LES, DNS. Wall modeling and wall resolving simulations.

11. Numerical considerations. Validation and verification. Mesh dependency studies. Accuracy and reliability of turbulent simulations.

Organization – Timetable

The program is divided between lectures and guided tutorials. At least one lecture will be delivered on every topic, and to reinforce the knowledge acquired, we will conduct numerical simulations or analyze data using modern software and applications.

Week	Date	Day	Time	Activity	Syllabus
1	02/03/2020	Mon.	14:00 – 17:00	Lec. (AB)	1
2	04/03/2020	Wed.	17:00 – 19:00	Lec. (AB)	1
3	09/03/2020	Mon.	14:00 – 17:00	Lec. (AB)	1
4	11/03/2020	Wed.	17:00 – 19:00	Lec. (AB)	1
5	16/03/2020	Mon.	14:00 – 17:00	Lec. (JG)	2
6	18/03/2020	Wed.	17:00 – 19:00	Lec. (JG)	3
7	23/03/2020	Mon.	14:00 – 17:00	GT. (JG)	2-3
8	30/03/2020	Mon	14:00 – 17:00	Lec. (JG)	4-5
9	01/04/2020	Wed.	17:00 – 19:00	Lec./GT. (JG)	4-5
10	06/04/2020	Mon.	14:00 – 17:00	GT. (JG)	4-5
11	08/04/2020	Wed.	17:00 – 19:00	Lec. (JG)	6
12	15/04/2020	Wed.	17:00 – 19:00	Lec./GT. (JG)	6
13	20/04/2020	Mon.	14:00 – 17:00	GT. (JG)	6
14	22/04/2020	Wed.	17:00 – 19:00	Review - Summary	1-6
15	27/04/2020	Mon.	14:00 – 17:00	Midterm	1-6
16	29/04/2020	Wed.	17:00 – 19:00	Lec./HW1 (JG)	7
17	04/05/2020	Mon.	14:00 – 17:00	Lec./GT (JG)	7
18	06/05/2020	Wed.	17:00 – 19:00	Lec./GT (JG)	7-8
19	11/05/2020	Mon.	14:00 – 17:00	Lec./HW2 (JG)	8
20	13/05/2020	Wed.	17:00 – 19:00	Lec. (JG)	9
21	18/05/2020	Mon.	14:00 – 17:00	GT. (JG)	7-8-9
22	20/05/2020	Wed.	17:00 – 19:00	Lec. (JG)	10
23	25/05/2020	Mon.	14:00 – 17:00	Lec./GT (JG)	10
24	27/05/2020	Wed.	17:00 – 19:00	Lec./GT (JG)	10
25	01/06/2020	Mon.	14:00 – 17:00	Lec./GT/DL (JG)	11
26	03/06/2020	Wed.	17:00 – 19:00	Closing remarks	All

Notes:

Lec. = Lecture

AB = Alessandro Bottaro

HW = Homework (there are two assignments)

GT. = Guided tutorial – Workshop

JG = Joel Guerrero

DL = Deadline for submitting the homework report

Software

During the course, we will use the following software and applications:

- Ansys Fluent (version 2020R1 and up) – CFD solver
  - https://www.ansys.com/academic/free-student-products

- Anaconda Python (Python distribution 3.7) – Data analysis (and more)
  - https://www.anaconda.com/distribution/

- Paraview (version 5.6 and up; however, I recommend version 5.6) – Scientific visualization
  - https://www.paraview.org/

The student should bring his/her computer with all the software installed. All the software to be used is free and can be downloaded at the links provided.

Recommended literature

- D. Wilcox. Turbulence Modeling for CFD. DCW Industries Inc., 2010.
- S. Pope. Turbulent Flows. Cambridge University Press, 2000.
- J. Mathieu and J. Scott. An Introduction to Turbulent Flow. Cambridge University Press, 2000.
- H. Tennekes and J. L. Lumley. A First Course in Turbulence. MIT Press, 1972.
- Lars Davidson. Turbulence modeling notes.
  - http://www.tfd.chalmers.se/~lada/comp_turb_model/
  - http://www.tfd.chalmers.se/~lada/comp_turb_model/ebook.html
- NASA Turbulence Modeling Resources.
  - https://turbmodels.larc.nasa.gov/
- And of course, the documentation of the CFD solver we will use:
  - Ansys Fluent User guide.
  - Ansys Fluent Theory guide.

Examination

The course will be graded in base of a midterm, continuous assignments, and a final project.

The midterm evaluation will address the theory studied until week 14. This theory covers the fundamentals of turbulence modeling in CFD.

Before starting the final project, two homework will be used to assess the ability of the student to independently setup a CFD simulation and analyze turbulent data. The homework must be delivered on week 25 or earlier. A written report and the case setup and scripts developed must be delivered. The homework will be graded pass/fail.

The final evaluation will consist of a CFD project where the student should put into practice all the knowledge acquired. The case to be developed should be agreed between the examiner and each student. A written report and the case setup and scripts developed must be delivered. Based on the feedback provided by the examiner, the student will have a one-time opportunity to improve his/her report.

When writing the reports, consider the following:

- Language. Is the report clear and well-written? Is the English/Italian understandable?
- Figures. Are the figures clear and understandable? Are all figures commented in the text? Does the figure give any valuable information?
- Tables. Are the tables clear and understandable? Are the tables split among many pages? Are all tables commented in the text? Does the table give any valuable information?
- Methodology. Is the methodology well explained? Am I given enough information so somebody else can reproduce my results (reproducible research)?
- Analysis. How well are the results analyzed?
- Hypothesis. Are all my hypotheses properly justified?
- Did I answer all the questions asked?
- Are all references cited in the text? Am I given credits where it is due? Is my bibliography complete and up to date? Am I citing all the references correctly?
- Is my report well formatted? Am I following all the guidelines given by the instructor?

Grading policy

	Percentage of the final grade
Midterm	20%
Homework	30%
Final exam	50%

- There will at least four homework.
- The midterm will be conducted after a review session to assess the knowledge acquired and address general questions.
- Students are encouraged to interact during the lectures as bonus points will be awarded (up to a maximum of 10% of the final grade).

Examiner

Joel Guerrero – guerrero@unige.it

Office hours:

10:00-16:00 – Monday to Thursday

Confirm appointment by sending an email.