Turbulence and CFD models:
Theory and applications

Course presentation – Syllabus – Timetable

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. CFD and turbulence modeling. 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. Reynolds-averaged Navier-Stokes equations (RANS).

6. Closure problem. Algebraic models. One equation models. Two equation models. Reynolds stress models (RSM). Unsteady RANS simulations (URANS). 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 in SRS.

11. Best practices in CFD and turbulence modeling. 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	22/02/2021	Mon.	14:00 – 17:00	Course introduction	-
2	24/02/2021	Wed.	17:00 – 19:00	LEC – HW1 (AB)	1
3	01/03/2021	Mon.	14:00 – 17:00	LEC – HW1 (AB)	1
4	03/03/2021	Wed.	17:00 – 19:00	LEC – HW1 (AB)	1
5	08/03/2021	Mon.	14:00 – 17:00	LEC – HW1 (AB)	1
6	10/03/2021	Wed.	17:00 – 19:00	LEC – HW1 (AB)	1
7	15/03/2021	Mon.	14:00 – 17:00	LEC (JG)	2-3
8	17/03/2021	Mon	14:00 – 17:00	LEC (JG)	3-4
9	22/03/2021	Wed.	17:00 – 19:00	LEC – GT – R – HW2 (JG)	2-3-4
10	24/03/2021	Mon.	14:00 – 17:00	LEC (JG)	5
11	12/04/2021	Wed.	17:00 – 19:00	LEC – GT (JG)	5
12	14/04/2021	Wed.	17:00 – 19:00	LEC (JG)	6
13	19/04/2021	Mon.	14:00 – 17:00	LEC – GT (JG)	6
14	21/04/2021	Wed.	17:00 – 19:00	LEC – GT – R (JG)	6
15	26/04/2021	Mon.	14:00 – 17:00	LEC (JG) – HW3	7-8
16	28/04/2021	Wed.	17:00 – 19:00	LEC – GT (JG)	7-8
17	03/05/2021	Mon.	14:00 – 17:00	LEC – GT (JG)	7-8
18	05/05/2021	Wed.	17:00 – 19:00	LEC (JG)	9
19	10/05/2021	Mon.	14:00 – 17:00	R – GT (JG)	7-8-9
20	12/05/2021	Wed.	17:00 – 19:00	LEC – HW4 (JG)	10
21	17/05/2021	Mon.	14:00 – 17:00	LEC – GT (JG)	10
22	19/05/2021	Wed.	17:00 – 19:00	LEC – GT (JG)	10
23	24/05/2021	Mon.	14:00 – 17:00	LEC – DL – GT (JG)	11
24	26/05/2021	Wed.	17:00 – 19:00	FR – CR	All

Notes:

AB = Alessandro Bottaro

JG = Joel Guerrero

LEC = Lecture

GT = Guided tutorial – Workshop

HW = Homework

DL = Deadline for submitting the homework report

R = Short review of the topics addressed

FR = Final review of all topics

CR = closing remarks

Software

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

- Ansys Fluent (version 2020R2 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 her/his 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.
- P. Bernard. Turbulent Fluid Flow. Wiley, 2019.
- M. T. Landahl and E. Mollo-Christensen. Turbulence and Random Processes in Fluid Mechanics. Cambridge University Press, 1992.
- 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.

Grading/Examination

The course will be graded based on continuous assignments and a final project.

There will be four homework, of which three are theoretical or related to bibliographical research, and the remaining one is numerical.

The final evaluation will consist of a CFD project where the student must put into practice all the knowledge acquired. The case to be developed must be agreed upon between the examiner and the student. A written report and a short presentation are also expected at the end of the final project.

Based on the feedback provided by the examiner, the student will have a one-time opportunity to improve her/his report.

	Percentage of the final grade
Homework	40%
Final exam	60%

- Students are encouraged to interact during the lectures as bonus points will be awarded (up to a maximum of 10% of the final grade).

Grading scale – Grading system

Point grades	Letter grades	Performance designation
31-32	A+	Excellent - Outstanding
29-30	A	Excellent
27-28	A-	
25-26	B+	Good
23-24	B	
21-22	B-	
20	C+	Satisfactory
19	C	Satisfactory
18	C-	Marginal
0-17	D	Unsatisfactory – Fail

Final presentation, examination, and deadlines

We strongly encourage students to deliver their homework two weeks after the initial date. The final date to deliver the homework is given in the timetable.

There will be three calls to deliver the final presentation:

- Mid-End of July.
- Beginning-Mid of September.
- Mid-End of October.

The report of the final project must be delivered at least two weeks before the selected call.

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 providing enough information so somebody else can reproduce my results (reproducible research)?
- Analysis. How well are the results analyzed?
- Hypothesis. Are all my hypotheses adequately justified?
- Did I answer all the questions asked?
- Are all references cited in the text? Am I giving credit 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?
- Is my report scientifically sound?
- Do I meet all the requirements of scientific rigor, transparency, and reproducibility?

Finally, it is strongly encouraged to use Latex when writing the report.

Course website:

http://www3.dicca.unige.it/guerrero/turbulence2021/teaching_turbulence2021.html

Contact information:

Course coordinator:

Joel Guerrero – joel.guerrero@unige.it

Instructors:

Joel Guerrero – joel.guerrero@unige.it

Alessandro Bottaro – alessandro.bottaro@unige.it

Teaching assistant:

N/A

Office hours:

10:00-16:00 – Monday to Thursday

Confirm appointment by sending an email.