Turbulence and CFD models:
Theory and applications

Course presentation – Syllabus – Timetable

Aim of the course.

The course's main objective is to give the students a thorough knowledge of turbulence modeling in CFD from the theoretical and practical points of view. We will cover RANS models and scale-resolving simulations or SRS (DES and LES) during the course. We will also address the accuracy and reliability of turbulent simulations, as well as discretization techniques, solution strategies, and best standard practices when conducting CFD simulations. At the end of the course, the students should be able to choose the best turbulence model for their applications and critically assess 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

0. Course presentation. Quick review of solution methods in CFD. Ansys Fluent executive summary.

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. Quantitative and qualitative post-processing of turbulent simulations. Data analysis and statistical tools used turbulence modeling. Descriptive statistics. Joint statistics. One-point correlation. Two-point correlations. Time series. Turbulent kinetic energy spectrum. Power spectrum.

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

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

10. 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. To reinforce the knowledge acquired, we will conduct numerical simulations or analyze data using modern software.

Week	Date	Day	Time	Activity	Syllabus
1	20/02/2023	Mon.	10:00 – 13:00	CP – LEC – GT (JG)	0
2	22/02/2023	Wed.	08:00 – 10:00	LEC (AB)	1
3	27/02/2023	Mon.	10:00 – 13:00	LEC (AB)	1
4	01/03/2023	Wed.	08:00 – 10:00	LEC (AB)	1
5	06/03/2023	Mon.	10:00 – 13:00	LEC (AB)	1
6	08/03/2023	Wed.	08:00 – 10:00	LEC – HW1 (AB)	1
7	13/03/2023	Mon.	10:00 – 13:00	LEC (JG)	2-3
8	15/03/2023	Wed.	08:00 – 10:00	LEC (JG)	3-4
9	20/03/2023	Mon.	10:00 – 13:00	LEC – GT – R – HW2 (JG)	2-3-4
10	22/03/2023	Wed.	08:00 – 10:00	LEC (JG)	5
11	03/04/2023	Mon.	10:00 – 13:00	LEC – GT (JG)	5-6
12	05/04/2023	Wed.	08:00 – 10:00	LEC – GT (JG)	6
13	12/04/2023	Wed.	08:00 – 10:00	LEC – GT (JG)	6
14	17/04/2023	Mon.	10:00 – 13:00	LEC – GT – R (JG)	6
15	19/04/2023	Wed.	08:00 – 10:00	Mid-term review – GT (JG)	0-6
16	26/04/2023	Wed.	08:00 – 10:00	LEC (JG) – HW3	7-8
17	01/05/2023	Mon.	10:00 – 13:00	LEC – GT (JG)	7-8
18	03/05/2023	Wed.	08:00 – 10:00	LEC – GT (JG)	7-8
19	08/05/2023	Mon.	10:00 – 13:00	R – GT (JG)	7-8-9
20	10/05/2023	Wed.	08:00 – 10:00	LEC – GT (JG)	9
21	15/05/2023	Mon.	10:00 – 13:00	LEC – GT (JG)	9
22	17/05/2023	Wed.	08:00 – 10:00	LEC – GT (JG)	9
23	22/05/2023	Mon.	10:00 – 13:00	LEC – GT (JG)	9-10
24	24/05/2023	Wed.	08:00 – 10:00	DL – FR	All

Notes:

AB = Alessandro Bottaro

JG = Joel Guerrero

CP = Course presentation

LEC = Lecture

GT = Guided tutorial – Bring your computer

HW = Homework

R = Short review of selected topics

DL = Deadline for submitting the homework report

FR = Final review and closing remarks

Software

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

- Ansys Fluent student edition (version 2023R1 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/

Students should bring their computer with all the software installed. All the software to be used is free and can be downloaded at the links provided.

You can find additional information regarding UNIGE Ansys Student license at the following link,

- https://dicca.unige.it/auleinformatiche/ansys

The following software is optional (also free):

- Paraview (version 5.9 and up; however, I recommend version 5.6) – Scientific visualization
    - https://www.paraview.org/

Recommended literature

- D. Wilcox. Turbulence Modeling for CFD. DCW Industries Inc., 2010.
- S. Pope. Turbulent Flows. Cambridge University Press, 2000.
- P. Bernard. Turbulent Fluid Flow. Wiley, 2019.
- 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/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 are no tests.

There will be three homework, two 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. 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	30%
Final exam	70%

- 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 homework has been assigned. The final date to deliver the homework is given in the timetable.

The call to deliver the final presentation is open. However, the date should be confirmed in advanced with the instructor. Alternatively, there will be three fixed calls to deliver the final presentation:

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

The corrected report and final project must be delivered at least two weeks before the selected call. The simulations case files must also be provided with the written report.

<u>Please submit all the files using the Teams channel.</u>

Written Report Guidelines

When writing your report, 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/teaching_turbulence.html

Please visit weekly the course website as new material is continuously added.

Contact information:

Course coordinator:

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Instructors:

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Office hours:

10:00-16:00 – Monday to Friday

Confirm appointment by sending an email.