**Title of the Unit:** Turbulence models

**Unit code:** MU5MEF001

**Total time per student:** 20h lecture 4h tutorial 8h lab 0h project

**Credit number:** 3 ECTS

**Master’s degree:**  Mechanics  Robotics & Auto. Cont.  Electrical Eng.

**Master program:** E3A : CIMES  Syscom  IPS

AR :  SAR  ISI

MECA :  MS2  MF2A  EE  CompMech  ACOU  EE APP

**Semester:**  S1  S2  S3  S4

**Teaching language:**  French  English

**Involved students:**  Sorbonne Université  Other (to be specified): ENSAM

**Localization:**  PMC campus  Other (to be specified):

**Objectives of the unit:**

The module provides an introduction to the modeling and numerical simulation of turbulent flows, essential for a large number of problems in science and engineering. We are particularly interested in the turbulence models known as " Reynolds-Averaged Navier-Stokes " (RANS), which constitute the most used approach in the major simulation codes in fluid mechanics, in particular for industrial applications. The course will provide a critical presentation of the main RANS models, the underlying assumptions, their limitations and their numerical behavior (robustness and computation time). These concepts will be illustrated through problem-solving studies and numerical applications using open-source computational fluid mechanics software (OpenFoam). A scientific opening towards automatic learning approaches (machine-learning) of models and the quantification and reduction of uncertainties is also proposed.

**Knowledge and skills mastered at the end of the unit :**

• Main turbulence modeling strategies, advantages and shortcomings of the most used models

• Set up of turbulent flow simulations by choosing the most suitable turbulence model and numerical ingredients (mesh, discretization scheme, etc.)

**Detailed content of the unit :**

• Reminders on turbulent flows

• Modeling levels: direct numerical simulation (DNS), large eddy simulation (LES), averaged approaches (RANS); RANS/LES hybridization

• RANS models: notion of average, averaged Navier-Stokes equations, closure problem

• Algebraic models: mixing length, corrections for wall-bounded flows. Baldwin and Lomax model. Application to canonical flows (mixed layer, jet, flat channel, turbulent boundary layer)

• Transport equation models: turbulent kinetic energy equation. Some popular one- and two-equation models (Spalart-Allmaras, k-epsilon, k-omega) and their variants. Numerical aspects (choice of mesh, numerical stiffness, boundary conditions).

• Reynolds stress models and nonlinear models

• Unsteady turbulent flows: limitations of the RANS approach. URANS models. RANS/LES hybrid models

• Modeling of compressible turbulence

• Turbulence models, machine learning techniques and quantification of uncertainties

**Prerequisites of the unit :**

Background of tensor calculus, fluid mechanics, numerical simulation of flows, turbulence dynamics.

**Evaluation of the unit (informative) :**

4 Wooclap tests, 2 Lab reports, 1 Written exam (2h)

**Bibliography :**

D.C. Wilcox, « Turbulence modeling for CFD » 3rd edition; S.B. Pope, “Turbulent Flows”, Cambridge University Press; P. Chassaing, “Turbulence en Mécanique des Fluides”, Cépaduès; G. Comte-Bellot et C. Bailly, “Turbulence”, Ed. CNRS.

**Teaching sequence (informative) :**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| week | lecture | tutorial | lab | project | test |
| W1 | 4h |  |  |  |  |
| W2 | 4h |  |  |  |  |
| W3 | 2h | 2h |  |  |  |
| W4 | 4h |  |  |  |  |
| W5 | 2h | 2h |  |  |  |
| W6 | 4h |  |  |  |  |
| W7 |  |  | 4h |  |  |
| W8 |  |  | 4h |  |  |
| W9 |  |  |  |  |  |
| W10 |  |  |  |  | 2h |
| W11 |  |  |  |  |  |
| W12 |  |  |  |  |  |
| W13 |  |  |  |  |  |
| W14 |  |  |  |  |  |

**Date**: 19/5/2022

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