module title: **TURBULENCE FOR CFD**		
field of study: **Mechanical Engineering**	type of study: **full-time**	course code: **S6_1-2**
course: **Modelling & Simulation in Mechanics**	degree: **Master (MSc)**	year: **I** semester: **I**
type of classes: **lecture, laboratory**	hours per week: **2L, 2Lab**	No of ECTS credits: **5**

MODULE DESCRIPTION

TARGETS

T1. Provide basic understanding of transport processes in turbulent flows.
T2. Provide ability to select turbulence models.
T3. Provide knowledge on simulations of free and wall bounded flows.
T4. To acquire capabilities to perform numerical analysis of the flow field.

PREREQUISITES & ADDITIONAL REQUIREMENTS

R1. Fundamentals of mechanics, thermodynamics and fluid mechanics.
R2. Statistics, first and second order moments.
R3. Safety rules during the use of laboratory equipment.
R4. Capability of using source literature.
R5. Capability of individual work and collaboration in a group.
R6. Data analysis and presentation of results.

LEARNING OUTCOMES

LO1. Knowledge on mathematical description of turbulence.
LO2. Knowledge on turbulence models and their limitations.
LO3. Knowledge on using commercial CFD software.

MODULE CONTENT

LECTURE	hours
L 1-6 - Energy losses in laminar and turbulent flows, laminar and turbulent diffusion, Reynolds decomposition of velocity field, vortex stretching and energy cascade, energy spectrum in turbulent flows, turbulence as stationary and ergodic statistical process, averaging rules for stochastic process.	**6**
L 7-10 - Reynolds averaging of continuity and Navier-Stokes equations, Reynolds stresses.	**4**
L 11-15 - Reynolds stress tensor, reduction of number of unknown stresses, Boussinesq's concept of eddy viscosity, Reynolds analogy for molecular and turbulent momentum transfer, Prandtl's analysis of turbulent boundary layer, idea of mixing length	**5**
L 16-17 - Algebraic stress models, comparative analysis of Prandtl's and Karman hypotheses, idea of algebraic turbulence models.	**2**
L 18-19 - Van Driest and Clauser improvements of mixing length concept, intermittency concept, modern algebraic turbulence models.	**2**
L 20-21 - Turbulence kinetic energy transport equation, energy transfer between mean and fluctuating motion.	**2**
L 22-24 - One- and two-equation turbulence models, idea of hybrid turbulence models.	**3**
L 25-26 - Limitations of one and two equation turbulence models, stress transport models.	**2**
L 27-30 - Navier-Stokes equations as chaotic system, Direct Numerical Simulation (DNS) and Large Eddy Simulation (LES) of turbulent flows.	**4**

LABORATORY	hours
Lab 1-2 - Laboratory rules. Organisation of work. Elementary information on used software.	**2**
Lab 3-6 - Usage of ANSYS Gambit/ICEM for mesh generation.	**4**
Lab 7-10 - Usage of ANSYS Fluent software - cavity and channel flows. Analysis of influence of turbulence RANS models.	**4**
Lab 11-16 - Flow modelling around cylinder: steady vs unsteady solution. RANS vs LES.	**6**
Lab 17-20 - Modelling of free jet flows and spatially evolving shear layer flow.	**4**
Lab 21-26 - Flow modelling around Ahmed body and airfoil - comparison of RANS models.	**6**
Lab 27-30 - Postprocessing and analysis of CFD data.	**4**

TEACHING TOOLS

1 - lecture with the use of multimedia presentations
2 - experimental stands equipped with measuring instrumentation
3 - computer laboratory, software for fluid flow simulation
4 - instructions to laboratory exercises

SOURCE LITERATURE

1. Pope S.B.: Turbulent Flows. Cambridge Univ. Press, 2000
2. Hinze J.O.: Turbulence. McGraw-Hill, New York, 1975
3. Lesieur M.: Turbulence in Fluids, Kluwer Academic Publisher, 1990
4. Ferziger J.H., Peric M.: Computational Methods for Fluid Dynamics, Springer, 2002
5. Wilcox D.C.: Turbulence Modeling for CFD
6. Geurts B., Elements of Direct and Large Eddy Simulation, Edwards, 2003
7. Lesieurs M., Metais O., Compte P., Large Eddy Simulation of Turbulence, Cambridge University Press, 2005
8. Sagaut P.: Large Eddy Simulation for Incompressible Flows, Springer, 2002
9. ERCOFTAC Best Practice Guidelines for Industrial CFD, 2000
10. ANSYS-CFD - software documentation

TEACHERS

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