Tárgytematika / Course Description

Computational fluid dynamics in vehicle engineering

AJNM_JFTA005

Tárgyfelelős neve / Teacher's name: dr. Feszty Dániel

Félév / Semester: 2020/21/1

Beszámolási forma / Assesment: Folyamatos számonkérés

Tárgy heti óraszáma / Teaching hours(week): 0/2/0

Tárgy féléves óraszáma / Teaching hours(sem.): 0/0/0

OKTATÁS CÉLJA / AIM OF THE COURSE

The goal of this course is to make engineering students informed users of Computational Fluid Dynamics (CFD) who can not only run CFD simulations but also fully understand their mathematical background and are able to make conscious choices of the appropriate numerical parameters. To achieve this, the relevant Fluid Mechanics laws, the governing equations as well as the applied numerical methods will be reviewed. Also, students will complete three practically oriented simulation assignments and learn how to present these in written form according to the internationally accepted standards. It is assumed that enrolled students have had at least one Fluid Mechanics course completed at the undergraduate level.

TANTÁRGY TARTALMA / DESCRIPTION

1) **Introduction:** Motivation, What is Computational Fluid Dynamics (CFD), Role of CFD in Vehicle Engineering and design

2) **Review:**

   Fundamentals of Fluid Mechanics: Properties of fluids, fluid as a continuum, Lagrangian and Eulerian viewpoints, Control Volume principle and applications, conservation of mass, momentum and energy, Bernoulli equations and its limitations

   Governing equations in CFD 1: Derivation of the Navier-Stokes equations, Flux vector formulation of the N-S equations, Conservative vs. primitive forms, Euler equations, Model equations

   Numerical solution of PDE's: Selection of mathematical model, Selection of discretization method (Finite Difference, Finite Volume, Finite Element, Spectral Method)

3) **Classification of differential equations:** ODE's vs. PDE's, Linear vs. non-linear equations, First-order vs. higher-order equations, Conservative vs. non-conservative forms

Assignment A2: **Simulation of a 2D airfoil in freestream**

(application: racecar wing aerodynamics)

4) **Classification of Partial Differential Equations (PDE's):** Determining the nature of PDE's (elliptic, parabolic, hyperbolic), Physical meaning for fluid flows, Computational meaning for fluid flows, Boundary and initial conditions for PDE's

5) **Turbulence 1:** Sources and physics of turbulence, Integral, Taylor and Kolmogorov scales, Differences between turbulence modelling, Large Eddy Simulation (LES) and Direct Numerical Simulations (DNS). Limitations and applicability.

6) **Turbulence 2:** Free turbulent flows, Boundary layers near solid walls, Turbulence modeling in CFD, Wall functions and implications for grid generation

7) **Grid generation:** Structured vs. unstructured grids, Grid transformation, Cartesian grids, Zonal or block-structured grids, Hybrid grids, Moving mesh techniques (Sliding mesh, CHIMERA grids) Deforming mesh techniques, Adaptive grids, Multigrid methods and their relation to grid generation, Basic guidelines for grid generation

Submission of Assignment A2

Assignment A3: **Simulation of a 2D airfoil in ground effect**

(application: racecar wing aerodynamics in ground effect)

8) **Boundary treatment:** Boundary conditions, Boundary treatment (Changing the numerical method at edges, Changing the computational domain at edges), Solid Wall boundary treatment, Far-field boundary treatment, Non-reflecting boundaries

9) **Solution techniques for the discretized equations:** Explicit vs. implicit formulations, Solutions techniques for explicit method (Lax-Wendroff, MacCormack, Runge-Kutta), Solution techniques for implicit methods (Direct methods /Gaussian elimination, Cramer's rule/, Indirect methods /Thomas algorithms, point-iterative methods, approximate factorization/)

10) **Errors and uncertainty in CFD:** Sources of error, Sources of uncertainty, Stability analysis of numerical errors (Discrete Perturbation analysis, Von Neumann Stability Analysis, Multidimensional considerations), The Courant-Friedrich-Loewy number (CFL), Stability vs. accuracy, Local vs. Global time stepping, Evaluation of convergence (Iterations convergence: residuals, Grid convergence, Time step convergence), Characteristic features related to stability (Consistency, Boundedness, Transportiveness)

11) **Special topics in CFD:** specifics of the Finite Volume Method, Riemann solvers, upwinding, higher order methods

12) Summary and review

Submission of Assignment A3

SZÁMONKÉRÉSI ÉS ÉRTÉKELÉSI RENDSZERE / ASSESMENT'S METHOD

This course is highly project-oriented and therefore the performance of the students will be evaluated on the basis of 2 assignments and a written final exam, as well as regular classroom quizzes.

The relative weight of the assignments and the final exam is:

Item	Weight	Assigned	Note
Classroom-quizzes	10%	Week 3 – 12	1% per class for 10 week
Assignment A2	30%	Week 3	due on Monday after Wk 7 lecture
Assignment A3	30%	Week 7	due on Monday after Wk 12 lecture

Final Exam	30%	on last lecture or in Exam period

CLASSROOM QUIZZES (10%) award students immediate comprehension of the material. They will run for 10 weeks, starting on Week 3. On each class, 3-5 multiple choice questions will be posed to the students, which weekly cumulative score will be worth 1% of the total mark for the entire course (i.e. 0.33 points for each question, if 3 questions are asked in a Classroom Quiz). Students shall answer the classroom quizzes via the internet. For this reason, each student is required to bring a laptop or a smartphone to the classroom. Those students who do not possess a smartphone or a laptop, should indicate the need for weekly paper-submission of the Classroom Quizzes to the Instructor via email by the end of the Week 2 lecture. Those students who do not participate in a specific Quiz, get zero mark for that week's Quiz.

THE ASSIGNMENTS (30% each) will be assigned on Weeks 3 and 7. It consist of completing a CFD simulation via Star CCM+ CFD software and the submission of an individually written Technical Report according to the worldwide accepted engineering standards.

NOTE: each student must submit an individually prepared Technical Report, which is 100% their own work, using their own wording. Copying sentences, parts, or the full report from someone else – including online sources from other universities – will be treated as plagiarism and will mean an automatic zero mark for the submission. If the report or its parts is identical to another student(s), then all involved students get an automatic zero for their reports. Plagiarism is a serious academic offense and might mean exclusion from the course or from the study program.

The Technical Reports will be marked in 3 categories: Technical Contents (10%), Layout/Accuracy (10%) and Quality of CFD work (10%). Marks for the Assignments will be conveyed to the students electronically. The marked assignments will be available for viewing at the final exam at the latest. More details on the format of submission are provided in the description of the assignments.

Submission of the Technical Reports for both Assignments is a requirement for completing the course. Failure to submit any of the reports means that the student gets a Failure grade in the course. Late submissions mean a 2% penalty per day. Even if a Technical Report is submitted so late that with penalties it can get only zero marks, it must be submitted in order to complete the course.

The Technical Reports must be submitted in printed form either personally at the Department of Whole Vehicle Engineering or via mail. For mail-in submissions, the date on the post office stamp will be taken as the submission date.

THE FINAL EXAM (30%) is 1.5 hrs long and of multiple choice format. The final exam is written in an online format and involves answering 45 multiple choice questions in a computer. The final exam is of closed-book format.

FINAL GRADING

The final grade for the course will be allocated based on the following scheme:

Percentage	Grade
0 - 39	1 (Fail)
40 - 54	2
55 - 69	3
70 - 84	4
85 - 100	5

KÖTELEZŐ IRODALOM / OBLIGATORY MATERIAL

LECTURE NOTES:

Electronic lecture notes will be provided for registered students.

TEXTBOOKS:

There is no set textbook required for this course. However, the following references will be useful for students:

1. Anderson, J.D. “Computational Fluid Dynamics: the basics with applications”, McGraw-Hill, 1995.

2. Hoffmann, K.A., Chiang, T., “Computational Fluid Dynamics, Vol. 1, 2, 3“, EES Books, Wichita, KS, 2000.

3. Versteeg, H.K., Malalasekera, W., “An introduction to CFD: the Finite Volume Method”, 2nd ed., Pearson Publishing, 2007.

4. Laney, C., “Computational Gas Dynamics”, Cambridge University Press, 1998.

COURSE INSTRUCTOR:

Dr. Daniel Feszty, feszty.daniel@sze.hu

CFD SOFTWARE

The Star CCM+ software will be used for completing the tutorials. Installation guidelines are available in Hungarian, as well as a step-by-step procedure of how to complete the first part of the tutorials. There will be two tutorials:

2D flat plate boundary layer:

2D airfoil (very similar to Assignment A2):

The first tutorial teaches not only the basics of how to set up a mesh and run a simulation, but also that how to extract useful plots, graphs, results, etc. from the simulations. This is not necessarily detailed in other tutorials, so it is best to learn and master it during the first tutorial.

Both tutorials provide examples on how to perform the **Verification and Validation** of the simulations. This is a very important part of the assignments and is expected that students will perform them and describe them in the deliverables – the technical report - too.

Details of what format and content should be the deliverable is described in the detailed description of Assignment A2 and A3.