Advanced Computation in Fluid Mechanics
Course PM 2013

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Description

Advanced trans-disciplinary course approaching fundamental problems in fluid mechanics of practical importance by tools from mathematical analysis and numerical analysis, using modern computational technology.

Prerequisites

The course DN2260 Finite element methods, or equivalent.

Course goals

The goal is that the students after the course should be aware of the main computational approaches to model turbulent flow, and to be able to analyze and use General Galerkin (G2) adaptive finite element methods for turbulence simulation. More precisely, the students should be able to:

- define the concepts weak solution and well-posedness,
- derive energy (stability) estimates for underlying equations and G2 approximations,
- analyse the global effect of friction boundary conditions (as a model of turbulent boundary layers) in G2,
- derive a posteriori output error estimates for G2 using duality,
- formulate adaptive algorithms based on a posteriori error estimates,
- use G2 software for adaptive computation of turbulent flow.

With mathematical analysis, computational simulations and a review of research literature, the student should be able to analyze the following fundamental (open) problems of fluid mechanics:

- well-posedness and computability of turbulent flow,

- boundary conditions, turbulent boundary layers and flow separation,
- prediction of aerodynamic forces for bluff and streamlined bodies,

with applications in a number of areas such as car-, ship- and aircraft industry. The purpose is that the students should develop a critical approach with the possibility to question established truths, and to form new hypotheses.

Examination

Below is listed the course examination together with respective deadlines:

Exam (4.0 hp)

- Home exam: Wednesday 10:15 February 13 (50% of course grade)
- Oral exam: Wednesday 10:15 February 13 (pass/fail)

Project (3.5 hp)

- Project report (max 10 pages/group): Monday March 11 (50% of course grade)
- Oral presentation of final report: Tuesday 10:15 March 5 (pass/fail)

Each part of the examination is mandatory to pass the course, and attendance to the seminars is also mandatory. The project report should be sent by email to both the course leader and the teaching assistant in time for the deadline, and the only accepted format is pdf-files. The home exam should be handed in to the curse leader, here also paper submissions are accepted. The home exam is submitted individually, whereas the project reports are submitted one for each group.

The percentages refer to the respective weights the activities have for the total grade in the course. The quality of each activity is then also graded, so that the total grade is given as the sum of the percentages times the quality (0-100%) of each activity. The total grade for the Exam and Project is given according to the following scale:

A 90%

B 80%

C 70%

D 60%

E 50%

F <50%

Failure to comply with deadlines for submissions automatically reduces the quality of the activity.

Project

The purpose of the course projects is for the students to use analysis, computation and available literature to study an (open) research problem in computational fluid dynamics. The course project consists of the following parts:

- 3 seminars: At a first introductory seminar the course leader gives a presentation followed by a project introduction. At the second seminar the project groups present their preliminary work together with a discussion. At the last seminar each group gives a presentation of their project where the other groups act as opponents.
- 1 project report by each group (max 10 pages: as pdf-file)
- 1 final presentation

The projects are done in groups (2-4 students), in one of the following themes:

1. Turbulence, computability and adaptive finite element methods
2. Turbulent flow separation and boundary layer modeling
3. Flight aerodynamics
4. Fluid-structure interaction

Project themes

Each group should use the computational software to address a set of basic problems connected to the group theme, and for the highest grades the group is also expected to study additional problems connected to the theme using computation. The basic problems for each theme are:

Theme 1: Turbulence, computability and adaptive FEM

1. Consider a circular cylinder with diameter $D = 1$ and length $4D$: compute mean drag $\bar{c}_D \equiv \int_I c_D(t)\, dt$ for the cylinder at $Re = 3900$ using adaptive mesh refinement: is the value for c_D converging as you refine the mesh? If so, after how many mesh refinements?
2. Is the value for the velocity field in a point in the turbulent wake converging as you refine the mesh? Why?
3. Is the time series $c_D(t)$ converging as you refine the mesh? How does the mean value $\bar{c}_D$ change with the length of the time interval I?

Theme 2: Turbulent flow separation and boundary layer modeling

1. Consider a circular cylinder with diameter $D = 1$ and length $4D$: compute $\bar{c}_D$ for $Re = 10^4$ and 10^6 using adaptive mesh refinement with no slip boundary conditions.

2. Compute $\bar{c}_D$ with skin friction boundary conditions on the cylinder and $\nu = 0$, how does $\bar{c}_D$ change for different friction parameters $\beta = 0.1, 10^{-2}, 10^{-3}, 0$? Why?

3. How does other flow features change with different friction parameters $\beta = 0.1, 10^{-2}, 10^{-3}, 0$? Why?

Theme 3: Flight aerodynamics

1. Consider a section of a NACA 0012 airfoil with $\nu = 0$ and free slip boundary conditions ($\beta = 0$): compute lift and drag coefficents for different angles of attack $\alpha = 2^\circ, 8^\circ, 14^\circ, 18^\circ$. How does the flow change? Why?

2. At what angle of attack α does the wing stall? Why? .

3. Change to no slip boundary conditions: how does this change the flow? Why?

Theme 4: Fluid-structure interaction

1. Consider a channel with an elastic beam attached to the floor with $Re = 10^3$ and no slip boundary conditions: compute the drag on the beam as a function of time for different Young's modulus.

2. Computer the deflection of a point at the top of the beam as a function of time for different Young's modulus.

3. Compute the spectrum of the drag and deflection for different Young's modulus.

Final report

The project report should be maximum 10 pages, including a cover page and reference list, and should give a presentation of the work carried out by the group; discussing the background of the problem, the computations (basic problems, together with other problems defined by the group), the literature and discussions from the seminars, and a summary and analysis by the group.

The format of the report should be the following:

1. Introduction (problem description)

2. Background (literature review, put problem in context)

3. Method (short description of computational method)

4. Results (computational results)

5. Summary and analysis (analysis of computational results with respect to problem and literature)

Course plan

Seminar 1 (Tuesday January 15)

- Course introduction, Fundamental equations, Energy
- Reading: [1] (chapters 1-12)

Seminar 2 (Friday January 18)

- Introduction to high performance computing, and FEM software

Seminar 3 (Tuesday January 22)

- Weak solutions, Finite element methods
- Reading: [1] (chapters 28-29)

Seminar 4 (Friday January 25

- Turbulence, Computational fluid dynamics, Exercises
- Reading: [1] (chapters 13-20 (hard), 25-27)

Seminar 5 (Tuesday January 29)

- Adaptive FEM, Exercises
- Reading: [1] (chapters 30,33)

Seminar 6 (Friday February 1)

- Fluid-structure interaction, multiphase flow, Exercises

Seminar 7 (Tuesday February 5

- Project seminar 1: introduction

Seminar 8 (Wednesday February 13)

- Oral examination: Home exam

Seminar 9 (Tuesday February 19)

- Project seminar 2: discussion on project drafts

Seminar 10 (Tuesday March 5)

- Project seminar 3: presentations of final report

References

[1] J. Hoffman and C. Johnson, *Computational Turbulent Incompressible Flow: Applied Mathematics Body and Soul Vol 4*, Springer-Verlag Publishing, 2006.

Contact

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