SYLLABUS VT23, version 3

MJ2515 Numerical Heat Transfer in Energy Technology

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Teachers: MSc Steffen Hammer, Dr. Taras Koturbash, MSc Carlos Tavera

Introduction

The purpose of this course is to provide a solid background on numerical methods relevant to fluid flow and heat transfer in energy applications. With this background, participants will have adequate insight in implementing models in commercial computational fluid dynamics (CFD) codes and in interpreting the results. The following topics are covered in the course:

1. Storing of large numbers in computers (single and double precision)
2. Numerical solutions to differential equations
3. Error analysis in numerical methods (rounding, truncation etc)
4. Main equations for heat transfer in solid materials
5. Divergence theorem
6. Equations for compressible flow: conservation of mass, linear momentum and energy
7. Finite difference method for 1D and 2D heat transfer
8. Euler's solution method for transient heat transfer
9. Stability curves for explicit time marching solutions
10. Higher order time discretization (Predictor-Corrector Scheme and Runge-Kutta method)
11. Crank-Nicolson method (implicit time marching)
12. Mesh generation
13. Advection equation and upwind schemes
14. Lax-Wendroff scheme
15. Introduction to solutions for inviscid flow
16. Introduction to Navier-Stokes equations and turbulence

Intended Learning Outcomes (ILO's)

After completing the course with a passing grade the student should be able to:

ILO1 Describe numerical methods for handling of partial differential equations and derive specific relationships for programming

ILO2 Define governing equations for relevant heat transfer processes and design representative numerical simulations

ILO3 Analyze simulation results, considering validity, precision and numerical stability

Target Group and Prerequisites

MJ2515 is recommended for students enrolled in Sustainable Energy Engineering (TSUEM), Renewable Energy (TIETM), and various double-degree MSc programs. Prerequisites: heat transfer, 6 credits, equivalent to contents of MJ1401; fluid mechanics, 6 credits, equivalent to contents of SG1220; programming in Matlab, Python, or similar.

Activities

- Lectures
  - Traditional teacher-led lectures, examples, and problem solving.
  - Most lectures will be offered in hybrid mode (in-class and Zoom) with recordings made available in Canvas. See schedule for details.
- Home assignments (INLA and INLB, 0.5 hp each)
  - Two assignments to be solved individually. Details including submission instructions available in Canvas.
  - All programming must be performed in Matlab.
  - Dedicated question and answer (Q&A) session for each home assignment
  - Each graded P/F
- Examination (TEN1, 2.0 hp)
  - Take-home exam with emphasis on topics included in home assignments.
  - After the exam the examiner will meet each student in a 15-minute, one-on-one session in order to confirm the uniqueness of the submission.
  - See appendix for more information.
  - Graded A-E.

Support for Students with Disabilities

English Students with special needs who have obtained a recommendation from KTH FUNKA for examination support are entitled to the following:

- Support linked to codes R (i.e. accommodations concerning room, duration, and physical surroundings) is granted without examiner approval required.
- In accordance with KTH regulations, a request for support linked to code P (pedagogical accommodation) is to be submitted by the student to the examiner, who needs to actively approve or reject the request.

svenska För studenter med funktionsvariationer som har utlåtande från KTHs FUNKA-enhet om rekommenderade stödinsatser vid examination gäller följande i denna kurs:

- Alla stödinsatser under kod R (d.v.s. anpassningar som rör rum, tid och fysisk omständighet) beviljas utan särskilt beslut av examinator
- Stödinsatser under kod P (pedagogisk anpassning) ska aktivt beviljas eller avslås av examinatorn efter kontakt tagen av studenten i enlighet med KTHs regler.

Please contact the course leader if there are any questions.

Assessment

The three ILO’s are mapped to each of the 16 topics covered in the course, which in turn are assessed according to the prevailing grading scale: P/F for the home assignments and A-E for TEN1. For the home assignments, the minimum thresholds or achieved learning outcomes, ALO’s, for receiving a passing score correspond to Grade E in the table below. For TEN1 the full grading scale is applied to each of the problems.

ILO1 *Describe numerical methods for handling of partial differential equations and derive specific relationships for programming*

ILO2 *Define governing equations for relevant heat transfer processes and design representative numerical simulations*

ILO3 *Analyze simulation results, considering validity, precision and numerical stability*

	Grade E	**Grade C**	**Grade A**
ALO1	List some of the characteristics of relevant numerical methods for the modeling of physical processes.	Analyze the characteristics of relevant numerical methods for the modeling of physical processes.	Criterion for Grade C including the ability to use more than one analysis method and /or handle more complex cases.
ALO2	Provide a rudimentary description of governing equations, set up a numerical solution procedure.	Provide rigorous definition of governing equations, identify and quantify applicable numerical methods.	Criterion for Grade C including the ability to use more than one analysis method and /or handle more complex cases.
ALO3	Provide a rudimentary analysis of simulation results with some insight into validity, precision and numerical stability.	Provide rigorous analysis of simulation results with some or good insight into validity, precision and numerical stability.	Criterion for Grade C including the ability to use more than one analysis method and /or handle more complex cases.

The level of difficulty for each of the home assignments is the reference for assessing the minimum level of achievement for the respective topic. Successful completion of a particular home assignment will thus greatly facilitate demonstrating Grade E for this topic on the exam. Topics and problem solving covered through lectures are indicative of the level of achievement for higher grades.

TEN1 features six problems and includes material representing the 16 topics of this course. As stated above, each problem is graded F (fail), E, C, or A according to the ALO table, with points assigned as follows:

Grade F	<10 points
Grade E	10 points
Grade C	11-17 points
Grade A	18-20 points

The overall exam grade is determined as follows:

Grade F	two or more problems at Grade F, irrespective of overall score
Grade Fx	no more than one problem at Grade F, irrespective of overall score
Grade E	60-66 points, with all problems at Grade E or higher (valid for all subsequent grades)
Grade D	67-79 points
Grade C	80-93 points
Grade B	94-105 points
Grade A	106-120 points

The final course grade is equivalent to the grade for TEN1, provided that home assignments are passed.

Re-exams

TEN1 is offered as a re-exam. It is possible to take a re-exam in order to make an attempt towards raising the final grade.

Late assignments

Late assignments will be graded after final grades are posted.

Schedule

Zoom links have been included below (all participants must log in with kth.se credentials). See KTH schedule for hybrid venues.

Date & Time	Activity	Instructor(s)
20 Mar 8:00-10:00 (digital only)	Course Preparation: Matlab Tutorial	Taras Koturbash
23 Mar 10:00-12:00 (hybrid)	Lecture 1: Course kick-off, Introduction to CFD; Storing large numbers, numerical solutions, error analysis	Andrew Martin
28 Mar 13:00-15:00 (hybrid)	Lecture 2: Heat conduction, divergence theorem, equations for compressible flow	Andrew Martin
3 Apr 10:00-12:00 (hybrid)	Lecture 3: Finite difference method for 1D/2D heat conduction, Euler's method for transient heat conduction	Andrew Martin
~~6 Apr 10:00-12:00 (in-class only)~~	~~Q&A Session, Home Assignment 1~~ **SESSION POSTPONED**	~~Steffen Hammer~~
~~14 Apr 19:00~~ 24 Apr 19:00	**Due date, Home Assignment 1**	--
17 Apr, 8:00-10:00 (in-class only)	Q&A Session, Home Assignment 1 ~~Lecture 4: Review of Home Assignment 1~~	Steffen Hammer
21 Apr, 8:00-10:00 (hybrid)	Lecture 5: Stability curves, higher order time discretization Crank-Nicholson method, mesh generation	Andrew Martin
25 Apr, 13:00-15:00 (hybrid)	Lecture 6: Advection equation and upwind schemes, Lax-Wendroff scheme	Andrew Martin
26 Apr, 8:00-10:00 (hybrid)	Review of Home Assignment 1 Q&A Session, Home Assignment 2	Steffen Hammer, Carlos Tavera
4 May 13:00-15:00 (hybrid)	Lecture 7&9: Introduction to solution of inviscid flow equations, Navier-Stokes equations; Turbulence	Andrew Martin
~~5 May 19:00~~ 10 May 19:00	**Due date, Home Assignment 2**	--
~~8 May 8:00-10:00 (hybrid)~~	~~Lecture 8: Review of Home Assignment 2~~ **SESSION POSTPONED**	~~Carlos Tavera~~
11 May 13:00-15:00 (hybrid)	~~Lecture 8: Review of Home Assignment 2~~ Lecture 9&10: Turbulence (cont); Course wrap-up and exam preparation	Andrew Martin
17 May 13:00-15:00 (hybrid)	~~Lecture 9&10: Turbulence (cont); Course wrap-up and exam preparation~~ Lecture 8: Review of Home Assignment 2	Carlos Tavera

30 May, 14:00-18:00 (extended to 31 May)	**TEN1 (Exam)**	--
31 May – 2 Jun	**Confirmation of exam submission**	
14-26 Aug (exact date TBD)	**re-exam, TEN1 (Exam)**	

Learning Resources

Jiyuan Tu, Guan-Heng Yeoh, and Chaoqun Liu, Computational Fluid Dynamics: A Practical Approach, 3rd ed., Butterworth-Heinemann (2018). [Available for download at KTH Library.]

S. D. Conte and Carl de Boor, Elementary Numerical Analysis: An Algorithmic Approach, SIAM (2018). [Available for download at KTH Library.]

APPENDIX – TEN1

As stated previously, the exam is offered in a take-home format. A dedicated Canvas event will be accessible for all students who sign up for the exam. The exam with six problems will be distributed at the scheduled starting time, 14:00 CET on 2023-05-30. The exam is four hours in duration, and solutions including Matlab codes must be uploaded no later than 18:30 CET.

All course materials including textbooks may be used along with materials obtained through Internet searches. Required programming must be done in Matlab; students are highly encouraged to use own codes developed for the home assignments as a starting point.

Help from persons enrolled in this course or outside the course is not permitted!

The following measures are adopted to ensure that each submission is original:

- Input data or other specific attributes for each problem will be varied. In some cases the exact details of a particular problem will be unique, while in others certain variations may be implemented for groups of students.
- A check will be make on submissions, including codes, to see if there are any instances of obvious duplication.
- Finally, the examiner will follow up with one-on-one interviews. These will be conducted in Zoom and scheduled during the remaining days of the exam period, 31 May – 5 June (details including sign-up to be announced in Canvas). During a maximum time of 15 minutes the examiner will ask each student to verify identification (passport, driver’s license) and explain the reasoning behind solutions for specific problems, with uploaded solutions and Matlab codes used as a basis.

The examiner may assign a failing grade if the student is unable to provide adequate clarification of the uploaded solutions or computer codes.