CARLETON UNIVERSITY
Department of Mechanical and Aerospace Engineering

COURSE OUTLINE
AERO 4304A
Computational Fluid Dynamics

Lectures 3 hrs/week
Week

1 Introduction. History of CFD. Possibilities and limitations of numerical methods. Differential equations of interest that govern physical phenomena. Classification of partial-differential equations: hyperbolic equations.
2 Classification of partial differential equations: parabolic and elliptic equations. Components of a numerical solution method: mathematical model, discretization method, co-ordinate system, spatial grid, finite approximations, solution technique, convergence criteria.
3 Properties of numerical solution methods: consistency, stability, convergence, conservation, boundedness. Discretization techniques: finite-difference, finite-volume and finite-element techniques. The finite difference method: use of Taylor series for discretization of the first derivative.
4 Discretization of the second derivative, mixed derivative and other terms. Implementation of boundary conditions. Discretization errors.
5 Initial-value problems: time discretization. Two-level methods; predictor-corrector and multi-point methods; Runge-Kutta methods.
6 Time and space discretization of a generic transport equation. Explicit solution methods: explicit Euler method; Leapfrog method. Implicit solution methods: implicit Euler method; Crank-Nicholson method.
7 Solution of linear equation systems. Direct methods: Gauss elimination; LU decomposition. Iterative methods: Gauss-Seidel; SOR; ADI.
8 Solution of coupled equations; solution of nonlinear equations.
9 The finite volume method: surface integrals; volume integrals; interpolation schemes; implementation of boundary conditions.
10 Integration of the Navier-Stokes equations: Reynolds-averaged Navier-Stokes (RANS) equations.
11 Turbulence modeling in RANS solutions.
12 Large-Eddy Simulation (LES) and Direct-Numerical Simulation (DNS) of fluid flows.

Learning Outcomes:

- Knowledge of the characteristics of partial differential equations governing convection and diffusion phenomena
- Knowledge of discretization and solution techniques to numerically integrate partial differential equations governing convection and diffusion phenomena
- Knowledge of numerical integration techniques for the Navier-Stokes equations

Lecture Format: All of the lectures of this course will be held in person at the formally scheduled dates and hours. The lectures will not be recorded. Audio or video recording of the lectures is not permitted.

Problems: Students will be assigned problem sets from time to time. The solutions to the problems will not be collected or graded, but students are strongly encouraged to solve these problems independently, as a learning exercise. The ability to apply the course material to solution of problems will be essential to success in the mid-term and final examinations.

Computer-based Assignments: Students will be given assignments involving numerical integration of differential equations that govern physical phenomena in fluid flows. Students will independently develop the relevant algorithm and computer program to perform each of these numerical integration assignments.

Computer-programming skills are essential for success in these assignments. You are strongly encouraged to perform the computer programming self-assessment exercise posted on the Brightspace page of this course before the start of the semester.

Course grading: There will be an 80-minute mid-term examination to be held during a lecture period, and a 3-hour final examination scheduled by the university during the formal final examination period. Both exams will be held in person. In the event of changes in university policy limiting examinations to the online setting, the university's e-proctoring system will be in effect during both the mid-term and the final examinations.

The mid-term and final examination grades will count towards 20% and 55% of the final course grade, respectively. The computer-based assignments will count towards 25% of the final grade in the course. Final; exams are for evaluation purposes only and will not be returned to students.

For each of the computer-based assignments, a passing mark (50% or higher) is required based on the contents of the assignment report to obtain a passing grade in the course. Additionally, the arithmetic average of the computer-based assignment marks after each is adjusted for any penalties due to late submission must be 50% or higher to obtain a passing grade in the course. Late report submission will result in a one-percent mark penalty for each hour of delay.

Students must earn a minimum of 50% mark in the final exam to pass the course. During both the midterm and final examinations, students are to develop their answers independently, use a standard calculator, and will have access only to their personal hand-written lecture notes and printed material made available during the lectures.

Strongly Recommended Text Covering the Topics of This Course:

- Applied Computational Aerodynamics, Publisher: Cambridge University Press, Authors: R.M. Cummings, W.H. Mason, S.A. Morton, D.R. McDaniel

Recommended Text For Further Reading on the Finite Volume Technique:

- An Introduction to Computational Fluid Dynamics – The Finite Volume Method, Publisher: Pearson, Author: H.K. Versteeg, W. Malalasekera

M.I. Yaras, January 2023
Office: ME 3254

Academic Dates

Students should be aware of the academic dates (eg. last day for academic withdrawal) posted on the Registrar's office web site https://carleton.ca/registrar/registration/dates/academic-dates/

Academic Integrity and Plagiarism

a) Please consult the Faculty of Engineering and Design information page about the Academic Integrity policy and our procedures: https://carleton.ca/engineering-design/current-students/fed-academic-integrity Violations of the Academic Integrity Policy will result in the assignment of a penalty such as reduced grades, the assignment of an F in a course, a suspension or, expulsion.

b) One of the main objectives of the Academic Integrity Policy is to ensure that **the work you submit is your own.** As a result, it is important to write your own solutions when studying and preparing with other students and to avoid plagiarism in your submissions. The University Academic Integrity Policy defines plagiarism as "presenting, whether intentionally or not, the ideas, expression of ideas or work of others as one's own." This includes reproducing or paraphrasing portions of someone else's published or unpublished material, regardless of the source, and presenting these as one's own without proper citation or reference to the original source.

Examples of violations of the policy include, but are not limited to:

- any submission prepared in whole or in part, by someone else;
- using another's data or research findings without appropriate acknowledgement;
- submitting a computer program developed in whole or in part by someone else, with or without modifications, as one's own; and
- failing to acknowledge sources of information through the use of proper citations when using another's work and/or failing to use quotations marks.

Academic Accommodations

You may need special arrangements to meet your academic obligations during the term. For an accommodation request the processes are as follows:

Pregnancy obligation: write to me with any requests for academic accommodation during the first two weeks of class, or as soon as possible after the need for accommodation is known to exist. For accommodation regarding a formally scheduled final exam, you must complete the Pregnancy Accommodation Form.

Religious obligation: write to me with any requests for academic accommodation during the first two weeks of class, or as soon as possible after the need for accommodation is known to exist.

Academic Accommodations for Students with Disabilities: The Paul Menton Centre for Students with Disabilities (PMC) provides services to students with Learning Disabilities (LD), psychiatric/mental health disabilities, Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorders (ASD), chronic medical conditions, and impairments in mobility, hearing, and vision. If you have a disability requiring academic accommodations in this course, please contact PMC at 613-520-6608 or pmc@carleton.ca for a formal evaluation. If you are already registered with the PMC, contact your PMC coordinator to send me your Letter of Accommodation at the beginning of the term, and no later than two weeks before the first in-class scheduled test or exam requiring accommodation. After requesting accommodation from PMC, meet with me to ensure accommodation arrangements are made.

Survivors of Sexual Violence: As a community, Carleton University is committed to maintaining a positive learning, working and living environment where sexual violence will not be tolerated, and where survivors are supported through academic accommodations as per Carleton's Sexual Violence Policy. For more information about the services available at the university and to obtain information about sexual violence and/or support, visit: https://carleton.ca/equity/sexual-assault-support-services