Faculty of Engineering and Design
Department of Mechanical and Aerospace Engineering

Course number	Course Title	Term	Year
MAAE4902	Optimum Design of Mechanical Systems	Fall	2024

Course Instructor	Office	Email	Office Hours
Dr. Mehdi Eshaghi	ME4252	mehdi.eshaghi@carleton.ca	By appointment

CLASS SCHEDULE

Days	Time	Location

COURSE CALENDAR DESCRIPTION

This course introduces students to the fundamentals of optimization methods that can be used in a design engineering process. Case studies in practical applications of optimization in mechanical systems will be investigated. The course covers the theory and applications of optimization methods to unconstrained and constrained engineering design. Terminology, problem formulation, single and multiple design variables, constraints, classical and heuristic methods such as Genetic algorithms, single and multi-objective problems will be studied. Computer-based implementation of these optimization methods will be discussed using MATLAB and Excel.

LEARNING OUTCOME

- Apply basic concepts of optimization and numerical techniques.
- Formulate optimization problems.
- Identify various optimization approaches including gradient based, stochastic and random methods.
- Enhance decision-making skills in selecting optimal methods.
- Utilize approximation methods to reduce computational efforts in complex problems.
- Develop optimization codes using commercial software to demonstrate proficiency in integrating optimization techniques with software tools for practical applications.

SUGGESTED TEXTBOOKS

- Engineering optimization theory and practice, Singiresu S. Rao 4th edition, John Wiley and sons Inc., 2009.
- Introduction to Optimum Design, Arora, J. S., Fourth Edition, Elsevier Academic Press, San Diego, CA, 2016. (ISBN: 9780-12-800806-5)
- Optimization in Practice with MATLAB by Messac, Cambridge Press, 2015

GRADING POLICY

Assignments	**10%**
Midterm Exam	**20%**
Project	**20%**
Final Exam	**50%**

PROJECT DESCRIPTION

In this team project, students (groups of two) are required to define and solve an optimization problem, which is concerned with a mechanical system. A two-page proposal should be submitted one month after starting the semester. It should include but not limited to

- Introduction
- Problem description
- Objective functions and constraints
- The methods of solution

The proposal should be approved by the instructor, before starting the project. The optimization process should be conducted through two of the modern optimization techniques as outlined below, and a comparison of the results should be conducted.

- Genetic algorithms
- Simulated annealing
- Particle swarm optimization
- Ant colony optimization
- Fuzzy optimization
- Neural-network-based methods

The final report should include but not limited to

- Introduction
- Governing equations
- Objective functions and constraints
- Description of the employed optimization algorithms
- Results and discussions.

Students are also required to present their works in the last lecture.

Week	Materials
1	1. Introduction to Design Optimization 2. Statement of an Optimization Problem 3. Design Vectors, Design Constraints, Objective Function 4. Graphical Solution Method for Finding Optimum Points
2	1. Review of Concepts Including, Numerical Methods in Solving System of Nonlinear Equations, Polynomial Interpolation, Sets, Convex Set, Convex Function, Multivariable Functions, Continuity, Partial Derivatives, Taylor's Expansion Theorem, Matrix Norm, Hessian Matrix, Rank of Matrix, Positive- and Negative-Definite Matrices, Eigenvalues
3	1. Optimum Design with Excel Solver 2. Optimum Design with MATLAB 3. Single-Variable Optimization 4. Multi-Variable Optimization with no Constraints
4	1. Multi-Variable Optimization with Equality Constraints 2. Lagrange Multipliers 3. Multi-Variable Optimization with Inequality Constraints 4. KKT Optimality Condition 5. Global Optimality
5	1. Linear Programming Methods for Optimum Solution 2. The Simplex Method 3. The Two-Phase Simplex Method- Artificial Variable
6	Fall Break
7	Midterm Exam
8	1. Numerical Methods for Unconstrained Optimum Design 2. The Steepest-Decent Method 3. The Conjugate Gradient Method 4. Newton Method 5. Step Size Determination: Basic Idea 6. Numerical Methods to Compute Step Function 7. Golden Section Method
9	1. Numerical Methods for Constrained Optimum Design 2. Basic Concepts Related to Numerical Methods 3. Linearization of the Constrained Problem 4. The Sequential Linear Programming Algorithm (SLP)
10	1. Sequential Quadratic Programming (SQP) 2. Search Direction Calculation: The QP Subproblem 3. The Step Size Calculation Subproblem 4. The Constrained Steepest-Decent Method
11	1. Modern Methods of Optimization 2. Genetic Algorithm (GA) 3. Problem Solving Using GA Toolbox of MATLAB
12	1. Practical Applications of Optimization in Mechanical Engineering 2. Minimization of Total Potential Energy 3. Solution of Nonlinear Equations 4. Optimum Design of Two-Member Frame with Out-of-Plane Load 5. Optimum Design of Tension Members
13	Presentation of Projects

ASSIGNMENTS		
Assignment #	**Date Assigned**	**Date Due**
1	Friday, September 21st	Friday, September 28th at 11:59 pm
2	Friday, October 12th	Friday, October 19th at 11:59 pm
3	Friday, November 2ed	Friday, November 9th at 11:59 pm
4	Friday, November 23ed	Friday, November 30th at 11:59 pm
Assignments will be completed online and in PDF format and will be accessible through the course page. A late penalty of 25% per day will be incurred for all late submissions.		

General Regulations:

Attendance:
Students are expected to attend all lectures. The University requires students to have a conflict-free timetable. For more information, see the current *Undergraduate Calendar, Academic Regulations of the University, Section 1.2, Course Selection and Registration and Section 1.5, Deregistration.*

Appeal of Grades:
The processes for dealing with questions or concerns regarding grades assigned during the term and final grades is described in the *Undergraduate Calendar, Academic Regulations of the University, Section 2.7, Informal Appeal of Grade and Section 2.8, Formal Appeal of Grade.*

Academic Integrity:
Students should be aware of their obligations with regards to academic integrity. Please review the information about academic integrity at: https://carleton.ca/registrar/academic-integrity/. This site also contains a link to the complete Academic Integrity Policy that was approved by the University's Senate.

Classroom Behavior:
Students are required to observe standards of behaviour expected in a university environment and in the profession of engineering. Excessive talking among students, texting, watching movies, etc. during lectures is disruptive of the learning atmosphere, and is a distraction for the instructor and the other students. Please maintain a quiet, attentive and engaging classroom environment.

Academic Accommodation:
You may need special arrangements to meet your academic obligations during the term. You can visit the Equity Services website to view the policies and to obtain more detailed information on academic accommodation at http://www.carleton.ca/equity/ For an accommodation request, the processes are as follows:

- **Pregnancy or Religious obligation**: Please contact your instructor 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 more details see https://carleton.ca/equity/wp-content/uploads/Student-Guide-to-Academic-Accommodation.pdf

- **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 (*if applicable*). **Requests made within two weeks will be reviewed on a case-by-case basis.** After requesting accommodation from PMC, meet with me to ensure accommodation arrangements are made. Please consult the PMC website (www.carleton.ca/pmc) for the deadline to request accommodations for the formally-scheduled exam (*if applicable*).

- **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/sexual-violence-support/.

- **Accommodation for Student Activities:** Carleton University recognizes the substantial benefits, both to the individual student and for the university, that result from a student participating in activities beyond the classroom experience. Reasonable accommodation must be provided to students who compete or perform at the national or international level. Please contact your instructor 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 more details, see https://carleton.ca/senate/wp-content/uploads/Accommodation-for-Student-Activities-1.pdf