

# DOCTORATE IN PHILOSOPHY MECHANICAL ENGINEERING

## Summary

- Degree offered: Doctorate in Philosophy (PhD)
- Registration status option: Full-time
- Language of instruction: English
- Program option (expected duration of the program):
  - within four years
- Academic units: Faculty of Engineering (<https://engineering.uottawa.ca/>), Department of Mechanical Engineering (<http://engineering.uottawa.ca/mechanical/>), Ottawa-Carleton Institute for Mechanical and Aerospace Engineering (<http://www.ocimae.ca/>)

## Program Description

### Ottawa-Carleton Joint Program

Established in 1983, the Ottawa-Carleton Institute for Mechanical and Aerospace Engineering (OCIMAE) combines the research strengths of the Department of Mechanical Engineering at the University of Ottawa and the Department of Mechanical and Aerospace Engineering at Carleton University.

Learn more about this program (<https://www.uottawa.ca/faculty-engineering/graduate-studies/programs/mechanical-engineering/>)

## Main Areas of Research

- Thermal and fluid engineering
- Solid mechanics and design
- Materials and manufacturing
- Controls and robotics
- Biomedical engineering
- Aeronautical and space engineering

## Other Programs Offered Within the Same Discipline or in a Related Area

- Master of Applied Science Mechanical Engineering (MASc)
- Master of Applied Science Advanced Materials and Manufacturing (MASc)
- Master of Engineering Mechanical Engineering (MEng)
- Master of Engineering in Advanced Materials and Manufacturing (MEng)
- Doctorate in Philosophy in Advanced Materials and Manufacturing (PhD)

## Fees and Funding

- Program fees

The estimated amount for university fees (<https://www.uottawa.ca/university-fees/>) associated with this program are available under the section Finance your studies (<http://www.uottawa.ca/graduate-studies/programs-admission/finance-studies/>).

International students enrolled in a French-language program of study may be eligible for a differential tuition fee exemption (<https://www.uottawa.ca/university-fees/differential-tuition-fee-exemption/>).

- To learn about possibilities for financing your graduate studies, consult the Awards and financial support (<https://www.uottawa.ca/graduate-studies/students/awards/>) section.

## Notes

- Programs are governed by the academic regulations (<https://www.uottawa.ca/about-us/leadership-governance/policies-regulations/>) in effect for graduate studies and by the general regulations of the Ottawa-Carleton Institute for Mechanical and Aerospace Engineering (OCIMAE).
- In accordance with the University of Ottawa regulation, students have the right to complete their assignments, examinations, research papers, and theses in French or in English.
- Research activities can be conducted either in English, French or both, depending on the language used by the professor and the members of his or her research group.

## Program Contact Information

Graduate Studies Office, Faculty of Engineering (<https://engineering.uottawa.ca/graduate-studies-office/>)

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Ottawa ON Canada

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Twitter | Faculty of Engineering (<https://twitter.com/uOttawaGenie/?lang=en>)

Facebook | Faculty of Engineer (<https://www.facebook.com/uottawa.engineering/>)

## Admission Requirements

For the most accurate and up to date information on application deadlines, language tests and other admission requirements, please visit the specific requirements (<https://www.uottawa.ca/graduate-studies/programs-admission/apply/specific-requirements/>) webpage.

## To be eligible, candidates must:

- Hold a master's degree in mechanical or aerospace engineering (or the equivalent) with a minimum average of 75% (B+).

Note: International candidates must check the admission equivalencies (<https://www.uottawa.ca/graduate-studies/international/study-uottawa/admission-equivalencies/>) for the diploma they received in their country of origin.

- Demonstrate a good academic research performance.
- Identify at least one professor who is willing to supervise your research and thesis.
  - We recommend that you contact potential thesis supervisors as soon as possible.
  - To enroll, you need to have been accepted by a thesis supervisor.

- The supervisor's name is required at the time of application.
- The choice of research supervisor will determine the primary campus location of the student. It will also determine which university awards the degree

## Language Requirements

Applicants must be able to understand and fluently speak the language of instruction (English) in the program to which they are applying. Proof of linguistic proficiency may be required.

Applicants whose first language is neither French nor English must provide proof of proficiency in the language of instruction.

Note: Candidates are responsible for any fees associated with the language tests.

## Notes

- The choice of research supervisor will determine the primary campus location of the student. It will also determine which university awards the degree.
- The admission requirements listed above are minimum requirements and do not guarantee admission to the program.
- Admissions are governed by the academic regulations (<https://www.uottawa.ca/about-us/leadership-governance/policies-regulations/>) in effect for graduate studies and by the general regulations of the Ottawa-Carleton Institute for Mechanical and Aerospace Engineering (OCIMAE).

## Fast-Track from MAsC to PhD

Students enrolled in the MAsC program in Mechanical Engineering at the University of Ottawa may be eligible to fast-track directly into the doctoral program without writing a master's thesis, provided the following conditions are met:

- Achieved an 80% (A-) average in their last two years of undergraduate studies
- Completion of 5 graduate courses (15 units) with a grade of A- or better in each;
- Satisfactory progress in the research program;
- Written recommendation from the supervisor;
- Approval by the graduate studies committee.

Note: The transfer must take place within sixteen months of initial enrollment in the master's. Following transfer, all the requirements of the doctoral program must be met.

## Program Requirements

### Doctorate

Students must meet the following requirements:

#### Compulsory Courses: <sup>1</sup>

9 optional course units in mechanical engineering (MCG) or advanced materials and manufacturing (AMM) at the graduate level <sup>2</sup> 9 Units

#### Seminar:

MCG 9900 PhD Seminar

#### Comprehensive Examination:

MCG 9998 PhD Comprehensive

#### Thesis Proposal:

MCG 9997 Preparation of Ph.D. Candidacy Paper

#### Thesis:

THD 9999 Doctoral Thesis <sup>3</sup>

#### Note(s)

- <sup>1</sup> The Department may require students to take additional courses depending on their backgrounds.
- <sup>2</sup> Students who have been permitted to transfer into the PhD program from a Master's program must successfully complete a total of 24 course units (Master's 15 and PhD 9).
- <sup>3</sup> Students are responsible for ensuring they have met all of the thesis requirements (<http://www.uottawa.ca/graduate-studies/students/theses/>). The thesis must be based on original research carried out under the direct supervision of a research faculty member in the Department.

## Minimum Requirements

The passing grade in all courses is B.

Students who fail 6 units, the thesis proposal, the comprehensive exam, the thesis, or whose progress is deemed unsatisfactory must withdraw from the program.

## Research

### Research at the University of Ottawa

Located in the heart of Canada's capital, a few steps away from Parliament Hill, the University of Ottawa ranks among Canada's top 10 research universities. Our research is founded on excellence, relevance and impact and is conducted in a spirit of equity, diversity and inclusion.

Our research community thrives in four strategic areas:

- Creating a sustainable environment
- Advancing just societies
- Shaping the digital world
- Enabling lifelong health and wellness

From advancing healthcare solutions to tackling global challenges like climate change, the University of Ottawa's researchers are at the forefront of innovation, making significant contributions to society and beyond.

### Research at the Faculty of Engineering

Areas of research:

- Chemical and Biological Engineering
- Civil Engineering
- Electrical Engineering and Computer Science
- Mechanical Engineering

For more information, refer to the list of faculty members and their research fields on **Uniweb**.

**IMPORTANT: Candidates and students looking for professors to supervise their thesis or research project can also consult the website of the faculty or department (<https://www.uottawa.ca/study/graduate-studies/academic-unit-contact-information/>) of their program of choice.**

Uniweb does not list all professors authorized to supervise research projects at the University of Ottawa.

## Courses

In all programs, the student may choose graduate courses from either university with the approval of the Advisor or Advisory Committee. The available graduate courses are listed below. Course descriptions are to be found in the departmental section of the calendar concerned. All courses are of one term duration. Courses of each department are indicated by the prefix of the first number given as follows:

**MCG 5XXXX Department of Mechanical Engineering, University of Ottawa**

**MAAJ XXXX Department of Mechanical and Aerospace Engineering, Carleton University**

Not all of the listed courses are given each year. The course is offered in the language in which it is described.

### **MCG 5104 Theory of Plates and Shells (3 units)**

A general coverage of various approaches to plate problems and the application of these methods to practical cases. A study of the theory of shells including deformation of shells without bending, stresses under various loading conditions, general theory of shells, shells forming surfaces of revolution. This course is equivalent to MAAJ 5004 at Carleton University.

**Course Component:** Lecture

### **MCG 5105 Continuum Mechanics (3 units)**

Fundamental equations of continuum mechanics. Thermodynamics of continua. Rheological equations. Hamilton's principle for continua. Analytical solution of some elasticity and incompressible fluid dynamic problems. Extension to viscoelasticity and plasticity. Sound waves. Shock waves. Numerical methods of solution. This course is equivalent to MAAJ 5005 at Carleton University.

**Course Component:** Lecture

### **MCG 5107 Advanced Dynamics With Applications (3 units)**

Review of Euler/Newton and D'Alembert formulation, Euler Angles, gyrokinematics, rotating machinery. Lagrangian dynamics, generalized co-ordinates, virtual work, generalized forces and the power function. Systems constraint forces and equilibrium. Modelling and formulation of multi-degree of freedom vibrational, electro-mechanical, dissipative systems, and other engineering applications. This course is equivalent to MAAJ 5007 at Carleton University.

**Course Component:** Lecture

### **MCG 5108 Finite Element Analysis (3 units)**

Review of matrix algebra and structural mechanics. Fundamentals of the finite element method. Analysis of two-dimensional trusses and the elastic continuum. Finite element program development, commercial programs, pre and post processors. Isoparametric concept, modelling issues. Steady-state field problems, axisymmetric analysis. Applications in mechanical engineering. This course is equivalent to MAAJ 5008 at Carleton University.

**Course Component:** Lecture

### **MCG 5109 Advanced Topics in Finite Element Analysis (3 units)**

Finite elements and their solution techniques. Multilayered plate, shell and continua. Eigenvalue and transient analysis, material and geometric non-linearities. Applications to fracture mechanics. Steady and transient state heat conduction. Potential flow. Creeping flow and incompressible viscous flow with inertia. This course is equivalent to MAAJ 5009 at Carleton University.

**Course Component:** Lecture

### **MCG 5110 Micromechanics of Solids (3 units)**

Introduction. Classes of materials in Micromechanics. Continuum Mechanics vs Probabilistic Micromechanics. Cartesian Tensor Notation. Analysis of stress, strain and motion. The stochastic deformation process and theory. Structured materials and intelligent systems. Experimental approaches. This course is equivalent to MAAJ 5100 at Carleton University.

**Course Component:** Lecture

### **MCG 5111 Gas Dynamics (3 units)**

Review of thermodynamics. Conservation equations. Wave propagation in compressible media. Isentropic flow. Normal and oblique shock waves. Prandtl-Meyer expansion fans. Applications. Ideal gas flow in ducts of variable section, friction, heat transfer. Method of characteristics. Imperfect gas effects, dissociation, ionization. Methods of measurement. This course is equivalent to MAAJ 5101 at Carleton University.

**Course Component:** Lecture

### **MCG 5115 Nonlinear Optimization (3 units)**

Formulation of optimization problems. Unconstrained optimization: direct search techniques, gradient techniques. Constrained optimization: by unconstrained minimization, by direct methods. Mathematical programming. Geometric programming. Dynamic programming. Examples and applications in Mechanical Engineering topics. This course is equivalent to MAAJ 5105 at Carleton University.

**Course Component:** Lecture

### **MCG 5120 Micro and Nano Systems (3 units)**

Fundamental principles governing micro and nano systems, case study of selected applications, and overview of semiconductor micro and nano fabrication techniques. Topics include statics and dynamics at reduced dimensions, electrostatic actuation techniques, nanomechanical resonators, and fundamental performance limits imposed by the equipartition theorem and the fluctuation dissipation theorem.

**Course Component:** Lecture

The courses MCG 5120, MCG 4137, and MCG 4537 cannot be combined for units.

### **MCG 5121 Space Mission Analysis and Design (3 units)**

Review of solar system and space exploration. Space mission design and geometry. Analysis of orbit design, transfers, interplanetary trajectories. Effect of environment on spacecraft design. Space propulsion and launch vehicle design. Launch sequence, windows, cost. Reusable launch systems. This course is equivalent to MECH 5106 at Carleton University.

**Course Component:** Lecture

### **MCG 5122 Smart Structures (3 units)**

Structural dynamics principles: modal analysis and wave propagation. Linear time invariant systems: feedback, feedforward, SISO, MIMO, digital and adaptive filters. "Smart" Structures: multifunctional materials, collocation principles, geometric filtering and control authority. Applications in aero-acoustics and aeroelasticity. Courses MCG 5122, MCG 5387 (MECH 5807) cannot be combined for units. This course is equivalent to MECH 5202 at Carleton University.

**Course Component:** Lecture

### **MCG 5124 Advanced Kinematics (3 units)**

Algebraic-geometry applications: kinematic calibration of serial and in-parallel robots; kinematic synthesis of planar, spherical, spatial mechanisms. Various DH-parametrisations, Jacobian formulations. Topics in projective geometry; Cayley-Klein geometries; Plücker line coordinates; Gröbner bases; Grassmannians; kinematic mapping; Burmester theory. Emphasis on practical applications. This course is equivalent to MECH 5507 at Carleton University.

**Course Component:** Lecture

### **MCG 5125 Advanced Dynamics (3 units)**

Developing and applying the governing equations of motion for discrete and continuous mechanical systems. Includes Newton-Euler and Lagrangian formulations; classical and finite element approaches for continuous systems; and linear stability, frequency response, and propagation solution methods. This course is equivalent to MECH 5501 at Carleton University.

**Course Component:** Lecture

Precludes additional credit for MCG 5350 (MECH 5500).

### **MCG 5131 Heat Transfer by Conduction (3 units)**

Steady one-dimensional systems. Equations of Bessel and Legendre. Extended surface. Fourier series and partial differential equations. Steady two-dimensional systems. Steady-state numerical methods. Steady heat source systems. Steady porous systems. Transient systems; stationary and moving sources. Transient numerical method. This course is equivalent to MAAJ 5301 at Carleton University.

**Course Component:** Lecture

### **MCG 5132 Heat Transfer by Convection (3 units)**

General problems of convection. Fundamental equations. Boundary layer equations. Forced convection in laminar flow. Forced convection in turbulent flow. Free convection. Condensing and boiling. Heat transfer to liquid metals. Heat transfer in high-speed flow. Special topics. This course is equivalent to MAAJ 5302 at Carleton University.

**Course Component:** Lecture

### **MCG 5133 Heat Transfer by Radiation (3 units)**

Thermal radiation and radiation properties. Radiant interchange among surfaces separated by radiatively non-participating media. Radiant energy transfer through absorbing, emitting and scattering media. Combined conduction and radiation. This course is equivalent to MAAJ 5303 at Carleton University.

**Course Component:** Lecture

### **MCG 5134 Heat Transfer With Phase Change (3 units)**

Pool boiling. Hydrodynamics of two-phase flow. Flow boiling and flow boiling crisis. Instability of two-phase flow. Condensation. This course is equivalent to MAAJ 5304 at Carleton University.

**Course Component:** Lecture

### **MCG 5136 Special Studies in Fluid Mechanics and Heat Transfer (3 units)**

This course is equivalent to MAAJ 5306 at Carleton University.

**Course Component:** Lecture

### **MCG 5138 Advanced Topics in Mechanical Engineering (3 units)**

This course is equivalent to MAAJ 5308 at Carleton University.

**Course Component:** Lecture

### **MCG 5141 Statistical Thermodynamics (3 units)**

Kinetic theory of an ideal gas. The distribution of molecular velocities. Transport phenomena. Maxwell-Boltzmann statistics. Quantum mechanics. Quantum statistics. Partition functions. Partition functions and thermodynamic properties. Derivations of specific heats of gases. Gas mixtures. Law of mass action. This course is equivalent to MAAJ 5401 at Carleton University.

**Course Component:** Lecture

### **MCG 5145 Machine Learning for Adaptive and Intelligent Control Systems (3 units)**

Main subjects: Linear Feedback Structures. Effects of Process Variations. Adaptive Schemes. Recursive Least Squares and Regression Models. Bellman's optimality. Dynamic Programming. Reinforcement Learning and Q-Learning. Temporal Difference Learning. Approximate Dynamic Programming. Adaptive Critics. Multi-Agent Adaptive Reinforcement Learning Systems. Integral Reinforcement Learning. Introduction to Differential Games. Model-Reference Adaptive Systems. Lyapunov Stability Theory. Self-Tuning Regulators. Model Following.

**Course Component:** Lecture

### **MCG 5147 Finite-Volume Methods for Compressible Gas Flows (3 units)**

Review of hyperbolic conservation laws and the compressible Euler equations. Godunov-type finite volume schemes. Approximate Riemann solvers. Time-marching methods. Polynomial solution reconstruction. Godunov's theorem. Solution monotonicity. Viscous operators.

**Course Component:** Lecture

### **MCG 5148 High-Performance Parallel Scientific Computing (3 units)**

Shared- and distributed-memory computer architectures. Parallel speedup, efficiency and Amdahl's law. Classical relaxation methods for linear systems. Domain decomposition methods. Shur-compliment method. Multigrid methods. Krylov subspace methods. Fast Fourier transforms and the Cooley-Tukey algorithm.

**Course Component:** Lecture

### **MCG 5149 Non-Equilibrium Gas Dynamics (3 units)**

Foundations and applications of compressible fluid flow with non-# equilibrium processes. Includes mechanical, chemical, and thermal non-#equilibrium with application to detonation waves in gases and solids, shock waves with chemical and vibrational relaxation and impulsive motion in arbitrary media.

**Course Component:** Lecture

### **MCG 5151 Laminar Flow Theory (3 units)**

Derivation and exact solutions of the Navier-Stokes equations. Low Reynolds number flows, Stokes flow. Oseen flow, lubrication theory. Laminar boundary layers. Introduction to hydrodynamic stability. This course is equivalent to MAAJ 5501 at Carleton University.

**Course Component:** Lecture

### **MCG 5152 Theory of Turbulence (3 units)**

Review of the basic theories and experimental results of turbulent flow. Universal equilibrium theory, locally isotropic theories, isotropic turbulence, homogeneous shear flow, turbulent pipe and channel flow, jets, wakes, boundary layers. Turbulent diffusion of passive contaminants. Modelling of turbulence. This course is equivalent to MAAJ 5502 at Carleton University.

**Course Component:** Lecture

### **MCG 5155 Inviscid Flow Theory (3 units)**

Langrangian and Eulerian description of fluid motion. Euler equations, velocity potential, irrotational flow, stream function, singular flows. Conformal mapping, Schwarz-Christoffel theorems. Airfoil theory, circulation and lift. This course is equivalent to MAAJ 5505 at Carleton University.

**Course Component:** Lecture

### **MCG 5156 Measurement in Fluid Mechanics (3 units)**

Review of the common experimental techniques used in fluid mechanical research and applications. Flow visualization techniques. Hot-wire anemometry. Laser-Doppler anemometry. Measurement of concentration, temperature, force, pressure. This course is equivalent to MAAJ 5506 at Carleton University.

**Course Component:** Lecture

### **MCG 5157 Numerical Computation of Fluid Dynamics and Heat Transfer (3 units)**

Governing equations. Explicit, implicit, finite difference and control volume procedures for approximating the parabolic and elliptic sets of partial differential equations and boundary conditions. Numerical solution by direct and iterative Gauss-Seidel relaxation methods. Considerations of stability, convergence, and numerical diffusion. Computational problems. This course is equivalent to MAAJ 5507 at Carleton University.

**Course Component:** Lecture

### **MCG 5167 Nuclear Reactor Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5169 Advanced Topics in Reliability Engineering (3 units)**

Overview of classical reliability concepts. Fault tree construction and evaluation. Common-cause failure analysis of engineering systems. Human reliability modelling in engineering systems. Human unreliability data banks. Reliability of information and communication systems. This course is equivalent to MAAJ 5609 at Carleton University.

**Course Component:** Lecture

### **MCG 5170 Computer-Aided Design (3 units)**

The design process. Structure of computer-aided drafting software. Analysis and optimization software. Software integration. Parametric design. Major group design project which integrates concepts from all major areas of mechanical engineering. Courses MCG 5170, MCG 4322 cannot be combined for units. This course is equivalent to MAAJ 5700 at Carleton University.

**Course Component:** Lecture

Exclusion: May not be taken for credit with MCG 4322.

### **MCG 5171 Applied Reliability Theory (3 units)**

Failure rate. Repair time. System reliability estimation: binomial model. Strength stress model. Failure detection and isolation. Statistical quality control. This course is equivalent to MAAJ 5701 at Carleton University.

**Course Component:** Lecture

### **MCG 5173 Systems Engineering and Integration (3 units)**

Introduction to modelling methods employed for the planning and design of sub-systems and complex systems. Discrete and continuous time, lumped and distributed parameters models. State estimation. Parameters identification. Discretization and stochastic effects. Technological systems modelling and simulation examples. This course is equivalent to MAAJ 5703 at Carleton University.

**Course Component:** Lecture

### **MCG 5177 Robot Mechanics (3 units)**

Robotics overview. Transformations. Basics of robot kinematics, statics and dynamics. Introduction to practical robots, control and programming. Project in analysis, design or application of manipulators. Courses MCG 5177, MCG 4132 cannot be combined for units. This course is equivalent to MAAJ 5707 at Carleton University.

**Course Component:** Lecture

### **MCG 5184 Mechatronics (3 units)**

Models for passive and active components for electro-mechanical systems. Network representation of signals and energy transmission and conversion. Selection of sensors and actuators for the control of mechanical systems. Modelling and simulation for the design of mixed dynamic systems. Courses MCG 5184, MCG 4136 cannot be combined for units. This course is equivalent to MAAJ 5804 at Carleton University.

**Course Component:** Lecture, Tutorial

### **MCG 5185 Multivariable Digital Control (3 units)**

Quantization. Z-Transform. State equations. Jordan canonical form. Multirate and nonsynchronous samplings. Controllability and observability of digital systems. Digital controllers design using bilinear transformation. Digital PID controller. Stability. Optimal control of digital systems. Examples of controlling mechanical system actuators. This course is equivalent to MAAJ 5805 at Carleton University.

**Course Component:** Lecture

### **MCG 5186 Non-Linear Discontinuous Dynamics and Control (3 units)**

Hamiltonian dynamics. Hamiltonian control systems. Lyapunov dynamics. Decoupling. Phase space analysis. Switching and sliding mode control. Boundary layer continuous approximation. Actuator, sensors and controller requirements. Manipulation control examples. This course is equivalent to MAAJ 5806 at Carleton University.

**Course Component:** Lecture

### **MCG 5191 Combustion in Premixed Systems (3 units)**

Stoichiometry, thermo-chemistry, ignition, flame propagation, flame stabilization, diffusion flames, turbulent combustion, modelling. This course is equivalent to MAAJ 5901 at Carleton University.

**Course Component:** Lecture

### **MCG 5192 Combustion in Diffusion Systems (3 units)**

Gaseous jet flames, combustion of liquid droplets, atomization, spray flames, coal combustion, fluidized bed combustion. This course is equivalent to MAAJ 5902 at Carleton University.

**Course Component:** Lecture

### **MCG 5300 Fundamentals of Fluid Dynamics (3 units)**

Differential equations of motion. Viscous and inviscid regions. Potential flow: superposition; thin airfoils; finite wings; compressibility corrections. Viscous flow: thin shear layer approximation; laminar layers; transition; turbulence modelling. Convective heat transfer: free versus forced convection; energy and energy integral equations; turbulent diffusion. This course is equivalent to MECH 5000 at Carleton University.

**Course Component:** Lecture

### **MCG 5301 Theory of Viscous Flows (3 units)**

Navier-Stokes and boundary layer equations; mean flow equations for turbulent kinetic energy; integral formulations. Stability, transition, turbulence, Reynolds stresses; separation. Calculation methods, closure schemes. Compressibility, heat transfer, and three-dimensional effects. This course is equivalent to MECH 5001 at Carleton University.

**Course Component:** Lecture

### **MCG 5303 Incompressible Non-Viscous Flows (3 units)**

The fundamental equations and theorems for non-viscous fluid flow; solution of two-dimensional and axisymmetric potential flows; low-speed airfoil and cascade theory; wing lifting-line theory; panel methods. This course is equivalent to MECH 5003 at Carleton University.

**Course Component:** Lecture

### **MCG 5304 Compressible Non-Viscous Flows (3 units)**

Steady isentropic, frictional, and diabatic flow; shock waves; irrotational compressible flow, small perturbation theory and similarity rules; second-order theory and unsteady, one-dimensional flow. This course is equivalent to MECH 5004 at Carleton University.

**Course Component:** Lecture

### **MCG 5305 Uninhabited Aircraft Systems Design (3 units)**

Theory of flight and air vehicle performance; propulsion systems; launch and recovery. Regulatory development; privacy policies. Mission design; sensor performance. Guidance, navigation, control and communications theory. System-level reliability; life cycle cost assessment. Includes: Experiential Learning Activity. This course is equivalent to MECH 5005 at Carleton University.

**Course Component:** Lecture

### **MCG 5306 Theory of Subsonic Flows (3 units)**

**Course Component:** Lecture

### **MCG 5307 Theory of Supersonic Flows (3 units)**

**Course Component:** Lecture

### **MCG 5308 Experimental Methods in Fluid Mechanics (3 units)**

Fundamentals of techniques of simulation of fluid dynamic phenomena. Theoretical basis, principles of design, performance and instrumentation of ground test facilities. Applications to aerodynamic testing. This course is equivalent to MECH 5008 at Carleton University.

**Course Component:** Lecture

### **MCG 5309 Environmental Fluid Mechanics Relating to Energy Utilization (3 units)**

Characteristics of energy sources and emissions into the environment. The atmosphere; stratification and stability, equations of motion, simple winds, mean flow, turbulence structure and dispersion near the ground. Flow and dispersion in groundwater, rivers, lakes and oceans. Physical and analytical modelling of environmental flows. This course is equivalent to MECH 5009 at Carleton University.

**Course Component:** Lecture

### **MCG 5310 Performance and Economics of V/Stol Aircraft (3 units)**

Aircraft performance analysis with emphasis on factors affecting take-off, landing and economic performance; high lift schemes; operating economics. This course is equivalent to MECH 5100 at Carleton University.

**Course Component:** Lecture

### **MCG 5311 Dynamics and Aerodynamics of Low Speed Flight (3 units)**

Static stability theory. Euler's equations for rigid body motion; the linearized equations of motion; stability derivatives and their estimation. Longitudinal and lateral dynamic response of an aircraft to control and disturbance. This course is equivalent to MECH 5101 at Carleton University.

**Course Component:** Lecture

### **MCG 5314 Ground Transportation Systems and Vehicles (3 units)**

Performance characteristics, handling and directional stability, ride comfort and safety of various types of ground vehicle systems including road vehicles, terrain-vehicle systems, guided transport systems, and advanced ground transport technology. This course is equivalent to MECH 5104 at Carleton University.

**Course Component:** Lecture

### **MCG 5315 Orbital Mechanics and Space Craft Control (3 units)**

Orbital dynamics and perturbations due to the Earth's figure, the sun, and the moon with emphasis on mission planning and analysis. Rigid body dynamics applied to transfer orbit and on-orbit momentum management and control of spacecraft. Effects of flexible structures on a spacecraft control system. This course is equivalent to MECH 5105 at Carleton University.

**Course Component:** Laboratory, Lecture

### **MCG 5321 Methods of Energy Conversion (3 units)**

Technical, economic and environmental aspects of present and proposed large-scale systems of energy conversion. This course is equivalent to MECH 5106/MECH 5201 at Carleton University.

**Course Component:** Lecture

### **MCG 5322 Nuclear Engineering (3 units)**

Reactor design and safety requirement overview; reactor physics, chemistry and engineering, CANDU reactor design and operation; CANDU reactor fuel channels, thermalhydraulics and fuel; reactor safety design and analysis; IAEA and Canadian safety analysis requirements; reactor accidents; nuclear energy policy.

**Course Component:** Lecture

### **MCG 5324 Building Performance Simulation (3 units)**

During this course students will develop an understanding of the methodologies and theory employed historically and contemporarily in the Building Performance Simulation (BPS) field, develop capabilities for extending the functionality of BPS tools, and establish skills in applying BPS tools in research, analysis, and design. Includes: Experiential Learning Activity

**Course Component:** Lecture

### **MCG 5325 Wind Engineering (3 units)**

Theoretical and practical areas pertinent to the operation of wind turbines. World energy needs, wind farms versus traditional power plants, global wind characteristics, efficient turbine design, electrical components, modes of turbine operation and control, mechanical design, economic and environmental concerns. This is equivalent to MECH5206 at Carleton.

**Course Component:** Lecture

### **MCG 5326 System Modelling, Dynamics and Control (3 units)**

The course provides an understanding of system modelling and the connection between energy domains. Within the temporal and/or frequency domains, system identification techniques and control aspects are explored for discrete and continuous systems along with lumped and distributed parameter models. This is equivalent to MECH5508 at Carleton

**Course Component:** Lecture

### **MCG 5327 Nonlinear Systems Analysis & Controls (3 units)**

Introduction to nonlinear systems, stability of periodic solutions and limit cycles. Second-order nonlinear systems. Mathematical foundations for stability analysis, Lyapunov and LaSalle's methods. Autonomous and non-autonomous systems. Input-Output stability formalisms. Basics of nonlinear control techniques based on Lyapunov methods. This is equivalent to MECH5509 at Carleton.

**Course Component:** Lecture

### **MCG 5328 3D Machine Vision: From Robots to the Space Station (3 units)**

Through lectures and project work, this course introduces fundamental 3D machine vision methods (triangulation and time-of-flight), presents cutting-edge neural network approaches, and explores major engineering applications (e.g. robotics, autonomous vehicles, space navigation) where perception of the 3D environment is essential. This is equivalent to MECH5103 at Carleton.

**Course Component:** Lecture

### **MCG 5329 Space Robotics (3 units)**

This graduate course in space robotics is designed to teach the full spectrum of manipulator robotics applied to in-orbit servicing and repair of spacecraft and the removal of orbital debris as the first step towards developing a space infrastructure. The course covers space manipulator missions, kinematics, dynamics, trajectory generation, control systems and some special topics. This course is equivalent to MECH 5108 at Carleton University.

**Course Component:** Lecture

### **MCG 5330 Engineering Acoustics (3 units)**

Review of acoustic waves in compressible fluids; acoustic pressure, intensity and impedance; physical interpretation and measurement; transmission through media; layers, in-homogeneous media, solids; acoustic systems; rooms, ducts, resonators, mufflers, properties of transducers; microphones, loudspeakers, computational acoustics. This course is equivalent to MECH 5300 at Carleton University.

**Course Component:** Lecture

### **MCG 5331 Aero-Acoustics (3 units)**

The convected wave equation; theory of subsonic and supersonic jet noise; propeller and helicopter noise; fan and compressor noise; boundary layer noise, interior noise; propagation in the atmosphere; sonic boom; impact on environment. This course is equivalent to MECH 5301 at Carleton University.

**Course Component:** Lecture

### **MCG 5332 Instrumentation Techniques (3 units)**

An introduction for the non-specialists to the concepts of digital and analog electronics with emphasis on data acquisition, processing and analysis. Topics covered include operational amplifiers, signal processing, digital logic systems, computer interfacing, noise in electronic systems. Hands-on sessions illustrate theory and practice. This course is equivalent to MECH 5302 at Carleton University.

**Course Component:** Lecture

### **MCG 5334 Computational Fluid Dynamics of Compressible Flows (3 units)**

Solution techniques for parabolic, elliptic and hyperbolic equations developed for problems of interest to fluid dynamics with appropriate stability considerations. A staged approach to solution of full Euler and Navier-Stokes equations is used. Grid generation techniques appropriate for compressible flows are introduced. This course is equivalent to MECH 5304 at Carleton University.

**Course Component:** Lecture

### **MCG 5341 Turbomachinery (3 units)**

Types of machines. Similarity: performance parameters; characteristics; cavitation. Velocity triangles. Euler equation: impulse and reaction. Radial pumps and compressors: analysis, design and operation. Axial pumps and compressors: cascade and blade-element methods; staging; off-design performance; stall and surge. Axial turbines. Current design practice. Courses MCG 5341, MCG 4110 (MECH 4305) cannot be combined for units. This course is equivalent to MECH 5401 at Carleton University.

**Course Component:** Lecture

### **MCG 5342 Gas Turbines (3 units)**

Interrelationship among thermodynamic, aerodynamic, and mechanical design. Ideal and real cycle calculations. Cycle optimization; turbo-shaft, turbojet, turbofan. Component performance. Off-design performance; matching of compressor, turbine, nozzle. Twin-spool matching. This course is equivalent to MECH 5402 at Carleton University.

**Course Component:** Lecture

### **MCG 5343 Advanced Thermodynamics (3 units)**

The course covers three major topics: review of fundamentals from a consistent viewpoint, properties and equations of state, and applications and special topics. The third topic includes an introduction to statistical thermodynamics. This course is equivalent to MECH 5403 at Carleton University.

**Course Component:** Lecture

### **MCG 5344 Gas Turbine Combustion (3 units)**

This course covers two major topics: combustion fundamentals and gas turbine combustor design. Combustion fundamentals include fuel evaporation, chemistry of combustion, chemical kinetics and emission formation and introduction to computational combustion modeling. Combustor design addresses the interrelationship between operational requirements and combustion fundamentals. Courses MCG 5344, MCG 5480 (MECH 5800) cannot be combined for units if MCG 5344 is taken as the topic. This course is equivalent to MECH 5400 at Carleton University.

**Course Component:** Lecture

### **MCG 5347 Conductive and Radioactive Heat Transfer (3 units)**

Analytical, numerical and analog solutions to steady-state and transient conduction heat transfer in multi-dimensional systems. Radiative heat exchange between black, grey, non-grey diffusive and specular surfaces, including effects of athermanous media. This course is equivalent to MECH 5407 at Carleton University.

**Course Component:** Lecture

### **MCG 5348 Convective Heat and Mass Transfer (3 units)**

Analogies between heat, mass and momentum transfer. Forced and free convection relations for laminar and turbulent flows analytically developed where possible and otherwise deduced from experimental results, for simple shapes and in heat exchangers. Mass transfer theory and applications. This course is equivalent to MECH 5408 at Carleton University.

**Course Component:** Lecture

### **MCG 5349 Two-Phase Flow and Heat Transfer (3 units)**

**Course Component:** Lecture

### **MCG 5350 Advanced Vibration Analysis (3 units)**

General theory of discrete multi-degree-of-freedom vibrating systems. Emphasis on numerical techniques of solving complex vibrating systems, with selected applications from aeronautical, civil, and mechanical engineering. This course is equivalent to MECH 5500 at Carleton University.

**Course Component:** Lecture

### **MCG 5352 Optimal Control Systems (3 units)**

Review of transfer function and state-space system descriptions. Elements of the optimal control problem. Variational calculus. Optimal state feedback control. Riccati equations. Optimal observers and Kalman-Bucy Filters. Extension to discrete time systems including an introduction to dynamic programming. Practical applications are emphasized throughout the course. This course is equivalent to MECH 5502 at Carleton University.

**Course Component:** Lecture

### **MCG 5353 Robotics (3 units)**

The history of and introduction to robotics methodology. Robots and manipulators; homogeneous transformation, kinematic equations, solving kinematic equations, differential relationships, motion trajectories, dynamics. Control; feedback control, compliance, servomotors, actuators, external and internal sensors, grippers and vision systems. Microprocessors and their application to robot control. Programming. This course is equivalent to MECH 5503 at Carleton University.

**Course Component:** Lecture

### **MCG 5354 Guidance, Navigation and Control (3 units)**

Guidance system classification, flight control systems, targeting, target tracking, sensing. Modern multivariable control analysis; design requirements, sensitivity, robustness, perturbations, performance analysis. Modern filtering and estimation techniques. Terrestrial navigation; tactical air navigation (TACAN), star trackers Guidance mission and performance. Aircraft, missile and spacecraft guidance and control. This course is equivalent to MECH 5504 at Carleton University.

**Course Component:** Lecture

### **MCG 5355 Stability Theory and Applications (3 units)**

Fundamental concepts and characteristics of modern stability definitions. Sensitivity and variational equations; linear variational equations; phase space analysis; Lyapunov's direct method. Autonomous and nonautonomous systems; stability in first approximation; the effect of force type on stability; frequency method. This course is equivalent to MECH 5505 at Carleton University.

**Course Component:** Lecture

### **MCG 5356 Neuro and Fuzzy Control (3 units)**

Knowledge-based controllers. Fuzzy control: mathematics, relations, operations, approximate reasoning. Fuzzy knowledge base control and structure. Fuzzification, inference engine; defuzzification. Nonlinear, adaptive fuzzy control systems. Stability, Neuro-Control: processing, learning. Adaptation of artificial neural systems: associative memories, algorithms, applications, and network implementation. Neurofuzzy systems: industrial applications. Courses MCG 5356, ELG 5386 (EACJ 5386), ELG 5196 (EACJ 5709) cannot be combined for units. This course is equivalent to MECH 5506 at Carleton University.

**Course Component:** Lecture

Exclusion: ELG 5386

### **MCG 5361 Creative Problem Solving and Design (3 units)**

Problem-solving processes and how they can be applied in engineering design. Emphasis on learning methodologies rather than accumulating information. Techniques can be successfully applied in any engineering speciality. This course is equivalent to MECH 5601/IDES 5301 at Carleton University.

**Course Component:** Lecture

### **MCG 5365 Finite Element Analysis I (3 units)**

An introduction to the finite element methodology, with emphasis on applications to heat transfer, fluid flow and stress analysis. The basic concepts of Galerkin's method, interpolation, numerical integration, and isoparametric elements are taught using simple examples. This course is equivalent to MECH 5605 at Carleton University.

**Course Component:** Lecture

### **MCG 5366 Finite Element Analysis II (3 units)**

Time marching heat flow problems with linear and nonlinear analysis. Static plasticity. Time-dependent deformation problems; viscoplasticity, viscoelasticity, and dynamic analysis. Isoparametric elements and numerical integration are used throughout. This course is equivalent to MECH 5606 at Carleton University.

**Course Component:** Lecture

### **MCG 5367 The Boundary Element Method (Bem) (3 units)**

Integral equations. The BEM for potential theory and for elastostatics in two-dimensions. Boundary elements and numerical integration schemes. Practical applications. This course is equivalent to MECH 5607 at Carleton University.

**Course Component:** Lecture

**MCG 5370 Special Topics in Mechanical and Aeronautical Engineering (3 units)**

Course Component: Lecture

**MCG 5375 CAD/CAM (3 units)**

Computer-aided design process, computer graphics including hardware and software standards. Wire frames, boundary representations, constructive solids geometry, sculptured surfaces. Data bases.

Graphics and product interchange files. Computer-aided manufacturing; numerical control, CNC, DNC, adaptive control. CAM programming, popular commercial CAD programs. Management issues. This course is equivalent to MECH 5705 at Carleton University.

Course Component: Lecture

**MCG 5376 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Topic will vary from year to year.

Course Component: Lecture

**MCG 5380 Safety and Risk Assessment of Nuclear Power (3 units)**

Course Component: Lecture

**MCG 5384 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Topic will vary from year to year.

Course Component: Lecture

**MCG 5396 Directed Studies (3 units)**

Course Component: Research

Permission of the Department is required.

**MCG 5398 Independent Engineering Study (3 units)**

Students pursuing a master's degree by course work carry out an independent study, analysis, and solution of an engineering problem or design project. The results are given in the form of a written report and presented at a departmental seminar. Carried out under the general direction of a faculty member. This course is equivalent to MECH 5908 at Carleton University.

Course Component: Lecture

**MCG 5470 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5471 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5472 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5473 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5474 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5475 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5476 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5477 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5478 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5479 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5480 Special Topics in Mechanical and Aerospace Engineering (3 units)**

In-depth study of a topic in Mechanical and Aerospace Engineering. This course is equivalent to MECH 5800 at Carleton University.

Course Component: Lecture

**MCG 5481 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5482 Special Topics in Mechanical and Aerospace Engineering (3 units)**

This course is equivalent to MECH 5805 at Carleton University.

Course Component: Lecture

**MCG 5483 Fundamentals of Combustion (3 units)**

Emphasis on gas phase reacting flows. Background of combustion thermodynamics, diffusion mass transfer, and chemical kinetics. Detonations and deflagrations. Chemical and dynamic structure of flames. Gaseous flame propagation under laminar and turbulent conditions. Flame stabilization and extinction. Introduction to burning rate theory.

Course Component: Lecture

**MCG 5484 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5485 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Course Component: Lecture

**MCG 5486 Special Topics in Mechanical and Aerospace Engineering (3 units)**

This course is equivalent to MECH 5806 at Carleton University.

Course Component: Lecture

**MCG 5487 Special Topics in Mechanical and Aerospace Engineering (3 units)**

This course is equivalent to MECH 5807 at Carleton University.

Course Component: Lecture

**MCG 5488 Special Topics in Mechanical and Aerospace Engineering (3 units)**

This course is equivalent to MECH 5803 at Carleton University.

Course Component: Lecture

### **MCG 5489 Special Topics in Mechanical and Aerospace Engineering (3 units)**

Topics will vary from year to year. This course is equivalent to MECH 5801 at Carleton University.

**Course Component:** Lecture

### **MCG 5490 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5491 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5492 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5493 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5494 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5495 Special Topics in Mechanical and Aerospace Engineering (3 units)**

**Course Component:** Lecture

### **MCG 5551 Théorie d'écoulement visqueux (3 crédits)**

Dérivation des solutions exactes des équations de Navier-Stokes. Écoulement à petit nombre de Reynolds. Écoulement de Stokes. Écoulement d'Oseen. Théorie de lubrification. Couches limites laminaires. Introduction à la stabilité hydrodynamique. Ce cours est équivalent à MAAJ 5408 à la Carleton University.

**Volet :** Cours magistral

### **MCG 5552 Théorie de turbulence (3 crédits)**

Révision des théories fondamentales et des résultats expérimentaux des écoulements turbulents. Théorie universelle de l'équilibre, théorie isotropique locale. Turbulence isotropique, contrainte homogène des écoulements, écoulements turbulents dans les tuyaux et les canaux, jets, sillages, couches limites. Diffusion turbulente. Modèles de turbulence. Ce cours est équivalent à MAAJ 5409 à la Carleton University.

**Volet :** Cours magistral

### **MCG 5557 Méthodes numériques en mécanique (3 crédits)**

Équations primitives. Méthodes de différences finies. Méthodes intégrales. Critère de stabilité. Calcul des écoulements transitoires laminaires tri-dimensionnels. Méthodes MAC de Los Alamos. Calcul des écoulements multidimensionnels turbulents. Modèles de turbulence. Méthode numérique de Gosman. Ce cours est équivalent à MAAJ 5500 à la Carleton University.

**Volet :** Cours magistral

### **MCG 5900 Séminaire de M.A.Sc. / MASC Seminar**

Une série de séminaires présentés par des étudiants aux cycles supérieurs et des chercheurs invités. En plus d'avoir à présenter un séminaire, les étudiants doivent assister et participer à au moins dix séminaires. Noté S (satisfaisant) ou NS (non satisfaisant). / A series of seminars presented by graduate students and invited researchers. Students are required to attend and participate in at least 10 seminars and to make one presentation. Graded S (Satisfactory) / NS (Not satisfactory).

**Volet / Course Component:** Séminaire / Seminar

### **MCG 5947 Séminaire de maîtrise en ingénierie / Master of Engineering Seminar**

Une série de séminaires présentés par des étudiants aux cycles supérieurs et des chercheurs invités. Les étudiants doivent assister et participer à au moins dix séminaires. Noté S (satisfaisant) ou NS (non satisfaisant). / A series of seminars presented by graduate students and invited researchers. Students are required to attend and participate in at least 10 seminars. Graded S (Satisfactory) / NS (Not satisfactory).

**Volet / Course Component:** Séminaire / Seminar

### **MCG 6998 Projet / Project (6 crédits / 6 units)**

Projet en génie mécanique ou en matériaux avancés et fabrication dirigé par un professeur approuvé par le directeur des études supérieures et donnant lieu à la rédaction d'un rapport approfondi (30-40 pages approx). Noté S (satisfaisant) ou NS (non satisfaisant) par le directeur du projet et un autre professeur nommé par le directeur des études supérieures en génie mécanique. Le projet est normalement complété en une session d'études à temps plein. / Project in mechanical engineering or in advanced materials and manufacturing supervised by a professor approved by the director of graduate studies and leading to the writing of an in-depth report (approx. 30-40 pages). Graded S (Satisfactory) or NS (Not satisfactory) by the supervisor and by another professor appointed by the director of graduate studies in Mechanical Engineering. The project can normally be completed in one session of full-time study.

**Volet / Course Component:** Recherche / Research

Permission of the Department is required.

### **MCG 9900 Séminaire de doctorat / PhD Seminar**

Une série de séminaires présentés par des étudiants aux cycles supérieurs et des chercheurs invités. En plus d'avoir à présenter un séminaire, les étudiants doivent assister et participer à au moins 15 séminaires. Noté S (satisfaisant) ou NS (non satisfaisant) / A series of seminars presented by graduate students and invited researchers. Students are required to attend and participate in at least 15 seminars and make one presentation. Graded S (Satisfactory) / NS (Not satisfactory).

**Volet / Course Component:** Séminaire / Seminar

### **MCG 9997 Préparation du rapport de candidature au doctorat / Preparation of Ph.D. Candidacy Paper**

À la suite de la réussite à l'examen de synthèse, inscription requise de tous les candidats au doctorat jusqu'à ce que le projet de thèse soit accepté par le Comité consultatif. / Following completion of the comprehensive examination, registration required for all PhD candidates until the thesis proposal is accepted by the Advisory Committee.

**Volet / Course Component:** Recherche / Research

**MCG 9998 Examen général du doctorat / PhD  
Comprehensive**

Inscription requise de tous les candidats au doctorat jusqu'à la réussite à l'examen de synthèse. / Registration required for all PhD candidates until the comprehensive examination is passed.

**Volet / Course Component:** Recherche / Research