ENGINEERING COURSE DESCRIPTIONS *Section 71.60*

ENGINEERING AND COMPUTER SCIENCE

ENCS 272 ***Composition and Argumentation for Engineers*** (3 credits)
Prerequisite: Completion of all ESL courses required on admission. Fundamentals of English composition and argumentation: grammar; reasoning and persuasion; persuasive proofs; argumentation; structuring and outlining; the problem statement; the body; and the conclusions. Language and persuasion for effective communication in professional engineering. Cultivation of a writing style firmly based on clear and critical thinking skills. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who pass this course with C- or higher will fulfill the GCS writing skills requirement, and will be eligible to enrol in ENCS 282.
NOTE: This course cannot be used for credit in any GCS degree or certificate program.

ENCS 282 ***Technical Writing and Communication*** (3 credits)
Prerequisite: Students must have satisfied the requirements in §71.20.7 by passing the Engineering Writing Test (EWT), or by passing ENCS 272 with a grade of C- or higher. Technical writing form and style. Technical and scientific papers, abstracts, reports. Library research and referencing methods for engineers and computer scientists. Technical communication using information technology: document processing software, computer-assisted presentation, analysis and design of web presentation, choice and use of appropriate tools. Students will prepare an individual major report and make an oral presentation. Lectures: three hours per week. Tutorial: two hours per week.

ENCS 393 ***Social and Ethical Dimensions of Information and Communication Technologies*** (3 credits)
Prerequisite: ENCS 282; 40 credits in BCompSc program. Ethics in an information society; surveillance and privacy; economic globalization and intellectual property in a digital world: the digital divide; computer-based profiling and hacking; electronic democracy; computer-mediated experience; and information productivity and the work/life balance. Lectures: three hours per week.

ENCS 483 ***Creativity, Innovation and Critical Thinking in Science and Technology*** (3 credits)
Prerequisite: Minimum of 60 credits in an engineering program or minimum of 45 credits in a non-engineering program. Understanding, thinking, arguing, and creativity in science and technology; analyzing and critiquing complex problems using multidisciplinary theories of creativity; exploring the processes of invention and innovation and their impact on economics, popular media, and social and cultural structures; case studies of why some inventions fail and others succeed. Students will be evaluated on case studies, assignments, and a project. Lectures: three hours per week.
NOTE: Students who have received credit for ENCS 283 may not take this course for credit.

ENCS 484 ***Development and Global Engineering*** (3 credits)
Prerequisite: Minimum of 60 credits in an engineering program or minimum of 45 credits in a non-engineering program. International development and global engineering: globalization; development projects; planning and analysis; and participatory data gathering. A project. Lectures: three hours per week.
NOTE: Students who have received credit for this topic under an ENCS 498 number may not take this course for credit.

ENCS 485 ***Field Course in Engineering and Sustainable Development*** (3 credits)
Prerequisite: Minimum of 24 credits completed towards an undergraduate program offered by the Gina Cody School of Engineering and Computer Science; minimum GPA of 2.50. This is a complementary field course for undergraduate students interested in areas of international development and global engineering. The course consists of lectures at Concordia University followed by a trip to a designated location where development is underway. Topics include location and context-specific history and evolution of development, globalization, sustainability initiatives, technological planning and analysis, and participatory data gathering. Students are required to complete a project-based research paper on a topic approved by the course instructor.
NOTE: Students from other Faculties may register for this course with permission from the course instructor.

ENCS 498 ***Topics in Engineering and Computer Science*** (3 credits)
Prerequisite: Permission of the GCS. This course may be offered in a given year upon the authorization of the GCS. The course content may vary from offering to offering.

ENGINEERING

ENGR 108 ***Engineering C.Edge Option Reflective Learning I*** (3 credits)
Prerequisite: Permission of the GCS. This course is a reflective learning module for students in their related field which is based on their academic requirements and their first C.Edge term.

ENGR 201 ***Professional Practice and Responsibility*** (1.5 credits)
Health and safety issues for engineering projects: Quebec and Canadian legislation; safe work practices; general laboratory safety common to all engineering disciplines, and specific laboratory safety pertaining to particular engineering disciplines. Review of the legal framework in Quebec, particularly the Professional Code and the Engineers Act, as well as professional ethics. Lectures: one and a half hours per week. Tutorial: one hour per week, alternate weeks.

ENGR 202 ***Sustainable Development and Environmental Stewardship*** (1.5 credits)
Introduction to the concept of sustainable development and the approaches for achieving it. Relationships with economic, social, and technological development. Methods for evaluating sustainability of engineering projects, including utilization of relevant databases and software. Impact of engineering design and industrial development on the environment. Case studies. Lectures: one and a half hours per week.

ENGR 208 ***Engineering C.Edge Option Reflective Learning II*** (3 credits)
Prerequisite: ENGR 108 and permission of the GCS. This course expands on the students' second C.Edge term in their related field of study to further develop their knowledge and work-related skills.

ENGR 213 ***Applied Ordinary Differential Equations*** (3 credits)
Prerequisite: MATH 204 (Cegep Mathematics 105) previously or concurrently; MATH 205 (Cegep Mathematics 203). This course introduces Engineering students to the theory and application of ordinary differential equations. Definition and terminology, initial-value problems, separable differential equations, linear equations, exact equations, solutions by substitution, linear models, orthogonal trajectories, complex numbers, form of complex numbers: powers and roots, theory: linear equations, homogeneous linear equations with constant coefficients, undetermined coefficients, variation of parameters, Cauchy-Euler equation, reduction of order, linear models: initial value, review of power series, power series solutions, theory, homogeneous linear systems, solution by diagonalisation, non-homogeneous linear systems. Eigenvalues and eigenvectors. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 233 ***Applied Advanced Calculus*** (3 credits)
Prerequisite: MATH 204 (Cegep Mathematics 105); MATH 205 (Cegep Mathematics 203). This course introduces Engineering students to the theory and application of advanced calculus. Functions of several variables, partial derivatives, total and exact differentials, approximations with differentials. Tangent plane and normal line to a surface, directional derivatives, gradient. Double and triple integrals. Polar, cylindrical, and spherical coordinates. Change of variables in double and triple integrals. Vector differential calculus; divergence, curl, curvature, line integrals, Green's theorem, surface integrals, divergence theorem, applications of divergence theorem, Stokes' theorem. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 242 ***Statics*** (3 credits)
Prerequisite: ENGR 213 previously or concurrently; PHYS 204; MATH 204. Resultant of force systems; equilibrium of particles and rigid bodies; distributed forces; statically determinate systems; trusses; friction; moments of inertia; virtual work. Shear and bending moment diagrams. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 243 ***Dynamics*** (3 credits)
Prerequisite: ENGR 213, 242. Kinematics of a particle and rigid body; forces and accelerations; work and energy; impulse and momentum; dynamics of a system of particles and rigid bodies, introduction to vibrations. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 244 ***Mechanics of Materials*** (3.75 credits)
Prerequisite: ENGR 213; ENGR 242 or 245; ENGR 233 previously or concurrently. Mechanical behaviour of materials; stress; strain; shear and bending moment diagrams; introduction to inelastic action. Analysis and design of structural and machine elements subjected to axial, torsional, and flexural loadings. Combined stresses and stress transformation. Deflections. Introduction to elastic stability. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: three hours per week, alternate weeks.

ENGR 245 ***Mechanical Analysis*** (3 credits)
Prerequisite: PHYS 204; ENGR 213 previously or concurrently. Forces in a plane and in space, moments of forces, Varignon's theorem, rigid bodies in equilibrium, free-body diagram. Centroids, centres of gravity. Distributed forces, moments of inertia. Principle of virtual work. Kinematics of particles and rigid bodies. Forces and accelerations; work and energy; impulse and momentum. Kinetics of particles and rigid bodies. Lectures: three hours per week. Tutorial: one hour per week.

ENGR 251 ***Thermodynamics I*** (3 credits)
Prerequisite: MATH 203 (Cegep Mathematics 103). Basic principles of thermodynamics and their application to various systems composed of pure substances and their homogeneous non-reactive mixtures. Simple power production and utilization cycles. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 290 ***Introductory Engineering Team Design Project*** (3 credits)
Prerequisite: ENCS 282; ENGR 213, 233. The introductory team design project introduces students to teamwork, project management, engineering design for a complex problem, technical writing and technical presentation in a team environment. Students work in teams and each team designs and builds a prototype defined by the Department. Students present their design and demonstrate that their design works in a competition at the end of the term. The students are also introduced to the basic principles of mechanics including the description of translational motion, rotational motion, forces and moments, work and energy, and they build a mechanical prototype to which the electronics and software are then added. A significant team project is required in this course. Lectures: three hours per week. Tutorial: two hours per week.
NOTE: All written documentation must follow the Concordia Form and Style guide. Students are responsible for obtaining this document before beginning the project.

ENGR 301 ***Engineering Management Principles and Economics*** (3 credits)
Introduction to project delivery systems. Principles of project management; role and activity of a manager; enterprise organizational charts; cost estimating; planning and control. Company finances; interest and time value of money; discounted cash flow; evaluation of projects in private and public sectors; depreciation methods; business tax regulations; decision tree; sensitivity analysis. Lectures: three hours per week. Tutorial: one hour per week.

ENGR 308 ***Engineering C.Edge Option Reflective Learning III*** (3 credits)
Prerequisite: ENGR 208 and permission of the GCS. This course further expands on the students' third C.Edge term in their related field of study to further develop their knowledge and work-related skills.

ENGR 311 ***Transform Calculus and Partial Differential Equations*** (3 credits)
Prerequisite: ENGR 213, 233. Elements of complex variables. The Laplace transform: Laplace transforms and their properties, solution of linear differential equations with constant coefficients. Further theorems and their applications. The Fourier transform: orthogonal functions, expansion of a function in orthogonal functions, the Fourier series, the Fourier integral, the Fourier transform, the convolution theorem. Partial differential equations: physical foundations of partial differential equations, introduction to boundary value problems. Lectures: three hours per week. Tutorial: two hours per week.

ENGR 361 ***Fluid Mechanics I*** (3 credits)
Prerequisite: ENGR 213, 233, 251. Basic concepts and principles of fluid mechanics. Classification of fluid flow. Hydrostatic forces on plane and curved surfaces, buoyancy and stability, fluids in rigid body motion. Mass, momentum, and energy conservation integral equations. Bernoulli equation. Basic concepts of pipe and duct flow. Introduction to Navier-Stokes equations. Similarity and model studies. Lectures: three hours per week. Tutorial: one hour per week.

ENGR 371 ***Probability and Statistics in Engineering*** (3 credits)
Prerequisite: ENGR 213, 233. Axioms of probability theory. Events. Conditional probability. Bayes theorem. Random variables. Mathematical expectation. Discrete and continuous probability density functions. Transformation of variables. Probabilistic models, statistics, and elements of hypothesis testing (sampling distributions and interval estimation). Introduction to statistical quality control. Applications to engineering problems. Lectures: three hours per week. Tutorial: one hour per week.

ENGR 391 ***Numerical Methods in Engineering*** (3 credits)
Prerequisite: ENGR 213, 233; COMP 248 or COEN 243 or MECH 215 or MIAE 215 or BCEE 231. This course focuses on roots of algebraic and transcendental equations; function approximation; numerical differentiation; numerical integration; solution of simultaneous algebraic equations; numerical integration of ordinary differential equations. Lectures: three hours per week. Tutorial: one hour per week.

ENGR 392 ***Impact of Technology on Society*** (3 credits)
Prerequisite: ENCS 282; ENGR 201, 202. Social history of technology and of science including the industrial revolution and modern times. Engineering and scientific creativity, social and environmental problems created by uncontrolled technology, appropriate technology. Lectures: three hours per week.

ENGR 411 ***Special Technical Report*** (1 credit)
Prerequisite: ENCS 282; permission of the Department. Students must submit a report on a topic related to the students' discipline and approved by the Department. The report must present a review of a current engineering problem, a proposal for a design project, or a current engineering practice.
NOTE: Students who have received credit for ENGR 410 may not take this course for credit.

ENGR 412 ***Honours Research Project*** (3 credits)
Prerequisite: ENCS 282; minimum 75 credits in the BEng program with a cumulative GPA of 3.00 or better; permission of the Department. Students work on a research project in their area of concentration, selected in consultation with and conducted under the supervision of a faculty member of the Department. The student's work must culminate in a final report, as well as an oral presentation. Students planning to register for this course should consult with the Department prior to term of planned registration. Intended for students with potential interest in graduate programs.
NOTE: Must be approved by the Department prior to registration.

ENGR 472 ***Robot Manipulators*** (3.5 credits)
Prerequisite: ELEC 372 or MECH 371. Spatial descriptions and transformations. Manipulator forward and inverse kinematics. Jacobians: velocities and static forces. Manipulator dynamics. Trajectory generation. Position control of manipulators. Force control of manipulators. Robot programming languages. Lectures: three hours per week. Laboratory: 15 hours total.

ENGR 490 ***Multidisciplinary Capstone Design Project*** (4 credits)
Prerequisite: Eligibility to register in one of these courses: AERO 490; BLDG 490; CIVI 490; COEN 490; ELEC 490; INDU 490; MECH 490; SOEN 490 or COMP 490. Students work on a supervised team project to solve a complex interdisciplinary design problem. The project is completed by a team of students from at least two different departments in GCS. The project must provide clear goals for each discipline-specific task and each student must have sufficient exposure to subjects in their program of study. Student eligibility and project topics for this course are subject to approval by the ENGR 490 Design Committee, which includes a member from each department in GCS that offers undergraduate programs. This committee vets each project to ensure the clarity

and scope of the goals and its relevance to the learning outcomes of students from each discipline. The project is carried out over both fall and winter terms. Students are expected to provide a preliminary project proposal, a progress and a final report (as a group); take part in group discussions in audit sessions during the design phase; and participate in a poster session involving individual oral presentations at the end of the winter term. In addition to the technical aspects, students are expected to learn how to evaluate their designs for compliance to regulations, environmental and societal expectations and economic issues. Students learn how to work in a multidisciplinary environment and receive exposure to entrepreneurial skills. Lectures: one hour per week, two terms. Equivalent laboratory time: three hours per week, two terms.
NOTE: Students work in groups under direct supervision of a faculty member.

ENGR 498 ***Topics in Engineering*** (3 credits)
Prerequisite: Permission of the GCS. This course may be offered in a given year upon the authorization of the GCS. The course content may vary from offering to offering.

AEROSPACE ENGINEERING

AERO 201 ***Introduction to Flight and Aerospace Systems*** (4 credits)
Prerequisite: ENGR 213 previously or concurrently. Introduction to flight vehicles in the atmosphere and in space; elements of aerodynamics, airfoils and wings; aerospace technologies including structures, materials and propulsion systems; elements of aircraft performance; basic principles of flight stability, control and systems integration; aspects of aircraft conceptual design. Lectures: three hours per week. Laboratory: four hours per week, alternate weeks.
NOTE: Permission of the Department is required for non-Aerospace Engineering students.

AERO 290 ***Introduction to Aircraft Design*** (3 credits)
Prerequisite: AERO 201; ENCS 282 previously or concurrently. Students taking this course will work as part of a multidisciplinary team to solve an assigned aerospace conceptual design problem. The course provides introductory, design-related knowledge on aerospace design topics including structural layout, powerplant integration, integrated systems requirements (such as avionics, electrical, flight controls, hydraulic, fuel, air, pressurization) and preliminary performance predictions. Lectures instruct students on the conceptual design process; aircraft sizing including take-off weight, empty weight and fuel-fraction estimates; mission analysis and trade studies; airfoil selection; constraint diagrams for thrust-to-weight and wing loading estimation; fuselage layout, engines and control surface sizing; structural and systems layout; introductory stability, control and performance; and cost analysis methods. Lectures: three hours per week. Tutorial: two hours per week.

AERO 371 ***Modelling and Control Systems*** (3.5 credits)
Prerequisite: PHYS 205; ENGR 213, 243; ENGR 311 or ELEC 342 or ELEC 364 previously or concurrently. Definition and classification of dynamic systems and components. Modelling of system components using ordinary differential equations: mechanical, electrical, electromechanical, and electrohydraulic subsystems in an airplane. Modelling of systems using transfer function models, block diagrams and signal flow graphs. Linearization of non-linear systems. Transient and steady-state characteristics of dynamic systems. Systems analyses using time domain methods, root-locus methods, and frequency response methods. Characteristics and performance of linear feedback control systems. System stability. Proportional, integral and derivative controllers. Simulation technique using Matlab/Simulink. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for ELEC 372 or MECH 371 may not take this course for credit.

AERO 390 ***Aerospace Engineering Design Project*** (3 credits)
Prerequisite: AERO 290, 371; ENCS 282. This course focuses on general design philosophy and the design process. The following topics are covered: design factors such as product safety, reliability, life cycle costs and manufacturability; design in the aerospace context (vehicle and system design with regard to mission requirements, configuration, sizing, loads, etc.); mathematical modelling, analysis, and validation; introduction to Computer-Aided Design and Engineering (CAD and CAE); design documentation. A team-based project in which an aerospace system/subsystem is designed, implemented, documented and presented is an intrinsic part of this course. Lectures: three hours per week. Tutorial: two hours per week.

AERO 417 ***Standards, Regulations and Certification*** (3 credits)
Prerequisite: ENGR 201. Overview of DoT and other international aviation standards (e.g. FAA), regulations and certification procedures; regulatory areas, namely, pilot training/testing, air traffic procedures, aircraft systems design and airworthiness; development process for new regulations and criteria for certification. Lectures: three hours per week.
NOTE: Students who have received credit for ENGR 417 or for this topic under an ENGR 498 number may not take this course for credit.

AERO 431 ***Principles of Aeroelasticity*** (3 credits)
Prerequisite: ENGR 243, 361; MECH 375. This course covers the following topics: aerodynamic loading of elastic airfoils; phenomenon of divergence; effect of flexible control surface on divergence of main structure; divergence of one- and two-dimensional wing models; phenomenon of flutter; flutter of two- and three-dimensional wings; flutter prevention and control; panel flutter in high-speed vehicles, flutter of turbomachine bladings, galloping vortex-induced oscillations, bridge buffeting. Lectures: three hours per week.
NOTE: Students who have received credit for MECH 431 may not take this course for credit.

AERO 446 ***Aerospace Vehicle Performance*** (3 credits)
Prerequisite: MECH 361. Introduction to fixed-wing aircraft operation. Flying environment and its measurement by aircraft instrumentation. Computation of lift and drag, effects of viscosity and compressibility. Review of piston, turboprop, turbojet and turbofan power plants. Operational performance of aircraft in climb, cruise, descent and on ground. Advanced aircraft systems. Operational considerations in aircraft design. Projects on selected topics. Lectures: three hours per week. Tutorial: one hour per week.

AERO 455 ***Computational Fluid Dynamics for Aerospace Applications*** (3.75 credits)
Prerequisite: ENGR 311, 391; MECH 361. Introduction to computational methods in fluid dynamics using commercial CFD codes; aspects of geometry modelling, structured and unstructured grid generation, solution strategy, and post-processing; conversion of CAD to CFD models; an overview of basic numerical methods for the Navier-Stokes equations with emphasis on accuracy evaluation and efficiency. Elements of turbulence closure modelling. User-defined function for customized physical models into commercial CFD codes. Lectures: three hours per week. Laboratory: three hours per week, alternate weeks.

AERO 462 ***Turbomachinery and Propulsion*** (3 credits)
Prerequisite: MECH 351, 361. Aircraft design process, preliminary sizing and thrust requirements. Rotary and fixed wing aerodynamics and stability. Helicopter configurations. Structure and fatigue design considerations. Review of the gas turbine cycle and components arrangement. Turbo-propulsion: turboprop, turbofan, turbojet and turboshafts. Energy transfer in turbo-machines: Euler equation, velocity triangles. Dimensional analysis of turbomachines. Flow in turbomachines. Three-dimensional flow in turbomachines. Mechanisms of losses in turbomachines. Axial-flow turbines and compressors. Centrifugal compressors. Compressor and turbine performance maps; surge and stall. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for MECH 462 may not take this course for credit.

AERO 464 ***Aerodynamics*** (3 credits)
Prerequisite: MECH 361. Flow conservation equations, incompressible Navier-Stokes equations, inviscid irrotational and rotational flows: the Euler equations, the potential and stream function equations. Dynamics of an incompressible inviscid flow field: the Kelvin, Stokes, and Helmholtz theorems. Elementary flows and their superposition, panel method for non-lifting bodies. Airfoil and wing characteristics, aerodynamic forces and moments coefficients. Incompressible flows around thin airfoils, Biot-Savart law, vortex sheets. Incompressible flow around thick airfoils, the panel method for lifting bodies. Incompressible flow around wings, Prandtl's lifting line theory, induced angle and down-wash, unswept wings, swept wings. Compressible subsonic flow: linearized theory, Prandlt-Glauert equation and other compressibility correction rules, the area rule. Transonic flow: Von Karman's ransonic small disturbance equation, transonic full potential equation, super-critical airfoils. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for MECH 464 may not take this course for credit.

AERO 465 ***Gas Turbine Design*** (3.5 credits)
Prerequisite: AERO 462. Review of turbo-propulsion types and energy transfer in turbomachines. Two- and three-dimensional flow. Lift and drag for airfoils. Cascade tests and correlations. Aerodynamic losses: physics, mechanisms, control of viscous effects. Preliminary and detailed design of turbines and compressors. Structural and thermal design requirements. Failure considerations: creep, fatigue and corrosion. Performance matching. Combustion and gearbox design. Air and oil systems design requirements. Installations and acoustics. Evolution of design. Recent trends in technologies. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 465 may not take this course for credit.

AERO 471 ***Aircraft Hydro-Mechanical and Fuel Systems*** (3.5 credits)
Prerequisite: AERO 201 or permission of the Department. This course focuses on design principles and sizing of the following aircraft systems: hydraulic system, primary and secondary flight control actuation systems, landing gear systems, and fuel system. Traditional and new technology implementations in aircraft, helicopters and other aerospace vehicles are considered. Associated standards and regulations are described. Principles of architecture development and integration, as well as engineering tools for system sizing and simulation, are covered. Lectures: three hours per week. Laboratory: 12 hours total.

AERO 472 ***Aircraft Pneumatic and Electrical Power Systems*** (3.5 credits)
Prerequisite: AERO 201; ENGR 361. This course focuses on design principles and sizing of the following aircraft systems: electrical power system, auxiliary and emergency power systems, environmental control system, ice and rain protection system, and pneumatic power system. Traditional and new technology implementations in aircraft, helicopters and other aerospace vehicles are considered. Associated standards and regulations are described. Principles of architecture development and integration, as well as engineering tools for system sizing and simulation, are covered. A project is required, including a laboratory component. Lectures: three hours per week. Laboratory: 12 hours total.

AERO 480 ***Flight Control Systems*** (3.5 credits)
Prerequisite: AERO 371 or ELEC 372 or MECH 371 or SOEN 385. Basic flight control and flight dynamics principles. Aircraft dynamic equations and performance data. Implementation of aircraft control: control surfaces and their operations, development of thrust and its control; autopilot systems, their algorithms, dynamics and interaction problems. Flight instruments, principles of operation and dynamics. Cockpit layouts — basic configuration, ergonomic design, control field forces; advanced concepts in instruments, avionics and displays; HUD; flight management systems, and communication equipment. Introduction to flight simulation: overview of visual, audio and motion simulator systems; advanced concepts in flight simulators. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for ELEC 415 or MECH 480 may not take this course for credit.

AERO 481 ***Materials Engineering for Aerospace*** (3.5 credits)
Prerequisite: MECH 221 or MIAE 221. Different types of materials used in aerospace. Metals, composites, ceramics, polymers. Failure prediction and prevention. Modes of material failure, fracture, fatigue, creep, corrosion, impact. Effect of high temperature and multiaxial loadings. High temperature materials. Cumulative damage in fatigue and creep. Materials selection. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 321 or 481 may not take this course for credit.

AERO 482 ***Avionic Navigation Systems*** (3 credits)
Prerequisite: ENGR 371 or COMP 233; AERO 371 or ELEC 372 or MECH 370 or SOEN 385. Basics of modern electronic navigation systems, history of air navigation, earth coordinate and mapping systems; basic theory and analysis of modern electronic navigation instrumentation, communication and radar systems, approach aids, airborne systems, transmitters and antenna coverage; noise and losses, target detection, digital processing, display systems and technology; demonstration of avionic systems using flight simulator. Lectures: three hours per week.
NOTE: Students who have received credit for ELEC 416 or MECH 482 may not take this course for credit.

AERO 483 ***Integration of Avionics Systems*** (3 credits)
Prerequisite: AERO 482. Introduction to the basic principles of integration of avionics systems; review of Earth's geometry and Newton's laws; inertial navigation sensors and systems (INS); errors and uncertainty in navigation; Global Positioning System (GPS); differential and carrier tracking GPS applications; terrestrial radio navigation systems; Kalman filtering; integration of navigation systems using Kalman filtering; integration of GPS and INS using Kalman filtering. Lectures: three hours per week.
NOTE: Students who have received credit for ENGR 418 may not take this course for credit.

AERO 485 ***Introduction to Space Systems*** (3 credits)
Prerequisite: MECH 351, 361. Classification of space propulsion systems; Tsiolkovskj's equation; ideal rocket and nozzle design; flight performance; basic orbital mechanics; chemical propellant rocket performance analysis; fundamentals of liquid and solid propellant rocket motors; electric, solar, fusion thruster. Lectures: three hours per week.
NOTE: Students who have received credit for MECH 485 or for this topic under a MECH 498 number may not take this course for credit.

AERO 486 ***Aircraft Stress Analysis*** (3 credits)
Prerequisite: ENGR 243, 244. Definition of load paths in typical aircraft structures. Derivation of analysis procedures to enable the designer to size preliminary designs. Internal shear flow distributions that balance external loads. Stress analysis of open and closed cell beams; statically indeterminate beams and frames; single and multi cell torque boxes; symmetric heavy fuselage frames. Structural instability of columns, beams, plates and flanges in compression and shear. Centres of twist and flexure; structural warping; margins of safety; concepts of optimum design; lug analysis and mechanical joints; matrix analysis methods leading to the Finite Element method. Stress analysis of thin-walled metallic structures. Lectures: three hours per week.
NOTE: Students who have received credit for MECH 486 may not take this course for credit.

AERO 487 ***Design of Aircraft Structures*** (3 credits)
Prerequisite: AERO 486. Design process for aircraft structures. Aero/performance aspects of aircraft structures. Airworthiness and design considerations. Materials. Static, vibratory and aeroelastic loadings. Propulsion-induced loadings. Functions and fabrication of structural components. Design for buckling of aircraft structures: local buckling, instability of stiffened panels, flexural torsional buckling. Design for fracture and fatigue failures. Stress analysis and design of wings, fuselages, stringers, fuselage frames, wing ribs, cut-outs in wings and fuselages, and laminated structures. Design using Finite Element Method. Concept of Optimum Design of Aircraft Structures. Design case studies. Lectures: three hours per week.
NOTE: Students who have received credit for MECH 487 may not take this course for credit.

AERO 490 ***Capstone Aerospace Engineering Design Project*** (4 credits)
Prerequisite: 75 credits in the program; AERO 390; ENGR 301. This course includes a supervised design, simulation or experimental capstone design project including a preliminary project proposal with complete project plan and a technical report at the end of the fall term; a final report by the group and presentation at the end of the winter term. Lectures: one hour per week, one term. Equivalent laboratory time: three hours per week, two terms.
NOTE: Students will work in groups under direct supervision of a faculty member.
NOTE: With permission of the Department, students may enrol in MECH 490 instead of AERO 490 on the condition that they choose to complete an aerospace-oriented project.

BUILDING, CIVIL AND ENVIRONMENTAL ENGINEERING

BCEE 231 ***Structured Programming and Applications for Building and Civil Engineers*** (3 credits)
Prerequisite: MATH 204; ENGR 242 previously or concurrently. Elements of procedural programming: variables, primitive data types, scope, operators and expressions, control structures, functions, derived data types and basic data structures. Program structure and development: specifications, analysis of requirements, flow charting, incremental development, testing, validation and program documenting. Application of procedural programming, graphics and numerical tool box to mathematics and building, civil and environmental engineering. Lectures: three hours per week. Tutorial: two hours per week.

BCEE 342 ***Structural Analysis I*** (3 credits)
Prerequisite: ENGR 244. Analysis of statically determinate structures: deflections, strain energy concepts, virtual work principles. Mueller Breslau principle, influence lines. Approximate methods for statically indeterminate structures. Collapse load analysis. Cables and Arches. Computer applications. Lectures: three hours per week. Tutorial: two hours per week.

BCEE 343 ***Structural Analysis II*** (3 credits)
Prerequisite: BCEE 342. Analysis of statically indeterminate structures: the methods of consistent deformations, slope deflection, and moment distribution. Application of virtual work principles. Introduction to matrix methods. Computer applications. Lectures: three hours per week. Tutorial: two hours per week.

BCEE 344 ***Structural Design of Steel and Wood Elements*** (3 credits)
Prerequisite: BCEE 342. This course covers the following topics: basis for limit states design, code requirements, structural steel design: tension and compression members, beams and beam-columns, connections, design of timber members. Lectures: three hours per week. Tutorial: two hours per week.

BCEE 345 ***Structural Design of Reinforced Concrete Elements*** (3 credits)
Prerequisite: BCEE 342. This course covers the behaviour of reinforced concrete elements in flexure, compression, shear and bond. Other topics covered in the course are limit states design of reinforced concrete beams, one-way slabs, columns, and footings; serviceability limits states; introduction to prestressed concrete and masonry structures. Lectures: three hours per week. Tutorial: two hours per week.

BCEE 371 ***Surveying*** (3 credits)
Prerequisite: BLDG 212 or CIVI 212. Elementary operations employed in engineering surveying; use, care, and adjustment of instruments; linear and angular measurements; traversing; earthwork calculations; theory of errors; horizontal and vertical curves and curve layout; slope stakes and grades, application of surveying methods to city, topographic surveying, and introduction to advanced surveying techniques; use of digital computers in surveying calculations. Summer school taken before entering second year of study in the BEng program. Lectures and fieldwork: eight hours per day; six days per week for three weeks.

BCEE 451 ***Construction Engineering*** (3 credits)
Prerequisite: BLDG 341 or CIVI 341. The nature of construction and the environment in which the industry works; organizational structures for project delivery; construction contracts and documents; introduction to construction processes: excavation and site works, foundation layout, concrete form design, concrete, steel, timber, and masonry construction; project planning, scheduling, and control; construction safety. Lectures: three hours per week.

BCEE 452 ***Fundamentals of Finite Element Analysis of Structures*** (3 credits)
Prerequisite: ENGR 213, 233; BCEE 231, 343. Matrix formulation of the force and of the displacement methods of analysis. Direct stiffness approach; finite element methods for structural analysis. Truss, beam, plane strain, plane stress, shell and solid elements. Computer applications. Lectures: three hours per week.

BCEE 455 ***Introduction to Structural Dynamics*** (3 credits)
Prerequisite: ENGR 243, 391; BCEE 342. Theory of vibration. Dynamic response of simple structural systems. Effects of blast, wind, traffic, and machinery vibrations. Basic concepts in earthquake resistant design. Computer applications. Lectures: three hours per week.

BCEE 464 ***Project Cost Estimating*** (3 credits)
Prerequisite: ENGR 301. Techniques and procedures used for estimating cost of construction projects. Cost estimation process; elements of project cost; conceptual and detailed cost estimation methods; risk assessment and range estimating; case studies; computer-aided estimating.

BCEE 465 ***Construction Planning and Control*** (3 credits)
Prerequisite: BCEE 478 or equivalent. This course covers the following topics: methods of delivering construction, contractual relationships and organizational structures, phases of project development, estimating resource requirements, costs and durations, bidding strategies, network analysis using CPM and PERT, time-cost trade-off, resource allocation, cash flow analysis, earned-value concept for integrated time and cost control, quality control, and value engineering. Lectures: three hours per week.

BCEE 466 ***Simulations and Design of Construction Operations*** (3 credits)
Prerequisite: BCEE 451. Principles of modelling and simulation. Classification and validation of simulation models. Analysis of input data and outputs. Object Oriented Simulation (OOS). Simulation languages. Application of discrete event simulation in construction operations including earthmoving operations, building construction operations, and tunnelling operations.

BCEE 478 ***Project Management for Construction*** (3 credits)
Prerequisite: BLDG 341 or CIVI 341. This course introduces project management techniques in construction, including project delivery methods, construction contracts, cost estimating and bidding planning and scheduling, cash flow analysis, project tracking, control and computer applications. Lectures: three hours per week.
NOTE: Students who have received credit for BLDG 478 may not take this course for credit.

BCEE 491 ***Labour and Industrial Relations in Construction*** (3 credits)
Prerequisite: ENGR 301. The study of labour legislation is covered, with special emphasis on the construction industry, union organization, the theory and practice of negotiations, mediation, contract administration, and arbitration. Moreover, the review of actual contracts and future trends are discussed. Lectures: three hours per week.
NOTE: Students who have received credit for BLDG 491 may not take this course for credit.

BCEE 492 ***Construction Processes*** (3 credits)
Prerequisite: BCEE 451 or ENGR 451. This course is a study of current construction methods and techniques. The subjects include site preparation and earth-work, wood framing, masonry, concrete forming, slip forming, precast construction, industrialized building, deep excavation shoring and underpinning. Other topics covered in the course are design, erection, and removal of temporary construction work, current field practice and safety considerations and site visits. Lectures: three hours per week.
NOTE: Students who have received credit for BLDG 492 may not take this course for credit.

BCEE 493 ***Legal Issues in Construction*** (3 credits)
Prerequisite: ENGR 301. Legal concepts and processes applicable to the development of constructed facilities and to the operation of the construction firm are covered. Emphasis is given to Quebec law and institutions. Lectures: three hours per week.
NOTE: Students who have received credit for BLDG 493 may not take this course for credit.

BUILDING ENGINEERING

BLDG 212 ***Building Engineering Drawing and Introduction to Design*** (3 credits)
Fundamentals of technical drawing, dimensioning practices, orthographic projections, auxiliary and sectional views of buildings. Theory and applications of descriptive geometry in building design. Computer-aided building drawing. Building sub-systems and related graphics standards; architectural and building engineering drawing at preliminary and final stages. Introduction to the design of light-frame buildings. Project: representation of a building and its sub-systems. Introduction to conceptual design. Lectures: three hours per week. Tutorial: two hours per week.

BLDG 341 ***Building Engineering Systems*** (3 credits)
Prerequisite: BCEE 231 previously or concurrently. Introduction to systematic solution of building engineering problems. Techniques treated include linear programming, network analysis, nonlinear programming. Introduction to decision analysis and simulation. Application of optimization methods for solution of design problems in building science, building environment, building structures, and construction management, taking into account sustainability issues. Lectures: three hours per week.

BLDG 365 ***Building Science*** (3.5 credits)
Prerequisite: ENGR 251. General introduction to the thermal environment and sustainable development issues. Topics include heat, temperature, one-dimensional steady-state processes. Convection: natural and forced. Radiation. Combined radiative and convective surface transfer. Psychrometrics. Thermal comfort. Air quality. Condensation: surface and interstitial. Introduction to compressible viscous flow, friction, and flow in pipes; boundary layer and wind effects. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

BLDG 366 ***Acoustics and Lighting*** (3.5 credits)
Prerequisite: ENGR 243. General introduction to the aural and visual environment. Psychological impact of environment. Subjective and objective scales of measurement. Introduction to vibration. The hearing mechanism. Transmission of sound, passive control of noise in buildings, transmission loss, absorption and reverberation time. Room acoustic assessment. Active control of the aural environment. Visual perception. Photometry, brightness, luminance, and illumination. Concept of natural lighting in building. Artificial lighting; light sources; luminaries. Calorimetry. Calculation methods for artificial lighting. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

BLDG 371 ***Building Service Systems*** (3.5 credits)
Prerequisite: BLDG 365 previously or concurrently. Principles of building service systems, including electrical, gas, communications, service-water supply and distribution; introduction to plans, codes, and standards for utility distribution systems. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

BLDG 390 ***Building Engineering Design Project*** (3.5 credits)
Prerequisite: BLDG 341; ENCS 282; BCEE 344 previously or concurrently. The project of each team will encompass various stages of design of a medium-size building. Students learn building engineering design process, methodology, identification of objectives, building codes, formulation of design problems, and estimation of loads on buildings. The design topics encompass the development and evaluation of sustainable building design alternatives; conceptual building design of spatial requirements, design of space layout; and building design accounting for the synthesis and design of structures, enclosure systems, and services (HVAC, lighting, electrical distribution) using computer-aided design tools. Additionally, performance evaluation using modelling, sensitivity analysis and cost estimation is presented. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

BLDG 432 ***Geology and Soil Mechanics*** (3.5 credits)
Prerequisite: ENGR 244. Basic principles of physical geology are covered, with emphasis on topics related to soil mechanics. Furthermore, this course covers the study of minerals, index properties and classification of soils, weight-volume relationships, soil structures and moisture-density relationships. Permeability, deformation, and strength of soils, principle of total and effective stresses, steady state seepage through isotropic soil media, stress distribution due to external loads and analysis of total settlements, and outline of theory of consolidation are covered. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

BLDG 462 ***Modern Building Materials*** (3 credits)
Prerequisite: CIVI 321. Engineering properties of building materials such as: plastics, synthetic fibres, adhesives, sealants, caulking compounds, foams, sandwich panels, composites, polymer concrete systems, fibre-reinforced concretes, plastic

mortars, polymers for flooring, roofing, synthetic wall papers. Their structural, thermal, and acoustical properties. Consideration of corrosion, bio- and thermal-degradation, stability to ultraviolet and solar radiation. Laboratory sessions to illustrate synthesis, application, testing, deterioration, and protection. Lectures: three hours per week.

BLDG 463 ***Building Envelope Design*** (3 credits)
Prerequisite: BLDG 365. Technical influences in the design of building envelope, including the control of heat flow, air and moisture penetration, building movements, and deterioration are covered. Other topics covered by the course are the application of air/vapour barrier and rain-screen systems, performance assessment and building codes through case studies and design projects, sustainable design principles, design of walls, roofs, joints and assemblies. Students also learn cause of deterioration and preventive measures, on-site investigation and relevant building codes and standards. Lectures: three hours per week.

BLDG 465 ***Fire and Smoke Control in Buildings*** (3 credits)
Prerequisite: BLDG 365. Topics treated include fire and smoke control; failure mechanisms of building enclosure illustrated by case studies; code requirements for enclosure systems; systems approach for fire safety. Lectures: three hours per week.

BLDG 471 ***HVAC System Design*** (4 credits)
Prerequisite: BLDG 371; BLDG 476 previously or concurrently. Principles of HVAC system design and analysis; sustainable design issues and impact on environment; component and system selection criteria including room air distribution, fans and air circulation, humidifying and dehumidifying processes, piping and ducting design. Air quality standards. Control systems and techniques; operational economics; computer applications. Lectures: three hours per week. Laboratory: two hours per week.

BLDG 472 ***Building Energy Conservation Technologies*** (3 credits)
Prerequisite: BLDG 471 previously or concurrently. Standards of energy efficiency in buildings.Trends in energy consumption. Energy audit: evaluation of energy performance of existing buildings, weather normalization methods, measurements, disaggregation of total energy consumption, use of computer models, impact of people behaviour. Energy efficiency measures in buildings: approaches, materials and equipments, operating strategies, evaluation methods of energy savings. Renewable energy sources: passive or active solar systems, geothermal systems, free-cooling. Optimum selection of energy sources. Impact of emerging technologies. Case studies. Lectures: three hours per week.

BLDG 473 ***Building Acoustics*** (3 credits)
Prerequisite: BLDG 366. Noise control criteria and regulations, instrumentation, noise sources, room acoustics, walls, barriers and enclosures, acoustical materials and structures, vibration and noise control systems for buildings. Lectures: three hours per week.

BLDG 474 ***Building Illumination and Daylighting*** (3 credits)
Prerequisite: BLDG 366. Production, measurement and control of light. Photometric quantities, visual perception and colour theory. Daylight and artificial illumination systems. Radiative transfer, fixture and lamp characteristics, control devices and energy conservation techniques. Design of lighting systems. Solar energy utilization and daylighting. Integration of lighting systems with mechanical systems for energy conservation and sustainable development. Lectures: three hours per week.

BLDG 475 ***Indoor Air Quality*** (3 credits)
Prerequisite: BLDG 371 previously or concurrently. Elements of indoor air quality, physical/ chemical characteristics of contaminants, health effects, standard requirements. Estimation of the levels of indoor air contaminants in buildings. Design of ventilation systems for pollutant control. Air pollution due to outdoor air supply through ventilation systems. Effect of outdoor air pollution on indoor air quality. Lectures: three hours per week.

BLDG 476 ***Thermal Analysis of Buildings*** (3 credits)
Prerequisite: BLDG 365; ENGR 361. Two- and three-dimensional steady-state and transient conductive heat transfer together with convection and radiation as applied to building materials and geometries. Heating and cooling load analysis, including building shapes, construction type, solar radiation, infiltration, occupancy effects, and daily load variations. Computer applications for thermal load analysis. Introduction to heat exchangers. Lectures: three hours per week. Tutorial: one hour per week.

BLDG 477 ***Control Systems in Buildings*** (3 credits)
Prerequisite: BLDG 371 previously or concurrently. Introduction to automatic control systems. Control issues related to energy conservation, indoor air quality and thermal comfort in buildings. Classification of HVAC control systems. Control system hardware: selection and sizing of sensors, actuators and controllers. Practical HVAC control systems; elementary local loop and complete control systems. Designing and tuning of controllers. Building automation systems. Case studies. Lectures: three hours per week.

BLDG 479 ***Commissioning of HVAC Systems in Buildings*** (3 credits)
Prerequisite: BLDG 471 previously or concurrently. This course covers the following topics: introduction; scope of commissioning of Heating, Ventilating and Air Conditioning (HVAC) systems including commissioning, retro-commissioning, recommissioning, continuous commissioning, and ongoing commissioning; process vs. technical commissioning; instrumentation for the monitoring of HVAC operation and performance; uncertainty analysis of experimental data; mathematical models of different classes of virtual sensors; data mining techniques applied to measurements from HVAC systems; development of benchmarking models of the normal HVAC operation including correlation-based models, Artificial Neural Networks, and calibrated models; methods for the automated faults detection and diagnostic (FDD); forecasting models of the energy demand in buildings; recommissioning measures for HVAC systems; methods of estimation of energy and cost savings due to the commissioning of HVAC systems. Lectures: three hours per week.

BLDG 480 ***Building Information Modelling in Construction*** (3 credits)
This course covers the following topics: introduction to Building Information Modelling (BIM) technologies; BIM implementation at different project stages (pre-construction, construction, and facility management); BIM-Aided design alternatives (constructability analysis, and development of space-time-cost models); BIM for visualization (trade coordination and processes monitoring). A project is required. Lectures: three hours per week.

BLDG 481 ***Fundamentals of Facility Management*** (3 credits)
The course provides a study of the fundamental practices concomitant with facility management. The subjects include facility management industry backgrounds, management of outsourced services, financial analysis, asset management as it relates to building systems and controls. The course has a focus on sustainability, finance, maintenance and operations of facilities and considers solutions to facility management challenges. Lectures: three hours per week.

BLDG 482 ***Impact of Technology on Society and Architecture*** (3 credits)
Prerequisite: 20 courses in the BEng program. History of architecture as the confluence of social and technological evolution. Methodology and thought processes in the theory and design of cities and the human habitat. Impact of technology on society. Energy conservation, environmental constraints and sustainability issues. Lectures: three hours per week.

BLDG 483 ***Integrated Solar Systems: Design and Operation*** (3 credits)
This course covers the following topics: energy modelling; analysis and design of solar buildings with passive and hybrid building-integrated systems; and photovoltaic systems. Students learn both fundamentals and applications, including use of software in Mathcad, TRNSYS and Retscreen. A project is required. Lectures: three hours per week.

BLDG 484 ***Diagnostics and Rehabilitation of Building Envelope*** (3 credits)
Prerequisite: BLDG 463 previously or concurrently. This course covers the following topics: modes of failures including wood decay, mould growth, freeze-thaw, corrosion, chemical reaction, and movements; common failures in building envelopes including contemporary and traditional walls, windows, roofs and below-grade structures; performance assessment protocols including diagnostics procedures, laboratory and field test methods; remedy strategies and maintenance plan; relevant building codes and standards. A project is required. Lectures: three hours per week.

BLDG 490 ***Capstone Building Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in the BEng (Bldg) program including ENCS 282; BCEE 344, 345; BLDG 371, 390; ENGR 301. The project of each team encompasses the integrated design of at least three sub-systems of a new or retro-fitted building to achieve high performance and efficiency at reasonable cost; sustainable design and environmental impact issues are addressed in all projects. In the process, students learn, through case studies and literature survey, the information gathering and decision/design process, problem-resolution as well as aspects related to management, teamwork and communication. Students registering for this course must contact the course coordinator for the detailed procedure. Lectures: two hours per week, two terms.

BLDG 490A ***Capstone Building Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in the BEng (Bldg) program including ENCS 282; BCEE 344, 345; BLDG 371, 390; ENGR 301. The project of each team encompasses the integrated design of at least three sub-systems of a new or retro-fitted building to achieve high performance and efficiency at reasonable cost; sustainable design and environmental impact issues are addressed in all projects. In the process, students learn, through case studies and literature survey, the information gathering and decision/design process, problem-resolution as well as aspects related to management, teamwork and communication. Students registering for this course must contact the course coordinator for the detailed procedure. Lectures: two hours per week, two terms.

BLDG 490B ***Capstone Building Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in the BEng (Bldg) program including ENCS 282; BCEE 344, 345; BLDG 371, 390; ENGR 301. The project of each team encompasses the integrated design of at least three sub-systems of a new or retro-fitted building to achieve high performance and efficiency at reasonable cost; sustainable design and environmental impact issues are addressed in all projects. In the process, students learn, through case studies and literature survey, the information gathering and decision/design process, problem-resolution as well as aspects related to management, teamwork and communication. Students registering for this course must contact the course coordinator for the detailed procedure. Lectures: two hours per week, two terms.

BLDG 498 ***Topics in Building Engineering*** (3 credits)
Prerequisite: Permission of the Department. This course may be offered in a given year upon the authorization of the Department. The course content may vary from offering to offering and will be chosen to complement the available elective courses. Lectures: three hours per week.

CIVIL ENGINEERING

CIVI 212 ***Civil Engineering Drawing and Introduction to Design*** (3 credits)
Fundamentals of technical drawing, orthographic projections, sectional views. Computer-aided drawing; slabs, beams, and columns; steel structures; building trusses and bridges, wood and masonry structures. Working drawing and dimensioning practice. Introduction to the design process. Lectures: three hours per week. Tutorial: two hours per week.

CIVI 231 ***Geology for Civil Engineers*** (3 credits)
Basic principles of physical and structural geology with emphasis on topics related to civil engineering, study of minerals, rocks and soil types, load formation, techniques of air-photo interpretations, and geological mapping. Geological site investigation. Preparation and interpretation of engineering geology reports. Lectures: three hours per week. Tutorial: one hour per week.

CIVI 321 ***Engineering Materials*** (3.75 credits)
Prerequisite: CHEM 205 or equivalent. Linear and nonlinear material behaviour, time-dependent behaviour; structural and engineering properties of structural metals; behaviour of wood; production and properties of concrete; bituminous materials, ceramics, plastics; introduction to composite materials. Lectures: three hours per week. Laboratory: three hours per week, alternate weeks.

CIVI 341 ***Civil Engineering Systems*** (3 credits)
Prerequisite: BCEE 231 previously or concurrently. Development of concepts and techniques commonly associated with systems engineering which are applicable to design and operation of systems that concern civil engineers. Design and planning process; problem formulation, optimization concepts, linear programming, decision analysis; system simulation; network planning and project scheduling; computer applications. The techniques developed are used to solve problems in transportation, water resources, structures, and construction management. Lectures: three hours per week.

CIVI 361 ***Introduction to Environmental Engineering*** (3.5 credits)
Prerequisite: ENGR 361. Ecosystems considerations, food chain, natural decomposition, and recycling; environmental problems and impact of engineering activities. Various modes of pollution, water, air, and soil contamination, noise pollution; pollution measurement and quantification. Water and waste-water physical, chemical and biological characteristics; turbidity and colour, dissolved oxygen, hardness, pH, alkalinity, organic content, sampling and analysis, chemical and biochemical oxygen demand. Basic processes of treatment: flocculation and coagulation, sedimentation, filtration. Lectures: three hours per week. Tutorial: two hours per week, alternate weeks. Laboratory: two hours per week, alternate weeks.

CIVI 372 ***Transportation Engineering*** (3 credits)
Prerequisite: BCEE 371; CIVI 341. Fields of transportation engineering; transportation's roles in society; planning and design of road, rail, air, and water-way system components: terminals, right-of-way; control systems: evaluation of alternative modes and decision-making process; introduction to computer-aided design and management of systems. Lectures: three hours per week. Tutorial: one hour per week.

CIVI 381 ***Hydraulics*** (3.5 credits)
Prerequisite: ENGR 361, 391. Basic hydrodynamics; boundary layer theory, principle of energy losses. Steady flow in open channel; uniform flow, specific energy and critical flow, transition; gradually varied flow in channels and conduits, water surface profiles, computer applications. Flow measurement in open channel, weirs, overflow spillways. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 382 ***Water Resources Engineering*** (3.5 credits)
Prerequisite: CIVI 381; ENGR 391 or EMAT 391. Sources of water: surface water, groundwater, water quantities and requirements. Water use cycle. Characteristics of water and wastewater. Demand forecast, water use prediction and planning. Groundwater withdrawal and well hydraulics. Water supply network analysis, design of distribution systems, storage, pumping. Sanitary and storm water quantities, urban hydrology. Design of sewer systems, interceptors, gravity sewer, computer applications. Sustainable use of water resources. Design case studies. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 390 ***Civil Engineering Design Project*** (3.5 credits)
Prerequisite: CIVI 361 previously or concurrently; ENCS 282; BCEE 344 or 345 previously or concurrently. The project of each team will encompass the various stages of design of a medium-size civil engineering project. Students learn civil engineering design process, methodology, identification of objectives, codes, formulation of design problems, and estimation of loads on structures. The topics of design include the development and evaluation of sustainable design alternatives; and the computer-aided design tools. Additionally, performance evaluation using modelling, sensitivity analysis, and cost estimation is presented. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

CIVI 432 ***Soil Mechanics*** (3.5 credits)
Prerequisite: ENGR 244. Index properties and classification of soils. Weight-volume relationships. Soil structures. Moisture-density relationships. Permeability, deformation, and strength of soils. Principle of total and effective stresses. Steady stage seepage through isotropic soil media. Stress distribution due to external loads and analysis of total settlements. Outline of theory of consolidation. Fundamentals of stability of earth retaining walls, slopes, and footings. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 435 ***Foundation Design*** (3 credits)
Prerequisite: CIVI 432. Site investigation. Shallow and deep foundations. Bearing capacity and settlement of foundations. Earth-retaining structures, sheet piles, cofferdams, anchors. Foundations subjected to dynamic loading. Foundations on difficult soils, soil improvement and underpinning. Lectures: three hours per week. Tutorial: two hours per week.

CIVI 437 ***Advanced Geotechnical Engineering*** (3 credits)
Prerequisite: CIVI 432. Mechanical properties of rocks and rock formations. Underground openings in rocks. Slope stability of stratified formations. Foundations on rocks. Rock bolting. Introduction of soil dynamics. Wave propagation in one and two dimensions in elastic media. Seismic waves. Foundations subjected to dynamic loading. Theory of liquefaction. Lectures: three hours per week.

CIVI 440 ***Computer Applications in Civil Engineering Practice*** (3 credits)
Prerequisite: BCEE 231; 75 credits in the program. General purpose IT tools for civil engineering applications: database programming and web-based tools. Introduction to remote sensing and GIS. Application of major software packages in selected areas of civil engineering practice with emphasis on modelling, data integration, and work-flow. Case studies in structural design, geotechnical engineering, transportation, and environmental engineering. Lectures: two hours per week. Laboratory: two hours per week.

CIVI 453 ***Design of Reinforced Concrete Structures*** (3.5 credits)
Prerequisite: BCEE 345; CIVI 390 or BLDG 390 previously or concurrently. This course covers a wide variety of topics on reinforced concrete including two-way slab systems (flat plate, flat slab and slab-on-beams); slender columns; columns subjected to biaxial bending; lateral loads resisting systems (moment-resisting frames, shear walls and coupled shear walls); prestressed concrete (losses, design requirements for flexure, shear, bond, anchorage and deflections). Design project. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 454 ***Design of Steel Structures*** (3.5 credits)
Prerequisite: BCEE 344; CIVI 390 or BLDG 390 previously or concurrently. This course covers a wide variety of topics on steel structures: trends and developments in structural-steel design, framing systems, floor systems such as composite construction and plate girders, braced frames, and moment-resisting frames. The subject includes connections and P-Delta effects. A design project is required. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 464 ***Environmental Impact Assessment*** (3 credits)
Prerequisite: CIVI 361. Engineering activities and the environment; environmental ethics. Prediction and estimation of impact on air, water, soil quality, and biological, socio-economic, cultural environments. Water and air pollution laws, solid and hazardous waste laws. Environmental inventories, assessment preparation, and review. Federal and provincial laws and regulations on environmental assessment. Strategies for environmental compliance, resolution of environmental conflicts. Case studies. Lectures: three hours per week.

CIVI 465 ***Water Pollution and Control*** (3.5 credits)
Prerequisite: CIVI 361. Physical, chemical, and biological characteristics of water, water quality standards, reaction kinetics and material balances, eutrophication. Containment of reactive contaminants. Natural purification processes in water systems, adsorption, absorption; diffusion and dispersion, oxidation. Large-scale transport of contaminants, single and multiple source models; modelling of transport processes, computer simulation. Introduction to ground-water pollution, sea-water intrusion. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

CIVI 466 ***Engineering Aspects of Chemical and Biological Processes*** (3 credits)
Prerequisite: CIVI 361. Introduction to water purification, chemical treatment, coagulation, disinfection, special purification methods. Primary and secondary waste-water treatment, solution and surface chemistry, microbiological consideration; reaction kinetics, diffusion processes, membrane processes, re-aeration. Biological treatment, activated sludge process, treatment and disposal; biological reactors; aerated lagoons; trickling filter; biological nutrient removal. Tertiary waste-water treatment. Lectures: three hours per week.

CIVI 467 ***Air Pollution and Emission Control*** (3 credits)
Prerequisite: CIVI 361. Types of air pollutants. Sources of air pollutants, effects of air pollutants on health, vegetation, materials, and the atmosphere; emission standards. Meteorological considerations, dispersion of pollutants in the atmosphere, distribution and cleansing of particle matter, atmospheric photochemical reactions. Particulate pollutant control, source correction, cooling treatment; control of gaseous pollutant, point sources, odour control; measurement techniques; computer applications. Lectures: three hours per week.

CIVI 468 ***Waste Management*** (3 credits)
Prerequisite: CIVI 361. Solid waste; source and generation, sampling and analysis, collection, transport, and storage. Waste recycling, physical and chemical reduction; drying; energy recovery; disposal of solid waste. Sanitary and secure landfill planning, site selection, design and operation; chemical and biological reactions. Hazardous waste, chemical and physical characteristics, handling, processing, transportation, and disposal. Resource recovery alternatives, material exchanges, hazardous waste management facilities, incinerators, landfills. Lectures: three hours per week.

CIVI 469 ***Geo-Environmental Engineering*** (3.5 credits)
Prerequisite: CIVI 361. Structure and surface chemistry of soil, ion exchange, hydrolysis equilibrium, adsorption. Biochemical degradation, toxic contaminants. Mechanical and thermodynamic equilibrium in soil. Geotechnical considerations in environmental design; soil decontamination. Barrier technologies and soil interaction. Landfill covers and leachate collection systems; subsurface investigation, soil-gas survey. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

CIVI 471 ***Highway and Pavement Design*** (3 credits)
Prerequisite: BCEE 371; CIVI 321. This course covers the following topics: design criteria, including capacity and level of service, route alignment and right-of-way considerations, geometric design, earthworks and construction practices; pavement materials and tests; flexible and rigid pavement design procedures including subgrade, base, and surfacing characteristics, loads, stresses in pavement systems, material characterization, pavement response models, effects of natural forces, and construction practices; pavement management; computer applications; geometric and pavement design projects. Lectures: three hours per week. Tutorial: two hours per week.

CIVI 474 ***Transportation Planning and Design*** (3 credits)
Prerequisite: CIVI 372. Transportation planning process; data collection and demand analysis; trip generation, trip distribution, modal split and route assignment; forecasting travel patterns. Design of transportation facilities: street sections, intersections, and parking areas. Computer applications and design projects. Lectures: three hours per week. Tutorial: two hours per week, alternate weeks.

CIVI 483 ***Hydrology*** (3 credits)
Prerequisite: CIVI 381. Weather elements; precipitation, stage-discharge relations; evapo-transpiration; ground-water flow; stream-flow hydrography, unit hydrography, synthetic hydrographs; laminar flow; hydrologic routing; instantaneous hydrograph; hydraulic routing, method of characteristics, kinematic routing; statistical analysis, confidence intervals, stochastic generator, autoregressive model; applications of hydrology. Lectures: three hours per week. Tutorial: two hours per week.

CIVI 484 ***Hydraulic Engineering*** (3.5 credits)
Prerequisite: CIVI 381. Development of surface water resource; basic measurements in hydraulic engineering; storage reservoirs; practical problems; run-off characteristics of natural steams; probabilistic models; control structures; economic analysis; production function; project optimization; energy dissipators; sediment transportation; elements of river engineering; navigation; control of floods; computer modelling application. Design examples. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

CIVI 490 ***Capstone Civil Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in BEng (Civil) including ENGR 301; CIVI 361, 390; BCEE 344, 345. The project of each team will encompass the integrated design of at least two sub-disciplines of civil engineering to achieve high performance at reasonable cost. Through case studies and literature survey, students learn the information gathering and decision/design process, problem resolution, and aspects related to management, teamwork, and communication. Students registering for this course must contact the course coordinator for the detailed procedure. Lectures: two hours per week, two terms.
NOTE: Students will work in groups under direct supervision of a faculty member.

CIVI 498 ***Topics in Civil Engineering*** (3 credits)
Prerequisite: Permission of the Department. This course may be offered in a given year upon the recommendation of the Department and approval of GCS Council. The course content may vary from offering to offering and will be chosen to complement the available elective courses. Lectures: three hours per week.

COMPUTER ENGINEERING

COEN 212 ***Digital Systems Design I*** (3.5 credits)
Prerequisite: MATH 204 (Cegep Mathematics 105). Modulo arithmetic: representations of numbers in binary, octal and hexadecimal formats; binary arithmetic. Boolean algebra; theorems and properties, functions, canonical and standard forms. Logic gates and their use in the realization of Boolean algebra statements; logic minimization, multiple output circuits. Designing with MSI and LSI chips, decoders, multiplexers, adders, multipliers, programmable logic devices. Introduction to sequential circuits; flip-flops. Completely specified sequential machines. Machine equivalence and minimization. Implementation of clock mode sequential circuits. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for COEN 312 may not take this course for credit.

COEN 231 ***Introduction to Discrete Mathematics*** (3 credits)
Prerequisite: MATH 204 (Cegep Mathematics 105). Fundamentals of logic: basic connectives and truth tables; logical equivalence; the laws of logic; logical implication; rules of inference; the use of quantifiers; proofs of theorems. Sets: the laws of set theory. Boolean algebra. Relation of Boolean algebra to logical and set theoretic operations. Modulo arithmetic: division algorithm. Induction and recursion: induction on natural numbers; recursive definitions. Functions and relations: cartesian products and relations; functions; function composition and inverse functions; equivalence relations. Elements of graph theory: basic definitions of graph theory; paths, reachability and connectedness; computing paths from their matrix representation; traversing graphs represented as adjacency lists; trees and spanning trees. Finite-state machines (FSM) deterministic and nondeterministic machines; regular languages; FSM with output; composition of FSM. Lectures: three hours per week. Tutorial: one hour per week.

COEN 243 ***Programming Methodology I*** (3 credits)
Prerequisite: MATH 204 (Cegep Mathematics 105). This course is an introduction to computer hardware and software, programming and programming paradigms; essential procedural programming languages: key elements; reserved words and identifiers; data types and declarations; statements; arithmetic expressions; different modes of execution. The course covers flow control using If-Else and Switch statements, repetition using loops, recursive functions, pointers, references and dynamic data structures and function pointer. The course material also includes Lambda expression, data structures, built-in arrays, template arrays and vectors, n-dimensional vectors, sorting and searching. Students learn object-oriented programming, user-defined classes, class attributes and methods, object creation, use and destruction. Students are also introducted to exception handling and UML class diagrams. Lectures: three hours per week. Tutorial: two hours per week.
NOTE: Students who have received credit for COMP 248, MIAE 215 or MECH 215 may not take this course for credit.

COEN 244 ***Programming Methodology II*** (3 credits)
Prerequisite: COEN 243 or MECH 215 or MIAE 215. This course covers advanced topics in computer programming. The course reviews object-oriented programming and further concepts, and revisits pointers. The following topics are covered: operator overloading (regular and advanced usage), fundamentals of file and stream processing. The course also covers class composition

and inheritance (regular and advanced usage), virtual functions, polymorphism, static and dynamic binding and abstract classes. A case study of a small-scale object-oriented project along with simplified analysis, design and implementation are discussed. Other topics in the course include files and streams, exception handling (advanced usage), templates (class templates, template instantiation and type binding), sequence containers and STL algorithms, UML modelling and an introduction to open software repository. Lectures: three hours per week. Tutorial: two hours per week.
NOTE: Students who have received credit for COMP 249 may not take this course for credit.

COEN 311 ***Computer Organization and Software*** (3.5 credits)
Prerequisite: COEN 212, 243. Introduction and terminology. Review of data representation and arithmetic. Floating-point representation and arithmetic. Functional units: CPU, memory, I/O, computer operation. Machine programming fundamentals: instruction structure, addressing modes, the assembly process, examples of architectures. Case study of a microprocessor architecture: programming model, assembler and addressing modes, instruction set and formats; programming examples. Stacks, subroutines, macros, exceptions, interrupts. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

COEN 313 ***Digital Systems Design II*** (3.5 credits)
Prerequisite: COEN 212, 231. Two-level and multi-level logic optimization techniques. Hardware description languages (VHDL) for synthesis and simulation. Asynchronous design. Algorithmic state machines. Clocking and clock skew. Metastability. Self-timed concepts. Finite state machine (FSM) optimization. State reduction. FSM partitioning. Programmable logic devices and field programmable gate arrays. Data path and control design for processors. Testing issues. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

COEN 315 ***Digital Electronics*** (3.5 credits)
Prerequisite: ELEC 311. Analysis and simulation of basic digital circuit blocks, in particular, CMOS, BiCMOS and ECL technologies. The focus is on the electronics aspect of digital circuits. Combinational and sequential circuit units, including logic gates, flip-flops, signal generators, static and dynamic memories, and interconnections. Performance analysis in terms of switching speeds, power dissipation, noise immunity, fan-in and fan-out. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

COEN 316 ***Computer Architecture and Design*** (3.5 credits)
Prerequisite: COEN 311, 313. Review of basic computer architecture designs. Fundamentals of computer design and performance. Cost issues. Instruction set design principles. Memory hierarchies: registers, caches, and virtual memories. Basic processor implementation issues. High performance computing issues such as pipelining, superscalar, and vector processing. Input/output subsystem designs. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

COEN 317 ***Microprocessor-Based Systems*** (3.5 credits)
Prerequisite: COEN 311 or COMP 228 or SOEN 228; COEN 313. This course covers the following topics: introduction to microprocessor interfacing; bus functions, bus interconnections, synchronous and asynchronous bus; signal flow, data transfer and memory Interfacing; parallel, serial, high-speed, analog interfacing; secure Digital Card Interface; the interrupt system; bus arbitration and DMA; data Acquisition Systems Network Interfacing. Lectures: three hours per week. Tutorials: one hour per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for COEN 417 may not take this course for credit.

COEN 320 ***Introduction to Real-Time Systems*** (3 credits)
Prerequisite: COEN 346 or COMP 346. Fundamentals of real-time systems: definitions, requirements, design issues and applications. Real-time operating systems (RTOS) feature: multi-tasking, process management, scheduling, interprocess communication and synchronization, real-time memory management, clocks and timers, interrupt and exception handling, message queues, asynchronous input/output. Concurrent programming languages: design issues and examples, POSIX threads and semaphores. Introduction to real-time uniprocessor scheduling policies: static vs. dynamic, pre-emptive vs. non-pre-emptive, specific techniques — rate-monotonic algorithm, earliest-deadline-first, deadline monotonic, least-laxity-time-first; clock-driven scheduling. Design and specification techniques — Finite state machine based State-chart, Dataflow diagram, Petri nets. Reliability and fault-tolerance. Case studies of RTOS — QNX, VxWorks, and research prototypes. Lectures: three hours per week. Tutorial: one hour per week.

COEN 345 ***Software Testing and Validation*** (3.5 credits)
Prerequisite: SOEN 341. Overview of the three phases and deliverables of a project. Validation vs. verification, reviews, walkthrough. Testing: acceptance testing, integration testing, module testing. Writing stubs. Performance testing. Role of formal methods. Code inspection. Defect tracking. Causality analysis. Software Metrics and quality management. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

COEN 346 ***Operating Systems*** (3.5 credits)
Prerequisite: COEN 311; COMP 352 or COEN 352. The evolution, architecture, and use of modern operating systems (OS). Multi-tasking, concurrency and synchronization, IPC, deadlock, resource allocation, scheduling, multi-threaded programming, memory and storage managements, file systems, I/O techniques, buffering, protection and security, the client/server paradigm and communications. Introduction to real time operating systems. Students write substantial programs dealing with concurrency and synchronization in a multi-tasking environment. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for COMP 346 may not take this course for credit.

COEN 352 ***Data Structures and Algorithms*** (3 credits)
Prerequisite: COEN 231, 244. Mathematical introduction: mathematical induction, program analysis, and algorithm complexity. Fundamental data structures: lists, stacks, queues, and trees. Fundamental algorithms: hashing and sorting. Graph structures and algorithms. Overview of algorithm design techniques, including greedy algorithms, divide and conquer strategies, recursive and backtracking algorithms, and heuristics. Application of data structures and algorithms to engineering. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for COMP 352 may not take this course for credit.

COEN 390 ***Computer Engineering Product Design Project*** (3 credits)
Prerequisite: Minimum of 45 credits in BEng (Computer); COEN 311, 352; ENGR 290. The Product Design Project reinforces skills introduced in ENGR 290, which include teamwork, project management, engineering design for a complex problem, technical writing, and technical presentation in a team environment. It also introduces students to product development. Students are assigned to teams and each team develops, defines, designs and builds a system and/or device under broad constraints set by the Department. Students present their product definition and design, and demonstrate that their system/device works at the end of the term. Tutorial: two hours per week. Equivalent laboratory time: six hours per week.
NOTE: All written documentation must follow the Concordia Form and Style guide. Students are responsible for obtaining this document before beginning the project.

COEN 413 ***Hardware Functional Verification*** (3 credits)
Prerequisite: COEN 313. Review of hardware design languages. Introduction to functional verification. Design for verification. Writing test benches, simulation engines, and coverage metrics. Introduction to verification languages. Verification plan: strategies, test cases, test benches. Modelling verification environments. Modelling input relations, intervals, events. Introduction to formal verification tools. Lectures: three hours per week.

COEN 421 ***Embedded Systems Design*** (4 credits)
Prerequisite: COEN 317, 320; SOEN 341. Embedded systems, foundations for cyber-physical systems design. Embedded HW architectures, sensors, actuators, processors. IO and peripherals, memory architectures, interfacing memory and peripheral. Hardware-software partitioning, software transformations, floating to fixed point conversion, loop transformations, code compaction, low-power design and embedded system testing. Lectures: three hours per week. Laboratory: 30 hours total.

COEN 422 ***Cyber-Physical Systems*** (3 credits)
Prerequisite: COEN 320; ELEC 372. Models of computation for cyber-physical systems. Models for computation and physical systems. Discrete event dynamic models, finite-state machines (FSMs). Extended FSMs, statecharts, petri nets. Continuous variable models. Scheduling and optimization of process networks, hybrid models. Specification, simulation and performance analysis of cyber-physical systems. Relationship of program execution with physical time constants. Lectures: three hours per week.

COEN 424 ***Programming on the Cloud*** (3 credits)
Prerequisite: COEN 346. Autonomy of cloud computing, service and business models, data centres and virtualization. CAP theorem, REST API and data models. Map reduce and programming model of distributed data processing on computer clusters. Distributed file systems for computer clusters, development environments and tools on clouds. Cloud-based data access and query. Cloud application design principles. Lectures: three hours per week.

COEN 432 ***Applied Evolutionary and Learning Algorithms*** (3 credits)
Prerequisite: COEN 352 or COMP 352. Heuristic learning algorithms applied to real-world problems of design, classification, prediction and abstraction. Genetic algorithms, genetic programming, evolutionary strategies, generative and developmental systems, artificial life approaches, swarm intelligence, self-modifying programs, tabu search, simulated annealing and support vector machines, introduction to deep learning architectures. Examples of practical applications and challenges focused on biological and biomedical engineering. Lectures: three hours per week.

COEN 433 ***(also listed as BIOL 475)***
Biological Computing and Synthetic Biology (3 credits)
Prerequisite: COEN 212, 244. Introduction to the cell and the genome. Foundations of synthetic biology and ethics. Synthetic genomes and metabolic engineering. Model organisms, such as E. coli bacteria and synthetic cells, self-replicating cells man-made from cloned genes, a cellular membrane and the basic elements of RNA and protein synthesis. Designing computational devices for implementation in biological cells. Introduction to modelling and computer simulation of gene regulatory networks. Methods of building and testing gene regulatory networks within and without cells. Expanding functionality via inter-cellular signaling. Basic interfacing to electronic sensors and actuators. Landmark and interesting applications of synthetic biology in computer engineering and other disciplines. Lectures: three hours per week.
NOTE: Students who have received credit for BIOL 475 or for this topic under a BIOL 498 number may not take this course for credit.

COEN 434 ***(also listed as BIOL 476)***
Microfluidic Devices for Synthetic Biology (3 credits)
Prerequisite: COEN 244 and ENGR 290; or BIOL 261 and COMP 249. This course introduces students to microfluidic components (pumps, valves, automation) programming microfluidics, paradigms, and applications for chemical and biological analysis. Introduction to synthetic biology; biological parts and their properties, network structure and pathway engineering, synthetic networks, manipulating DNA and measuring responses, basic behaviour of genetic circuits, building complex genetic networks; integration of microfluidics and synthetic biology; economic implications. Lectures: three hours per week.
NOTE: Students who have received credit for BIOL 476 or for this topic under a BIOL 498 number may not take this course for credit.

COEN 445 ***Communication Networks and Protocols*** (3.5 credits)
Prerequisite: COEN 346. Communications protocols basics, flow control, error detection and error control techniques. Network topologies including local area networks (LANs) and wide area networks (WANs). Layered architecture standards (OSI and TCP/IP) and protocols. Internetworking. Application and socket programming. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for ELEC 463 may not take this course for credit.

COEN 446 ***Internet of Things*** (3 credits)
Prerequisite: COEN 445 or ELEC 463. From internet and devices to internet of things (IoT), business models and applications including health monitoring and smart cities. Devices and their connection including wireless sensor networks (WSN). Constraints and requirements. Network access protocols, routing protocols (RPL), transport layer and message queuing telemetry transport (MQTT). Constrained application protocol (CoAP) and efficient XML interchange (EXI). Protocol stack and contrast with internet stack. Security threats. Introduction to IoT analytics. Platforms and tools. Lectures: three hours per week.

COEN 447 ***Software-Defined Networking*** (3 credits)
Prerequisite: COEN 317; COEN 445 or ELEC 463. Control and data planes, centralized vs. distributed control. Network operating systems, network function virtualization. Programmable data planes, network processors, programmable switch pipelines. High-level data-plane programming with P4 and data plane development kit. Software-defined network emulation project. Lectures: three hours per week.

COEN 451 ***VLSI Circuit Design*** (4 credits)
Prerequisite: COEN 212; ELEC 311. Analysis and design of electronic circuits using Very Large Scale Integration (VLSI) technologies. Physical design of MOS digital circuits. CMOS circuit schematic and layout. CMOS processing technology, design rules and CAD issues. Physical layers and parasitic elements of CMOS circuits. Characterization and performance evaluation. Constraints on speed, power dissipation and silicon space consumption. Design and implementation of CMOS logic structures, interconnections and I/O structures. Circuit design project using a specified CMOS technology. Lectures: three hours per week. Laboratory: 30 hours total.

COEN 490 ***Capstone Computer Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in BEng (Computer) or permission of the Department; ENGR 301, 371; COEN 390; SOEN 341. Students are assigned to groups, and work together under faculty supervision to solve a complex interdisciplinary design problem — typically involving communications, control systems, electromagnetics, power electronics, software design, and/or hardware design. The project fosters teamwork between group members and allows students to develop their project management, technical writing, and technical presentation skills. Tutorial: one hour per week, two terms. Equivalent laboratory time: four hours per week, two terms.
NOTE: All written documentation must follow the Concordia Form and Style guide. Students are responsible for obtaining this document before beginning the project.

COEN 498 ***Topics in Computer Engineering*** (3 credits)
Prerequisite: Permission of the Department. The course, when offered, will include topics which complement elective courses in computer engineering and computer science. Lectures: three hours per week.

ELECTRICAL ENGINEERING

ELEC 242 ***Continuous-Time Signals and Systems*** (3 credits)
Prerequisite: ELEC 273; ENGR 213. Continuous-time signals. Properties of continuous-time systems. Linear Time Invariant (LTI) systems. Impulse response and convolution. Systems based on linear constant-coefficient differential equations. Fourier series representation of periodic signals. The Fourier transform representation of signals and systems. Inverse Fourier transform. Laplace Transform. Inverse Laplace Transform. Unilateral Laplace Transform. Natural and forced responses of linear differential equations. Transfer function and block diagram representation of LTI systems. Time and frequency domain characteristics of ideal and non-ideal filters. Amplitude modulation and demodulation. Lectures: three hours per week. Tutorial: two hours per week.
NOTE: Students who have received credit for ELEC 264 may not take this course for credit.

ELEC 251 ***Fundamentals of Applied Electromagnetics*** (3 credits)
Prerequisite: ELEC 273 or ENGR 273; ENGR 233 previously or concurrently. Electric charge, Coulomb's law, electrostatic forces, electric field, Gauss' law, electric potential, stored energy. Dielectrics, properties of materials in electric fields. Electric current, conduction in a vacuum and in material media, displacement current, magnetic field of a current, force on a current-carrying wire, magnetic induction, electromotive force, energy stored in a magnetic field. Magnetism in material media, magnetic circuits. Time-varying fields. Capacitance, resistance, inductance, elements of electric circuits. Lectures: three hours per week. Tutorial: one hour per week.

ELEC 273 ***Basic Circuit Analysis*** (3.5 credits)
Prerequisite: ENGR 213 previously or concurrently; PHYS 205. Units: current, voltage, power, and energy. Elementary wave-forms. Time averages. Ohm's law. KVL and KCL. Ideal sources. Mesh and node analysis of resistive circuits. Network theorems. Inductors and capacitors and their response to the application of elementary waveforms. Transient response of simple circuits. Natural frequency and damping. Initial conditions. Steady state AC analysis: resonance, impedance, power factor. Delta and Y connections. Ideal operational amplifiers. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: 15 hours total.

ELEC 275 ***Principles of Electrical Engineering*** (3.5 credits)
Prerequisite: ENGR 213 previously or concurrently; PHYS 205. Fundamentals of electric circuits: Kirchoff's laws, voltage and current sources, Ohm's law, series and parallel circuits. Nodal and mesh analysis of DC circuits. Superposition theorem, Thevenin and Norton Equivalents. Use of operational amplifiers. Transient analysis of simple RC, RL and RLC circuits. Steady state analysis: Phasors and impedances, power and power factor. Single and three phase circuits. Magnetic circuits and transformers. Power generation and distribution. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: 15 hours total.

ELEC 311 ***Electronics I*** (3.5 credits)
Prerequisite: ELEC 273. Diodes: terminal characteristics of junction diodes; analysis of diode circuits; the small signal model and its application; operation in the reverse-breakdown region — Zener diodes; rectifiers, limiting and clamping circuits. Principle of signal amplification: small signal models; linearity; loading effects; cascaded amplifiers. MOSFETs: structure and physical operation; current-voltage characteristics; MOSFET as switch, DC analysis; biasing considerations; small signal analysis, models and parameters; three basic configurations: common gate, common source, common drain, or amplification. Overview of BJT circuits: structure and physical operation of BJT; DC analysis; biasing considerations: small signal analysis and parameters; basic configurations for amplification. PSPICE: laboratory pre-labs and extensive simulation exercises. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: 15 hours total.

ELEC 312 ***Electronics II*** (3.5 credits)
Prerequisite: ELEC 311; ELEC 242 or 364. Differential and multi-stage amplifiers: differential pair; differential gain; common-mode gain and common-mode rejection ratio (CMRR) current mirrors. High frequency models: s-domain analysis, transfer functions; common gate, common source, common drain configurations; common base, common emitter, common collector configurations; wide-band amplifiers. Feedback: general feedback structure; properties of negative feedback; the four basic feedback configurations; loop gain and stability problems. Power amplifiers: classification and output stages; class A, B, C, and AB amplifiers; biasing the class AB amplifier. Introduction to filters, tuned amplifiers, oscillators and mixers. PSPICE: Laboratory pre-labs and extensive simulation exercises. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

ELEC 321 ***Introduction to Semiconductor Materials and Devices*** (3.5 credits)
Prerequisite: CHEM 205; ENGR 213. Fundamentals underlying optical and electronic devices. The structure and growth of crystals. The energy band model for elemental and compound semiconductors. Electronic and optical properties of semiconductors. Electroluminescence and photoluminescence. The semiconductor in equilibrium. Carrier transport and non-equilibrium phenomena. Introductions to junctions and devices. The laboratory demonstrates the basic electrical and optical properties of semiconductor materials. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

ELEC 331 ***Fundamentals of Electrical Power Engineering*** (3.5 credits)
Prerequisite: ELEC 251, 273. Review of fundamentals of AC circuit analysis. Overview of power systems. Three-phase circuits: balanced three-phase circuits with star and delta connected loads, power measurements. Magnetic circuits. Transformers. Power conversion techniques: single phase AC/DC rectifiers, DC/DC choppers and DC/AC converters. DC machines: Operating principle, separately excited DC motor, torque speed characteristics and control methods using rectifiers and choppers. Induction machines: Theory of three-phase induction machines, equivalent circuit parameters, efficiency, torque speed characteristics and control methods using inverters. Overview of power distribution systems. Safety codes. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.

ELEC 342 ***Discrete-Time Signals and Systems*** (3.5 credits)
Prerequisite: ELEC 242 or 264. Discrete vs. continuous-time signals. Properties of discrete-time systems. Linear Time Invariant (LTI) systems. Unit impulse response and convolution. Systems based on linear constant-coefficient difference equations. Discrete Fourier series. The Fourier transform representation of signals and systems. Inverse Fourier transform. Sampling of continuous-time signals. Reconstruction of a signal from its samples. Discrete-time processing of continuous-time signals. Quantization. The Z-Transform and inverse Z-Transform. Unilateral Z-Transform. Transfer function and block diagram representation of LTI systems. Basic structures for Finite-Impulse-Response and Infinite-Impulse-Response filters. Computer-based MATLAB simulation. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for ELEC 364 may not take this course for credit.

ELEC 351 ***Electromagnetic Waves and Guiding Structures*** (3 credits)
Prerequisite: ELEC 251, 242; ENGR 233. This course covers the following topics: partial differential equations, Maxwell's equations; differential forms of the laws of electromagnetism; boundary conditions; power and energy; uniform plane waves; transmission line theory; rectangular waveguides; antennas. Lectures: three hours per week. Tutorial: one hour per week.

ELEC 365 ***Complex Variables and Partial Differential Equations*** (3 credits)
Prerequisite: ENGR 213, 233. Review of complex arithmetic. Analytic functions. Taylor and Laurent series. Residue theory. Fourier series. Partial differential equations. Applications to Laplace, heat, and wave equations. Bessel and Legendre functions. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for ELEC 261 or 362 may not take this course for credit.

ELEC 367 ***Introduction to Digital Communications*** (3.5 credits)
Prerequisite: ELEC 342 or 364; ENGR 371. Analog communications and frequency multiplexing; pulse-code-modulation and time multiplexing; additive white Gaussian noise; matched filter and correlator receiver; maximum likelihood receiver and

error probability; intersymbol interference, pulse shaping filter; Signal Space Analysis; Union Bound on the probability of error; Pass-band communication Systems; coherent and non-coherent communication systems. Introduction to synchronization. Lectures: three hours per week. Laboratory: 15 hours total. Tutorial: one hour per week.
NOTE: Students who have received credit for ELEC 462 may not take this course for credit.

ELEC 372 ***Fundamentals of Control Systems*** (3.5 credits)
Prerequisite: ELEC 242 or 364. Mathematical models of control systems. Characteristics, performance, and stability of linear feedback control systems. Root-locus methods. Frequency response methods. Stability in the frequency domain. Design and compensation of feedback control systems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for AERO 371 or ENGR 372 or MECH 371 may not take this course for credit.

ELEC 390 ***Electrical Engineering Product Design Project*** (3 credits)
Prerequisite: Minimum of 45 credits in BEng (Electrical); COEN 352; ELEC 311; ENGR 290. The Product Design Project reinforces skills introduced in ENGR 290, which include teamwork, project management, engineering design for a complex problem, technical writing, and technical presentation in a team environment. It also introduces students to product development. Students are assigned to teams and each team develops, defines, designs and builds a system and/or device under broad constraints set by the Department. Students present their product definition and design, and demonstrate that their system/device works at the end of the term. Tutorial: two hours per week. Equivalent laboratory time: six hours per week.
NOTE: All written documentation must follow the Concordia Form and Style guide. Students are responsible for obtaining this document before beginning the project.

ELEC 413 ***Mixed-Signal VLSI for Communication Systems*** (4 credits)
Prerequisite: ELEC 312, 372. Overview of wireline communication links, mechanisms of signal degradation, modulation formats, TX/RX synchronization options, IC technology limitations, transmitter front-end circuits, receiver front-end circuits, decision circuits, clock and data recovery systems, phase-locked loops, jitter, continuous-time and discrete-time equalizers, system metrics. Lectures: three hours per week. Laboratory: 30 hours total.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 421 ***Solid State Devices*** (3.5 credits)
Prerequisite: ELEC 321. Junction theory (PN junctions, Schottky and ohmic contacts, hetero-junctions). Structures and characteristics of diodes, solar cells, bipolar transistors, and fundamentals of MOSFETs. Planar silicon junctions and transistors will be designed, fabricated and evaluated in the laboratory, including resistivity measurements, semiconductor cleaning, oxidation, diffusion, photolithography, etching, metallization, and comparison of design with experimental results. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 422 ***Design of Integrated Circuit Components*** (3.5 credits)
Prerequisite: ELEC 421. Structures, characteristics and design of MOS capacitors and MOSFETs. FinFETs, SOI FETs, velocity-modulation transistors, and HFETs. Role of strain in operation of modern FETs. Planar MOS devices, including capacitors and MOSFETs will be designed, fabricated, and evaluated in the laboratory. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 423 ***Introduction to Analog VLSI*** (4 credits)
Prerequisite: ELEC 312. CMOS transistor layout considerations, design rules, circuit extraction. MOSFET modelling, I-V equations, AC equivalent circuits for high-frequency operation, computer-based simulation. Analysis and design of small-scale integrated circuit building blocks including MOS switch, active resistor, current source, current mirror, voltage amplifiers, voltage-reference circuits, multipliers. Analysis and design of medium-scale integrated circuit building blocks including op-amps, fully-differential op-amp and common mode feedback circuits, transconductance amplifiers, transimpedance amplifiers, comparators. Noise analysis. Mismatch analysis and modelling, offset removal techniques. Analog VLSI system examples. Lectures: three hours per week. Laboratory: 30 hours total.

ELEC 424 ***VLSI Process Technology*** (3.5 credits)
Prerequisite: ELEC 311, 321. Introduction to basic VLSI technologies; crystal growth, thermal oxidation, diffusion, ion implantation, chemical vapour deposition, wet and dry etching, and lithography. Layout, yield, and VLSI process integration. The lab demonstrates a semiconductor device fabrication process. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 425 ***Optical Devices for High-Speed Communications*** (3.5 credits)
Prerequisite: ELEC 321, 351. Optical properties of semiconductors. Fundamental principles for understanding and applying optical fibre technology. Fundamental behaviour of the individual optical components and their interactions with other devices. Lasers, LEDs, optical fibres, light detectors, optical switches. Concepts of WDM and DWDM. Components required for WDM and DWDM. A comprehensive treatment of the underlying physics: noise and distortion in optical communications, light polarization, modulation and attenuation. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 430 ***Electrical Power Equipment*** (3.5 credits)
Prerequisite : ELEC 331. Components of a transmission system. Transmission line; modelling and parameters. Transformers: equivalent circuits, losses, connections and protection. Breakers: operation and design. Compensation equipment: capacitors, inductors, series and shunt connections. Insulation coordination. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: This course is usually offered in the French language.

ELEC 431 ***Electrical Power Systems*** (3.5 credits)
Prerequisite: ELEC 331. Inductance, capacitance, resistance of polyphase transmission lines; current and voltage relations of transmission lines; load flow studies; symmetrical and unsymmetrical faults; power system stability. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 432 ***Control of Electrical Power Conversion Systems*** (3.5 credits)
Prerequisite: ELEC 331, 372. Basic considerations and control requirements. Control system principles and structures. Controller characteristics and operation. Static power conversion systems. Electromechanical systems and electrical machine modelling. Control system design. Applications to electric motor drives and typical power conversion systems. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: This course is usually offered in the French language.

ELEC 433 ***Power Electronics*** (3.5 credits)
Prerequisite: ELEC 311, 331. Review of basic electrical concepts. Power electronic systems. Power semiconductor switches. AC controllers. Line frequency AC-DC converters: diodes and thyristor circuits. DC-DC converters. DC-AC converters. Utility applications: STATCOM and power electronic interfaces. Industrial and utility applications. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 434 ***Behaviour of Power Systems*** (3.5 credits)
Prerequisite: ELEC 331. Introduction: classification of phenomena, structure of power systems. Review of component models: lines, transformers, electrical machines and load. Excitation systems of machines. Steady-state operation. Transient stability, voltage stability and small signal stability. Compensation methods: stabilizer, series and shunt compensators. Sub-synchronous resonances. Transient electromagnetic phenomena. Methods and tools for numerical simulation. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: This course is usually offered in the French language.

ELEC 435 ***Electromechanical Energy Conversion Systems*** (3.5 credits)
Prerequisite: ELEC 331. Lumped parameter concepts of electromechanics. Energy, co-energy in the derivation of torques and forces. Examples of electric machines: dc, synchronous and induction types. Steady-state, transient and stability analysis. Power electronic controllers. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 436 ***Protection of Power Systems*** (3.5 credits)
Prerequisite: ELEC 331. General aspects of protection systems. Measurement transformers. Grounding. Overcurrent and ground fault protection. Protection of transformers, shunt capacitors and buses. Protection of transmission lines. Telecommunication for protection and automation systems. Protection of inverters. Protection of distribution networks. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: This course is usually offered in the French language.

ELEC 437 ***Renewable Energy Systems*** (3 credits)
Prerequisite: ELEC 331. Electrical basics and models of solar energy (photo-voltaics), electrical power from wind energy, electrical power from water, including wave energy, tidal energy, micro-hydro. Case studies, for example the application of solar PV to street lighting. Electrical engineering design implications. Design assignments. Lectures: three hours per week.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 438 ***Industrial Electrical Systems*** (3.5 credits)
Prerequisite: ELEC 331. Structures of industrial power systems. Voltage levels. Electric installations, codes and standards. Short-circuits, protection and coordination. Grounding. Power quality. Power factor, tariffs and energy management. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: This course is usually offered in the French language.

ELEC 439 ***Hybrid Electric Vehicle Power System Design and Control*** (3 credits)
Prerequisite: ELEC 331. Introduction to Electric Vehicles (EV), Hybrid Electric Vehicles (HEV). Vehicle design fundamentals. Traction motors for EV/HEV propulsion. On-board energy sources and storage devices: high-voltage traction batteries, fuel cells, ultra-capacitors, flywheels. Power electronic converters and control. Various EV/HEV/Fuel Cell Vehicle topologies and modelling. Energy management strategies. Practical design considerations. Engineering impact of electric, hybrid electric, and fuel cell vehicles. Lectures: three hours per week.

ELEC 440 ***Controlled Electric Drives*** (3.5 credits)
Prerequisite: ELEC 331, 372. Elements of a drive system, characteristics of common mechanical systems, drive characteristics, operation in one, two, or four quadrants. Fully controlled rectifier drives, braking of DC motors, control of DC motors using DC/DC converters. Control of polyphase induction motors, voltage-source and current-source inverter drives, frequency-controlled induction motor drives, introduction to vector control of induction motor drives, field oriented control, sensor-less operation. Control of synchronous motors, permanent magnet motors. Switched reluctance motor drives, stepper motors. Brushless DC motor drives, low-power electronic motor drives. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 441 ***Modern Analog Filter Design*** (3.5 credits)
Prerequisite: ELEC 342 or 364. Review of network analysis. Magnitude and frequency scaling. Magnitude and phase approximation in synthesis of filter functions. Second-order active RC filters. Synthesis of all-pole LC ladder filters. Second-order switched-capacitor filters. Realization of high-order active filters. Current mode filters. Switched-current filters. Integrated circuit filters. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 442 ***Digital Signal Processing*** (3.5 credits)
Prerequisite: ELEC 342 or 364; ENGR 371. Review of Z-transform; linear phase and non-linear phase systems; all-pass and minimum phase systems, recursive and non-recursive digital filters; common digital filter structures, common design approaches for digital filters; description of typical Digital Signal Processor chips; Review of sampling, reconstruction, interpolation and decimation; changing the sampling rate by integer and non-integer factor; multirate signal processing, polyphase decomposition, multirate filter banks; digital processing of analog signals, A/D and D/A converters; discrete Fourier transform; random signals, Least-Mean-Square (LMS) filters. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 443 ***Electric Power Distribution Networks*** (3 credits)
Prerequisite: ELEC 331. This course covers the following topics: fundamentals of distribution systems; overhead lines and cables, physical characteristics; neutral network; distribution protection; protection coordination, equipment failures; service continuity, norms, fault duration and damage; network architectures; distributed generation, network integration; power quality, connection requirements, harmonics, voltage sag, flicker; distribution network analysis software, unbalanced power flow, faulted operation. Lectures: three hours per week. Laboratory: 12 hours total.
NOTE: This course is usually offered in the French language.

ELEC 444 ***Medical Image Processing*** (3 credits)
Prerequisite: ELEC 342 or 364. Principles and techniques used in the processing and analysis of medical images. Image quality metrics, denoising medical images, quantification, rigid and deformable registration. Similarity metrics such as mutual information (MI). Images from the most common medical imaging modalities (X-ray, CT, MRI and ultrasound) will be used. Lectures: three hours per week.

ELEC 445 ***Biological Signal Processing*** (3 credits)
Prerequisite: ELEC 442. This course covers signal processing through discussion of current bioengineering activities which rely on signal processing and include assessment of neural function with simultaneous collection of electroencephalogram (EEG) and functional MRI data; the non-invasive assessment of cardiac autonomic regulation using electrocardiography; assessment of neural function using near-infrared spectroscopy (NIRS); assessment of muscle activity using electromyography (EMG). Topics include modern spectral analysis, time-frequency analysis (short-time Fourier transforms and wavelets); signal modelling; multivariate analyses and adaptive filtering. Lectures: three hours per week.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 446 ***Electrical Power Generation*** (3 credits)
Prerequisite: ELEC 431. This course covers the following topics: primary energy resources, conventional and renewable; electric power generation principles; rotating and static power conversion, frequency and voltage control; synchronous generators, design and operation; generation control; static power converter interfaces, principles and operation; wind energy conversion principles, generator control and wind farm control; energy storage control and integration; generation protection; distributed generation interconnection requirements. Lectures: three hours per week. Laboratory: nine hours total.

ELEC 453 ***Microwave Engineering*** (3.5 credits)
Prerequisite: ELEC 351. Properties of waveguides, striplines, and microstrips. Scattering parameters. Butterworth and Chebyshev impedance transformers. Microwave couplers, cavities, and Fabry-Perot resonators. Periodic structures. Microwave filter design. Faraday rotation and non-reciprocal devices. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 455 ***Acoustics*** (3 credits)
Prerequisite: ELEC 351. Sound generation and propagation in elastic media; conversion between acoustical, electrical, and mechanical energy. Lumped-parameter approximations, sound in rooms, underwater acoustics, microphones; loudspeakers and audio communications problems; noise and vibration control problems. Lectures: three hours per week.

ELEC 456 ***Antennas*** (3.5 credits)
Prerequisite: ELEC 351. Antenna fundamentals and definitions. Radiation integrals. Dipoles and loops. Arrays. Antenna self and mutual impedance. Matching techniques. Travelling wave antennas. Broadband antennas. Equivalence principle. Aperture antennas. Antenna measurement techniques. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 457 ***Design of Wireless RF Systems*** (3 credits)
Prerequisite: ELEC 453. Introduction to wireless systems. Noise and distortion in microwave systems. Antennas and propagation. Amplifiers. Mixers. Transistor oscillators and frequency synthesizers. Modulation techniques. Receiver design. Use of RF CAD tools. Lectures: three hours per week.

ELEC 458 ***Techniques in Electromagnetic Compatibility*** (3 credits)
Prerequisite: ELEC 351. Introduction to EMC procedures, control plans, and specifications. Radiated and conducted susceptibility and emission testing. Introduction to EMC antennas, antenna concepts, electric and magnetic dipoles, biconical dipoles, conical

log spiral antennas, setting up fields for susceptibility testing, measuring radiation from equipment. Coupled transmission lines, pulse propagation, closely spaced parallel transmission lines, capacitive coupling, inductive coupling, shielding against magnetic fields. Shielding and enclosures, electric and magnetic field screening mechanisms, shielding effectiveness, grounding considerations. EMC test facilities, screened rooms, TEM cells, signals and spectra, intermodulation, cross-modulation, the spectrum analyzer. Noise and pseudo-random noise, noise performance of measurement/receiving systems, noise equivalent bandwidth, noise figure, antenna noise temperature and S/N ratio. Lectures: three hours per week.

ELEC 463 ***Telecommunication Networks*** (3.5 credits)
Prerequisite: COEN 352; ELEC 342 or 364; ENGR 371. This course covers the following topics: communication networks and services; introduction to layered network architectures; transmission systems and the telephone network, including multiplexing, circuit switches, routing and signalling; peer-to-peer protocols including ARQ protocols, data-link controls, packet multiplexing; multiple access communications including Aloha, CSMA, reservation schemes, polling, token-passing ring, LAN standards, LAN bridges; packet-switching networks including datagrams and virtual circuits; TCP/IP architecture including Internet protocol, transmission control protocol. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for COEN 445 may not take this course for credit.

ELEC 464 ***Wireless Communications*** (3 credits)
Prerequisite: ELEC 367. Introduction to error control coding: linear block codes, syndrome-based decoding, coding vs. modulation, convolutional codes, Viterbi decoder. Communications link analysis. Introduction to cellular systems: frequency reuse, trunking and grade of services, sectoring and cell splitting, coverage and capacity. Modulation techniques for mobile communications. Mobile radio channels. Spread-spectrum techniques. Multiplexing and multiple access techniques. Wireless standards from first generation to fourth generation; OFDM: an architecture for the fourth generation. Lectures: three hours per week.

ELEC 465 ***Networks Security and Management*** (3.5 credits)
Prerequisite: COEN 445 or ELEC 463. Network security threats. Importance of security policy. Principles and techniques of encryption and authentication. Network security protocols: X509, IPSEC (Internet Protocol Security Architecture). Network management: issues, architectures, and protocols. Fault management, configuration management, security management, performance management, and accounting management. Management Information Bases (MIBs). SNMP and its evolution. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 466 ***Introduction to Optical Communication Systems*** (3.5 credits)
Prerequisite: ELEC 351, 367. Overview of optical fibres and optical fibre communications. Signal propagation in optical fibres: attenuation, chromatic dispersion, mode coupling, and nonlinearities. Optical transmitters' characteristics and requirements for optical networks. Power launching and coupling: optical transmitter-to-fibre coupling, fibre-to-fibre joints, and optical fibre connectors. Optical receivers: basic structures, noise analysis, characteristics and requirements for optical networks. Digital/analog transmissions: link power budget, rise-time budget, line coding, error correction, and noise effects on transmissions. WDM concepts: operation principle of WDM. Optical amplifiers: characteristics and requirements for optical networks, amplifier noise, system applications, and wavelength conversion. Optical networks: basic topologies, SONET/SDH, broadcast-and-select WDM networks, wavelength-routed networks. Optical measurements: test equipments, attenuation/dispersion measurements, OTDR, eye pattern and OSA. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 470 ***Broadcast Signal Transmission*** (3 credits)
Prerequisite: ELEC 363 or 367. Topics include signal definition, human eye limitations, pixel representation schemes, interfaces serial digital interface (SDI), image formats (1080i, 720i, 4k, 8k), compression schemes: MPEG-2, MPEG-4, moving JPEG. Modulation techniques: QPSK, QAM, VSB. Advanced terrestrial transmission standards such as DVB-T2, ATSC-3. Satellite broadcasting standards such as DVB/S2. Path calculation: antennas, up and down conversion, solid state and travelling wave tube amplifiers. Transmission lines, waveguide and coaxial cable. Lectures: three hours per week.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 472 ***Advanced Telecommunication Networks*** (3.5 credits)
Prerequisite: ELEC 463 or COEN 445. Routing in packet networks, shortest-path algorithms, Internet routing protocols, ATM networks: ATM and ATM adaptation layers, traffic management and QoS, congestion control, ATM signalling, advanced network architectures: classical IP over ATM, MPLS, integrated and differentiated services, mobile communications: wireless transmission, medium access control, GSM system, mobile IP, mobile transport layer and support for mobility. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 473 ***Autonomy for Mobile Robots*** (3 credits)
Prerequisite: ELEC 372; ENGR 371. The course discusses application of autonomous wheeled robots such as autonomous cars, indoor robots, and (off-road) unmanned ground vehicles. Topics include robot motion models, robot odometry, robot sensor models (beam models of range finders and feature-based measurement models) and occupancy grid mapping. The course also covers state estimation for robot localization and introduction to simultaneous localization and mapping (SLAM). Assignments include algorithm implementation on a robot. Lectures: three hours per week.
NOTE: Students who have received credit for this topic under an ELEC 498 number may not take this course for credit.

ELEC 481 ***Linear Systems*** (3.5 credits)
Prerequisite: AERO 371 or ELEC 372 or MECH 371. Review of matrix algebra. State-space description of dynamic systems: linearity, causality, time-invariance, linearization. Solution of state-space equations. Transfer function representation. Discrete-time

models. Controllability and observability. Canonical forms and minimal-order realizations. Stability. Stabilizability and pole placement. Linear quadratic optimal control. Observer design. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for ENGR 471 may not take this course for credit.

ELEC 482 ***System Optimization*** (3.5 credits)
Prerequisite: ENGR 391 or EMAT 391. Linear least squares. Properties of quadratic functions with applications to steepest descent method, Newton's method and Quasi-Newton methods for nonlinear optimization. One-dimensional optimization. Introduction to constrained optimization, including the elements of Kuhn-Tucker conditions for optimality. Least p^{th} and mini-max optimization. Application of optimization techniques to engineering problems. Lectures: three hours per week. Laboratory: 15 hours total.
NOTE: Students who have received credit for ENGR 472 may not take this course for credit.

ELEC 483 ***Real-Time Computer Control Systems*** (3.5 credits)
Prerequisite: AERO 371 or ELEC 372; ELEC 342 or 364. Introduction to real-time computer control systems; a review of discrete-time signals and systems, difference equations, z-transform; sampled-data systems, sample and hold, discrete models; discrete equivalents of continuous-time systems; stability analysis; design specifications; design using root locus and frequency response methods; implementation issues including bumpless transfer, integral windup, sample rate selection, pre-filtering, quantization effects and computational delay; scheduling theory and priority assignment to control processes, timing of control loops, effects of missed deadlines; principles and characteristics of sensors and devices, embedded processors, processor/device interface. Lectures: three hours per week. Laboratory: 15 hours total.

ELEC 490 ***Capstone Electrical Engineering Design Project*** (4 credits)
Prerequisite: Minimum of 75 credits in BEng (Electrical) or permission of the Department; ENGR 301, 371; COEN 311; ELEC 342 or 364; ELEC 390. Students are assigned to groups, and work together under faculty supervision to solve a complex interdisciplinary design problem — typically involving communications, control systems, electromagnetics, power electronics, software design, and/or hardware design. The project fosters teamwork between group members and allows students to develop their project management, technical writing, and technical presentation skills. Tutorial: one hour per week, two terms. Equivalent laboratory time: four hours per week, two terms.
NOTE: All written documentation must follow the Concordia Form and Style guide. Students are responsible for obtaining this document before beginning the project.

ELEC 498 ***Topics in Electrical Engineering*** (3 credits)
Prerequisite: Permission of the Department. This course may be offered in a given year upon the authorization of the Electrical and Computer Engineering Department. The course content may vary from offering to offering and will be chosen to complement elective courses available in a given year.

CONCORDIA INSTITUTE FOR AEROSPACE DESIGN AND INNOVATION

IADI 301 ***Undergraduate Aerospace Industry Project I*** (0 credit)
Prerequisite: Acceptance into CIADI. The activities associated with this course include participation in regular meetings at the Institute and with faculty and industry members, attendance at training sessions (as applicable), industry training and tours. A project is assigned to the students. Students are also required to prepare and present progress reports on their project. A final report of their project must be submitted to the director of CIADI. A grade of pass or fail will be awarded based on the evaluation of the above activities. All students accepted to CIADI are required to register for this non-credit course activity.

IADI 401 ***Undergraduate Aerospace Industry Project II*** (0 credit)
Prerequisite: Pass in IADI 301. The activities associated with this course deal with participation in regular meetings at the Institute and with faculty and industry members, attendance at training sessions (as applicable), industry training and tours. A project is assigned to the students. Students are also required to prepare and present progress reports on their project. A final report of their project must be submitted to the director of CIADI. A grade of pass or fail will be awarded based on the evaluation of the above activities. Students wishing to use their research and design project for their capstone project (e.g. MECH 490, COEN 490) must receive written approval from the Capstone Design Project coordinator in their respective department at the commencement of their CIADI project, and meet all requirements set out by both CIADI and their individual department.

INDUSTRIAL ENGINEERING

INDU 211 ***Introduction to Production and Manufacturing Systems*** (3 credits)
History of industrial engineering. Role of industrial engineers. Types of manufacturing and production systems. Material flow systems. Job design and work measurement. Introduction to solution methodologies for problems which relate to the design and operation of integrated production systems of humans, machines, information, and materials. Lectures: three hours per week. Tutorial: one hour per week.

INDU 311 ***Simulation of Industrial Systems*** (3.5 credits)
Prerequisite: ENGR 371. Modelling techniques in simulation; application of discrete simulation techniques to model industrial systems; random number generation and testing; design of simulation experiments using different simulation languages; output data analysis. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks. Tutorial: one hour per week.

INDU 320 ***Production Engineering*** (3 credits)
Prerequisite: INDU 323. The systems approach to production. Interrelationships among the component blocks of the system: forecasting, aggregate planning, production, material and capacity planning, operations scheduling. An overview of integrated production planning and control including MRP II, Just in Time manufacturing (JIT). Lectures: three hours per week. Tutorial: one hour per week.

INDU 321 ***Lean Manufacturing*** (3 credits)
Prerequisite: INDU 320. Lean fundamentals; lean manufacturing; lean engineering; lean principles, tools and techniques, practices, and implementation; five S's, process analysis/spaghetti charts, value engineering; value stream mapping; standardized work/ standard times; set-up reduction/line balancing; unit manufacturing; cell layout/cellular manufacturing; total productive maintenance; kanban; lean supply chain management; transition-to-lean roadmap; people/organizational issues in the lean enterprise; Six Sigma; TOM; agile manufacturing. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for INDU 420 may not take this course for credit.

INDU 323 ***Operations Research I*** (3.5 credits)
Prerequisite: ENGR 213, 233; INDU 211. An introduction to deterministic mathematical models with emphasis on linear programming. Applications to production, logistics, and service systems. Computer solution of optimization problems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

INDU 324 ***Operations Research II*** (3.5 credits)
Prerequisite: INDU 323. Integer programming (IP), including modelling and enumerative algorithms for solving IP problems; post-optimality analysis. Network flows, dynamic programming and non-linear programming. Applications in the design and operation of industrial systems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for INDU 430 may not take this course for credit.

INDU 330 ***Engineering Management*** (3 credits)
Prerequisite: ENCS 282; ENGR 301 previously or concurrently. Organizational structures, their growth and change. Motivation, leadership, and group behaviour. Design of alternatives for improving organizational performance and effectiveness. Planning, organization and management of engineering projects. Management for total quality. Lectures: three hours per week.

INDU 342 ***Logistics Network Models*** (3 credits)
Prerequisite: INDU 324. Overview of transportation systems; airlines, railways, ocean liners, cargo, energy transportation and pipelines. Supply chain characterization. Site location. Distribution planning. Vehicle routing. Fleet scheduling. Crew scheduling. Demand management. Replenishment management. Revenue management. Geographic information systems. Real-time network control issues. Project. Lectures: three hours per week.
NOTE: Students who have received credit for INDU 442 may not take this course for credit.

INDU 371 ***Stochastic Models in Industrial Engineering*** (3 credits)
Prerequisite: ENGR 371. Overview of probability theory; probability distributions; exponential model and Poisson process; discrete-time and continuous-time Markov chains; classification of states; birth and death processes; queuing theory. Application to industrial engineering problems. Lectures: three hours per week. Tutorial: one hour per week.

INDU 372 ***Quality Control and Reliability*** (3 credits)
Prerequisite: ENGR 371. Importance of quality; total quality management; statistical concepts relevant to process control; control charts for variables and attributes; sampling plans. Introduction to reliability models and acceptance testing; issues of standardization. Lectures: three hours per week.

INDU 410 ***Safety Engineering*** (3 credits)
Prerequisite: MECH 311 or MIAE 311. This course focuses on the following topics: engineering design for the control of workplace hazards; occupational injuries and diseases; codes and standards; Workplace Hazardous Materials Information Systems (WHMIS); hazard evaluation and control; design criteria; risk assessment; safety in the manufacturing environment; applications in ventilation, air cleaning, noise and vibration. Lectures: three hours per week.

INDU 411 ***Computer Integrated Manufacturing*** (3.5 credits)
Prerequisite: MECH 311 or MIAE 311. This course focuses on concepts and benefits of computer integrated manufacturing (CIM); design for manufacturing; computer-aided design, process planning, manufacturing (computer numerical control parts programming), and inspection; robots in CIM; production planning and scheduling in CIM; system integration. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

INDU 412 ***Human Factors Engineering*** (3.5 credits)
Prerequisite: ENGR 371. Elements of anatomy, physiology, and psychology; engineering anthropometry; human capacities and limitations; manual material handling; design of workplaces; human-machines system design; design of controls and displays; shift work. Applications to a manufacturing environment. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

INDU 421 ***Facilities Design and Material Handling Systems*** (3.5 credits)
Prerequisite: INDU 311 previously or concurrently; INDU 320. An introduction to planning and design of production and manufacturing. Facility layout and location. Material handling systems and equipment specifications. Computer-aided facilities planning. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

INDU 423 ***Inventory Control*** (3.5 credits)
Prerequisite: INDU 320. Inventory analysis and control systems; the role of forecasting in controlling inventories; the role of inventories in physical distribution; supply chain management; work in process inventories; inventory in just-in-time manufacturing systems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

INDU 431 ***Quantitative Methods in Health-care Systems*** (3 credits)
Topics include mathematical modelling and optimization methods in health-care problems, health-care staff planning and scheduling, operating room management, appointment scheduling in clinics, production and delivery of radio-pharmaceuticals, resource allocation and capacity planning in hospitals, ambulance redeployment and dispatching, routing and scheduling of caregivers in home-health industries, health-care facility location, inventory management of blood products, kidney exchange optimization and optimization in radiation therapy (IMRT and VMAT). A project is required. Lectures: three hours per week. Tutorial: one hour per week.

INDU 441 ***Introduction to Six Sigma*** (3 credits)
Prerequisite: INDU 372. Overview of the Six Sigma concepts and tools. Six Sigma deployment practices: Define, Measure, Analyze, Improve and Control phases (DMAIC). Project development, and the DMAIC problem-solving approach. Project. Lectures: three hours per week.

INDU 466 ***Decision Models in Service Sector*** (3 credits)
Prerequisite: ENGR 371; INDU 320. Introduction to service strategy and operations. Service demand forecasting and development of new services. Service facility location and layout planning. Applications of decision models in service operations and service quality control. Cost analysis, queuing models, risk management and resource allocation models for service decisions. Service outsourcing and supply chain issues. Efficiency and effectiveness issues in different service sectors such as emergency force deployment, municipal resource allocation and health care. Case studies using operations research, operations management, and statistical techniques. Lectures: three hours per week.

INDU 475 ***Advanced Concepts in Quality Improvement*** (3 credits)
Prerequisite: INDU 372. Statistical experimental design issues such as randomized blocks, factorial designs at two levels, applications on factorial designs, building models, Taguchi methods. Lectures: three hours per week.

INDU 480 ***Cases in Industrial Engineering*** (3 credits)
Prerequisite: INDU 311, 324. This course uses the case teaching method to train industrial engineering students to analyze real-world situations using the tools of operations research. Students assume the roles of engineering consultants working together to solve a problem posed by the client in each case. As a consequence, students obtain experience dealing with all steps involved in solving a real problem, from identification of stakeholders, problem formulation and identification of data requirements, to model implementation and analysis of results. Students are required to participate in class discussions of the case and to present their solutions in either report or presentation form. Lectures: three hours per week.

INDU 490 ***Capstone Industrial Engineering Design Project*** (4 credits)
Prerequisite: 75 credits in the program; ENGR 301; MIAE 380; INDU 421 previously or concurrently. A supervised design, simulation or experimental capstone design project including a preliminary project proposal with complete project plan and a technical report at the end of the fall term; a final report by the group and individual oral presentation at the end of the winter term. Lectures: one hour per week, one term. Equivalent laboratory time: three hours per week, two terms.
NOTE: Students will work in groups under direct supervision of a faculty member.

INDU 498 ***Topics in Industrial Engineering*** (3 credits)
Prerequisite: Permission of the Department Chair. This course may be offered in a given year upon the authorization of the Mechanical, Industrial and Aerospace Engineering Department. The course content may vary from offering to offering and will be chosen to complement the elective courses available in the Industrial Engineering program. Lectures: three hours per week.

MECHANICAL ENGINEERING

MECH 321 ***Properties and Failure of Materials*** (3.5 credits)
Prerequisite: MECH 221 or MIAE 221. This course covers the following topics: the service capabilities of alloys and their relationship to microstructure as produced by thermal and mechanical treatments; tensile and torsion tests; elements of dislocation theory; strengthening mechanisms; composite materials; modes of failure of materials; fracture, fatigue, wear, creep, corrosion, radiation damage; failure analysis; material codes; material selection for design. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for AERO 481 may not take this course for credit.

MECH 343 ***Theory of Machines*** (3.5 credits)
Prerequisite: ENGR 213, 233, 243. Introduction to mechanisms; position and displacement; velocity; acceleration; synthesis of linkage; robotics; static force analysis; dynamic force analysis; forward kinematics and inverse kinematics; introduction to gear analysis and gear box design; kinematic analysis of spatial mechanisms. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

MECH 344 ***Machine Element Design*** (3 credits)
Prerequisite: ENGR 244; MECH 313 or MIAE 313; MECH 343 previously or concurrently. This course covers the following topics: introduction to machine design; static failure theories; failure of ductile vs. brittle materials under static loading; fatigue failure theories; fatigue loads; notches and stress concentrations; residual stresses; designing for high cycle fatigue; design of shafts, keys and couplings; design of spur gears; spring design; design of screws and fasteners; design of bearings; case studies. Lectures: three hours per week. Tutorial: two hours per week.
NOTE: Students who have received credit for MECH 441 may not take this course for credit.

MECH 351 ***Thermodynamics II*** (3.5 credits)
Prerequisite: ENGR 251. Brief review of ideal gas processes. Semi-perfect gases and the gas tables. Mixtures of gases, gases and vapours, air conditioning processes. Combustion and combustion equilibrium. Applications of thermodynamics to power production and utilization systems: study of basic and advanced cycles for gas compression, internal combustion engines, power from steam, gas turbine cycles, and refrigeration. Real gases. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

MECH 352 ***Heat Transfer I*** (3.5 credits)
Prerequisite: ENGR 311, 361. Analytical and numerical methods for steady-state and transient heat conduction. Empirical and practical relations for forced- and free-convection heat transfer. Radiation heat exchange between black bodies, and between non-black bodies. Gas radiation. Solar radiation. Effect of radiation on temperature measurement. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

MECH 361 ***Fluid Mechanics II*** (3.5 credits)
Prerequisite: ENGR 361. Differential analysis of fluid flows, vorticity, stream function, stresses, and strains. Navier-Stokes equations and solutions for parallel flows. Euler's equations, irrotational and potential flows, plane potential flows. Viscous flows in pipes, laminar and turbulent flows, major and minor losses. Flow over immersed bodies, boundary layers, separation and thickness. Drag, lift and applications. Introduction to compressible flows, speed of sound, Mach cone, and some characteristics of supersonic flows. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.

MECH 368 ***Electronics for Mechanical Engineers*** (3.5 credits)
Prerequisite: PHYS 205; ENGR 311 previously or concurrently. Dependent sources, voltage and current dividers, voltage and current sources, superposition, Thevenin and Norton equivalent sources, linear and nonlinear circuit analysis. Semiconductors and diodes. Bipolar Junction Transistors (BJT), Field Effect Transistors (FET); amplifiers and switches. Operational amplifiers; circuits and frequency response. Digital logic components and circuits. Digital systems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 470 may not take this course for credit.
NOTE: Electrical Engineering and Computer Engineering students may not take this course for credit.

MECH 370 ***Modelling and Analysis of Dynamic Systems*** (3.5 credits)
Prerequisite: PHYS 205; ENGR 213; ENGR 311 previously or concurrently; ENGR 245 or 243. Definition and classification of dynamic systems and components. Modelling of dynamic systems containing individual or mixed mechanical, electrical, fluid and thermal elements. Block diagrams representation and simulation techniques using MATLAB/Simulink. Time domain analysis. Transient and steady-state characteristics of dynamic systems. Linearization. Transfer functions. Introduction to feedback control systems. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for ELEC 370 may not take this course for credit.

MECH 371 ***Analysis and Design of Control Systems*** (3.75 credits)
Prerequisite: ENGR 311; MECH 370. Stability of linear feedback systems. Root-Locus method. Frequency response concepts. Stability in the frequency domain. Feedback system design using Root Locus techniques. Compensator concepts and configurations. PID-controller design. Simulation and computer-aided controller design using Matlab/Simulink. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: three hours per week, alternate weeks.
NOTE: Students who have received credit for ELEC 372 may not take this course for credit.

MECH 375 ***Mechanical Vibrations*** (3.5 credits)
Prerequisite: AERO 371 or MECH 370. Transient vibrations under impulsive shock and arbitrary excitation: normal modes, free and forced vibration. Multi-degree of freedom systems, influence coefficients, orthogonality principle, numerical methods. Continuous systems; longitudinal torsional and flexural free and forced vibrations of prismatic bars. Lagrange's equations. Vibration measurements. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 443 may not take this course for credit.

MECH 390 ***Mechanical Engineering Design Project*** (3.5 credits)
Prerequisite: ENCS 282; MECH 311 or MIAE 311; MECH 343; MIAE 380; MECH 344 previously or concurrently. This course covers the following topics: the design process; product cost, quality and time to market, open and concept design problems, problem description; geometric and type synthesis; direct and inverse design problems; material selection and load determination; mathematical modelling, analysis, and validation; introduction to Computer-Aided Design and Engineering (CAD and CAE); product evaluation for performance, tolerance, cost, manufacture, assembly, and other measures; design documentation. A team-based design project is an intrinsic part of this course. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: one hour per week.

MECH 411 ***Instrumentation and Measurements*** (3.5 credits)
Prerequisite: ENGR 311; AERO 371 or MECH 370. Unified treatment of measurement of physical quantities; static and dynamic characteristics of instruments — calibration, linearity, precision, accuracy, and bias and sensitivity drift; sources of errors; error analysis; experiment planning; data analysis techniques; principles of transducers; signal generation, acquisition and processing; principles and designs of systems for measurement of position, velocity, acceleration, pressure, force, stress, temperature, flow-rate, proximity detection. The course includes demonstration of various instruments. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 373 may not take this course for credit.

MECH 412 ***Computer-Aided Mechanical Design*** (3.5 credits)
Prerequisite: MECH 313 or MIAE 313. This course is an introduction to computational tools in the design process. The following topics are covered: introduction to the fundamental approaches to computer-aided geometric modelling, physical modelling and engineering simulations; establishing functions and functional specifications with emphasis on geometric tolerancing and dimensioning, manufacturing and assembly evaluation. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 414 ***Computer Numerically Controlled Machining*** (3.5 credits)
Prerequisite: MECH 311 or MIAE 311; MECH 412. This course focuses on computer-aided design and manufacturing (CAD/CAM) hardware and software. The following topics are covered: essentials of Computer Numerical Control (CNC) machine tools and systems; process planning and tooling systems for CNC machining, theory of CNC programming of sculptured parts; multi-axis CNC tool path generation; project using CAD/CAM software; CATIA for complex mechanical parts design and a CNC machine tool to manufacture parts. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 415 ***Advanced Programming for Mechanical and Industrial Engineers*** (3 credits)
Prerequisite: MECH 215 or MIAE 215. This course focuses on class definitions. The following topics are covered: designing classes and member functions; constructors and destructors; class libraries and their uses; input and output; data abstraction and encapsulation; introduction to software engineering; computer graphics and visualization; numerical methods; advanced mechanical and industrial engineering applications. This course includes a substantial project. Lectures: three hours per week. Tutorial: one hour per week.

MECH 421 ***Mechanical Shaping of Metals and Plastics*** (3.5 credits)
Prerequisite: MECH 221 or MIAE 221. This course focuses on metal forming: extrusion, forging, rolling, drawing, pressing, compacting; shear line theory, sheet forming limits; metal cutting, machinability, tooling; plastics shaping: extrusion, moulding, vacuum forming; consideration of the mechanical parameters critical for process control and computer applications; interaction of materials characteristics with processing to define product properties (cold working, annealing, hot working, super plasticity, thermomechanical treatment); energy conservation, safety, product quality, and liability. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 422 ***Mechanical Behaviour of Polymer Composite Materials*** (3 credits)
Prerequisite: ENGR 233, 244; MECH 221 or MIAE 221. This course focuses on general applications of polymer composite materials in aircraft, aerospace, automobile, marine, recreational, and chemical processing industries. The following topics are covered: mechanics of a unidirectional lamina; transformation of stress, strain, modulus, and compliance; off-axis engineering constants, shear and normal coupling coefficients; in-plane and flexural stiffness and compliance with different laminates, including cross-ply, angle-ply, quasiisotropic, and general bidirectional laminates; hygrothermal effects; strength of laminates and failure criteria; micromechanics. Lectures: three hours per week.

MECH 423 ***Casting, Welding, Heat Treating, and Non-Destructive Testing*** (3.5 credits)
Prerequisite: MECH 221 or MIAE 221. This course focuses on comparative analysis of the various techniques of casting, welding, powder fabrication, finishing, and non-destructive testing. The following topics are covered: consideration of the control parameters that are essential to define both automation and robot application; materials behaviour which determines product micro-structure and properties; technology and theory of solidification, normalizing, quenching, surface hardening, tempering, aging, and thermomechanical processing for steels, cast irons and Al, Cu, Ni and Ti alloys; energy conservation, worker safety, quality control, and product liability. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 424 ***MEMS — Design and Fabrication*** (3.5 credits)
Prerequisite: MECH 311 or MIAE 311; MECH 343. This course is an introduction to microsystems and devices; mechanical properties of materials used in microsystems; microfabrication and post-processing techniques; sacrificial and structural layers;

lithography, deposition and etching; introduction and design of different types of sensors and actuators; micromotors and other microdevices; mechanical design, finite element modelling; design and fabrication of free-standing structures; microbearings; special techniques: double-sided lithography, electrochemical milling, laser machining, LIGA, influence of IC fabrication methods on mechanical properties; application examples in biomedical, industrial, and space technology areas; integration, bonding and packaging of MEMS devices. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 425 ***Manufacturing of Composites*** (3.5 credits)
Prerequisite: MECH 311 or MIAE 311. This course focuses on fibres and resins. The following topics are covered: hand lay up; autoclave curing; compression molding; filament winding; resin transfer molding; braiding. Injection molding; cutting; joining; thermoset and thermoplastic composites; Polymer Nanocomposites; process modelling and computer simulation; non-destructive evaluation techniques. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 426 ***Stress and Failure Analysis of Machinery*** (3 credits)
Prerequisite: ENGR 233, 244; AERO 481 or MECH 321. Analysis of stresses, strains and deformations in machine elements; non-symmetric bending of beams; shear centre for thin-walled beams; curved beams; torsion of non-circular shafts and tubes; thick wall cylinders; plates and shells; contact elements; stress concentrations; energy methods; failure modes, analysis and prevention; buckling, fracture, fatigue and creep. Lectures: three hours per week.

MECH 444 ***Guided Vehicle Systems*** (3 credits)
Prerequisite: MECH 375. Definition and classification of guided transportation systems. Track characterization: alignment, gage, profile, and cross-level irregularities. Wheel-rail interactions: rolling contact theories, creep forces. Modelling of guided vehicle components: wheel set, suspension, truck and car body configurations, suspension characteristics. Performance evaluation: stability hunting, ride quality. Introduction to advanced vehicles. Lectures: three hours per week.

MECH 447 ***Fundamentals of Vehicle System Design*** (3.5 credits)
Prerequisite: MECH 343. Mechanics and construction of wheels and tires: rolling resistance, tractive and braking forces, brake system design: components of mechanical, hydraulic and pneumatic brake systems, braking efficiency, antilock braking devices, performance characteristics of road vehicles: transmission design, driving condition diagrams, acceleration, speed and stopping distance, gradability, steering mechanisms: design and kinematics, suspension spring and shock absorbers: anti-roll and anti-pitch devices, chassis and body design considerations. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 448 ***Vehicle Dynamics*** (3 credits)
Prerequisite: MECH 447 previously or concurrently. Tire-terrain interactions; side-slip, cornering and aligning properties of tires; camber angle and camber torque; estimation of braking/tractive and cornering forces of tires; steady-state handling of road vehicles; steering response and directional stability; handling and directional response of vehicles with multiple steerable axles; handling of articulated vehicles; handling and directional response of tracked and wheeled off-road vehicles; directional response to simultaneous braking and steering. Lectures: three hours per week.

MECH 452 ***Heat Transfer II*** (3.5 credits)
Prerequisite: MECH 351, 352, 361. Heat exchangers. Condensation and boiling heat transfer. Principles of forced convection. Analysis of free convection from a vertical wall. Correlations for free convection in enclosed spaces. Mass transfer. Special topics of heat transfer. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 453 ***Heating, Ventilation and Air Conditioning Systems*** (3 credits)
Prerequisite: MECH 352. Heating and cooling load calculation. Overview of heating and air conditioning systems. Review: Vapour compression refrigeration cycles, refrigerant properties, psychometrics. Performance characteristic of components: evaporators, condensers, compressors, throttling devices (expansion valves, capillary tubes). System performance characteristics: calculation of system operating conditions based on the capacities of its components and outdoor and indoor conditions. Controls: operational, capacity. Computer-aided design methods. Defrosting. Estimation of energy consumption for heating with heat pumps. Fundamentals of refrigerant piping, water piping, and air distribution systems. Experimental methods for system development. Lectures: three hours per week.

MECH 454 ***Vehicular Internal Combustion Engines*** (3 credits)
Prerequisite: MECH 351, 361. Mechanical design of vehicular engines for different applications. Gas exchange and combustion engine processes. Combustion chambers design. Fuels for vehicular engines. Fuel supply, ignition and control systems. Cooling and lubrication of engines. Emissions formation and control. Engines' operational characteristics — matching with vehicles. Enhancement of engine performance. Engine testing. Environmental impact of vehicular engines on global pollution. Recent developments in energy efficient and "clean" engines. Design or calculation project of vehicular engine. Lectures: three hours per week.

MECH 460 ***Finite Element Analysis*** (3.75 credits)
Prerequisite: ENGR 244, 391. Formulation and application of the finite element method to modelling of engineering problems, including stress analysis, vibrations, and heat transfer. Examples illustrating the direct approach, as well as variational and weighted residual methods. Elements and interpolation functions. Meshing effect. Error analysis. One- and two-dimensional boundary value problems. Development of simple programs and direct experience with general purpose packages currently used in industry for design problems. Lectures: three hours per week. Laboratory: three hours per week, alternate weeks.

MECH 461 ***Gas Dynamics*** (3.5 credits)
Prerequisite: MECH 361. Review of one-dimensional compressible flow. Normal and oblique shock waves; Prandtl-Meyer flow; combined effects in one-dimensional flow; non-ideal gas effects; multi-dimensional flow; linearized flow; method of characteristics. Selected experiments in supersonic flow, convergent-divergent nozzles, hydraulic analog and Fanno tube. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 462 ***Wind Turbine Engineering*** (3 credits)
Prerequisite: MECH 343, 361; MECH 344, 371 previously or concurrently. This course is designed to cover the theoretical and practical areas pertinent to the operation of wind turbines. Energy in the wind. Aerodynamic drag and lift of turbine blades. Horizontal axis and vertical axis wind turbine designs. Generators. Control systems. Mechanical load analysis: blade, tower, generator and gearbox. Blade and tower design. Turbine braking. Economical, environmental and safety aspects.

MECH 463 ***Fluid Power Control*** (3.5 credits)
Prerequisite: ENGR 361; MECH 371. This course is an introduction to fluid power; pneumatic devices; fluidic devices; hydraulic system components; hydraulic and electro-hydraulic systems; dynamic performance of fluid power systems; fluid logic. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 471 ***Microcontrollers for Mechatronics*** (3.5 credits)
Prerequisite: ENGR 311; MECH 368. Introduction to the concepts and practices of microcontrollers and their application for the control of electromechanical devices and systems. Study of the internal architecture of microcontrollers; programming in assembly language for specific microcontroller functions and controller algorithms; timing of the microcontroller and interfacing with peripheral devices. Students undertake hands-on project work by controlling the position or speed of a DC motor with a feed-back sensor. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 472 ***Mechatronics and Automation*** (3.5 credits)
Prerequisite: MECH 215 or MIAE 215; MECH 371 previously or concurrently. This course focuses on design and analysis of mechatronic and automation systems. The following topics are covered: selection and integration of actuators, sensors, hardware, and software; computer vision; programming and software design for mechatronic systems; modelling and simulation; design of logic control systems; finite state machine methods; feedback control and trajectory generation; safety logic systems; case studies including automation systems, mobile robots, and unmanned vehicle systems. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 473 ***Control System Design*** (3.5 credits)
Prerequisite: ELEC 372 or MECH 371. Analog and digital controller designs. Analog controllers: lead/lag compensators, pole placement, model matching, two-parameter configuration, plant input/output feedback configuration. Digital controllers: difference equations, Z-transform, stability in the Z-domain, digital implementation of analog controllers, equivalent digital plant method, alias signals, selection of sampling time. Introduction to analog/digital state-space: controllability, observability, state feedback, state estimator. PI and PID controllers. Simulink assignments and project. Hardware laboratory project: analog and digital controller design for motor with inertial plus generator load. Lectures: three hours per week. Laboratory: two hours per week, alternate weeks.

MECH 474 ***Mechatronics*** (3.75 credits)
Prerequisite: ELEC 372 or MECH 371. Introduction to mechatronics; basic elements of mechatronic systems. Measurement systems: including principles of measurement systems; sensors and transducers; signal conditioning processes and circuits; filters and data acquisition. Actuation systems: mechanical actuation systems and electrical actuation systems. Controllers: control modes; PID controller; performance measures; introduction to digital controllers and robust control. Modelling and analysis of mechatronic systems; performance measures; frequency response; transient response analysis; stability analysis. Lectures: three hours per week. Laboratory: three hours per week, alternate weeks.

MECH 476 ***Generative Design and Manufacturing in Engineering*** (3 credits)
Prerequisite: MECH 313 or MIAE 313; AERO 390 or MECH 390 previously or concurrently. Generative design is a form-finding process that can mimic nature's evolutionary approach to design. It can start with design goals and then explore innumerable possible permutations of a solution to find the best option. This course provides fundamental information on generative design and manufacturing in engineering. The core techniques from mathematics to artificial intelligence that are commonly used in the creative industry are discussed. The formal paradigms and algorithms used for generation as well as cloud computing are also covered. Lectures: three hours per week.

MECH 490 ***Capstone Mechanical Engineering Design Project*** (4 credits)
Prerequisite: 75 credits in the program; ENGR 301; MECH 344, 390. This course includes a supervised design, simulation or experimental capstone design project including a preliminary project proposal with complete project plan and a technical report at the end of the fall term; a final report by the group and presentation at the end of the winter term. Lectures: one hour per week, one term. Equivalent laboratory time: three hours per week, two terms.
NOTE: Students will work in groups under direct supervision of a faculty member.
NOTE: With permission of the Department, students may enrol in AERO 490 instead of MECH 490.

MECH 498 ***Topics in Mechanical Engineering*** (3 credits)
Prerequisite: Permission of the Department Chair. This course may be offered in a given year upon the authorization of the Mechanical, Industrial and Aerospace Engineering Department. The course content may vary from offering to offering and will be chosen to complement the elective courses available in a given option or options. Lectures: three hours per week.

MECHANICAL AND INDUSTRIAL ENGINEERING

MIAE 211 ***Mechanical Engineering Drawing*** (3.5 credits)
This course is an introduction to graphic language and design — means and techniques. The following topics are covered: the third and the first angle projections; orthographic projection of points, lines, planes and solids; principal and auxiliary views; views in a given direction; sectional views; intersection of lines, planes and solids; development of surfaces; drafting practices; dimensioning, fits and tolerancing; computer-aided drawing and solid modelling; working drawings — detail and assembly drawing; design practice; machine elements representation. Lectures: three hours per week. Tutorial: two hours per week — includes learning of a CAD software. Laboratory: two hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 211 may not take this course for credit.

MIAE 215 ***Programming for Mechanical and Industrial Engineers*** (3.5 credits)
Prerequisite: MATH 204 (Cegep mathematics 105). This course focuses on writing programs using assignment and sequences; variables and types; operators and expressions; conditional and repetitive statements; input and output; file access; functions; program structure and organization; pointers and dynamic memory allocation; introduction to classes and objects; mechanical and industrial engineering applications. Lectures: three hours per week. Tutorial: one hour per week. Laboratory: one hour per week.
NOTE: Students who have received credit for COEN 243 or MECH 215 may not take this course for credit.

MIAE 221 ***Materials Science*** (3 credits)
Prerequisite: CHEM 205 (Cegep Chemistry 101). This course focuses on relationships between properties and internal structure, atomic bonding; molecular, crystalline and amorphous structures, crystalline imperfections and mechanisms of structural change; microstructures and their development from phase diagrams; structures and mechanical properties of polymers and ceramics; thermal, optical, and magnetic properties of materials. Lectures: three hours per week. Tutorial: one hour per week.
NOTE: Students who have received credit for MECH 221 may not take this course for credit.

MIAE 311 ***Manufacturing Processes*** (3.75 credits)
Prerequisite: MECH 313 or MIAE 313. This course focuses on the fundamentals of manufacturing processes and their limitations, metrology, machine shop practice, safety and health considerations, forming, conventional machining and casting processes, welding and joining, plastic production, and non-conventional machining techniques; sustainable technologies. Laboratory includes instruction and practice on conventional machine tools and a manufacturing project. Lectures: three hours per week. Tutorial: two hours per week, including industrial visits and field trips to local industries. Laboratory: three hours per week, alternate weeks.
NOTE: Students who have received credit for MECH 311 may not take this course for credit.

MIAE 313 ***Machine Drawing and Design*** (3.5 credits)
Prerequisite: MECH 211 or MIAE 211. This course is an introduction to engineering design and design process. The following topics are covered: problem definition, solution formulation, model development and collaboration aspects of design process; the use of drawings and other graphical methods in the process of engineering design; industrial standards and specifications, design of fits, linear and geometrical tolerances. Design projects based on design philosophies will involve design and selection of many standard machine components like mechanical drives, cams, clutches, couplings, brakes, seals, fasteners, springs, and bearings. Drawing representation of standard components is also covered. Design projects are an integral part of this course. Lectures: three hours per week. Tutorial: two hours per week. Laboratory: 12 hours total.
NOTE: Students who have received credit for MECH 313 may not take this course for credit.

MIAE 380 ***Product Design and Development*** (3 credits)
Prerequisite: MECH 211 or MIAE 211. This course focuses on development processes and organizations, product planning, identifying customer needs, product specifications, concept generation, concept selection, concept testing, product architecture, industrial design, design for manufacturing, prototyping robust design, patents and intellectual property. Lectures: three hours per week.
NOTE: Students who have received credit for AERO 444 or INDU 440 may not take this course for credit.