Syllabus: Special projects in ECET

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I. COURSE DESCRIPTION

This is a 4 credit semester long course on Special Projects in Electronics and Computer Engineering Technology (ECET) for undergraduate students. The course focuses on electronic technologies and parallel computing technologies. This course involves creatively applying state-of-the-art engineering and prototyping methodologies. The students design and build a special project device appropriate for the semester the course is offered. The students investigate physical principles and new engineering techniques while designing and building the special project. This entails learning how to generate design schematics, electrical circuit designs and subsystem specifications. The course includes learning programming languages (for example Mathematica and Python), the Debian/Linux Operating System, 3D printing, and device operation characterization using analytical methods. The course includes mechanical and electrical fabrication, including printed circuit boards, testing and troubleshooting. Finally, the course includes technical report writing, program management strategies, and practices that are suited to achieving all the various milestones for a successful functional operational test and evaluation of the special project device by the end of the semester.

During this Spring 2019 semester, the students will design, build, test and evaluate an electroaeroplane. The first proof-of-concept of electroaerodynamic propulsion was recently achieved in Fall 2018 by Steven Barrett and his team at the MIT Department of Aeronautics and Astronautics [Nature, Vol. 563, 22 November 2018 pages 532–535]. This project includes designing and building all the major subsystems of the electroaeroplane, including (1) a multistage Cockcroft-Walton generator, (2) a full-bridge square-wave generator, (3) LCC resonant tank circuit, (4) emitter-airgap-collector electrotrode solid-state thruster with a two-stage configuration of four sets of parallel electrotrodes, (5) NACA 0010 airfoil collectors, and (6) a digital flight controller. The entire electroaeroplane will be 3D printed. Finally, this project also includes designing and building a 96-core parallel computer array, using the Message Passing Interface, for computational fluid dynamics and electrohydrodynamics modeling and simulation.

A. Course plan

Students should have facility with building and testing electrical circuits including digital simulations of electrical circuits (for example, using National Instruments Multisim).

Each student will turn in his or her own version of the Final Project.

The Special Project will entail:

1. designing, building, testing and demonstrating an operational electroaeroplane
2. interim report on the major subsystem components
3. characterization and evaluation of the performance of the major subsystems
4. final report on the integrated electroaeroplane system.

Each student will summarize his or her special project study in written technical/journal article format for turn in as interim reports and a compiled final project report.

A basic physics, electrical engineering and aerodynamic engineering tutorials are provided at the outset and as needed throughout the semester.

The class meets Tuesday 12:45-3:30pm the Electronics Lab in KAA 217 and Friday 12:45-3:30pm in the Physics Lab in IKE 112.

Office Hours: Wednesday afternoon (after 3:30pm) in IKE 136.

Prerequisites: ETRO 140 and ETRO 201 and MATH 119 and Math 135 with grade C or better. These prerequisites cannot be waived.

B. Mathematical skill set

Calculus and electrical circuit analysis (application of Kirchhoff's Law).

II. PROSPECTUS

1. Introduction
   - Introduction to electroareodynamic (EAD) solid-state propulsion
2. Introduction to an ionic accelerator solid-state technology
   - Simulation and experimental investigation of a multistage Cockcroft-Walton generator (voltage multiplier)
   - Simulation and experimental investigation of a full-bridge square-wave generator and LCC resonant tank circuits
   - 40kV voltage multiplier circuit to drive the emitter-airgap-collector electrodes
3. Introduction to electroaeroengineering
   - Introduction to Gauss's law, electric field and scalar voltage potential
   - Charge, length and time (QLT) physical dimensions applied to the fundamental field quantities
   - Pressure, charge density, current density, thrust, power
   - Break down electric field strength, thrust-to-power ratio, thrust density and electroaerodynamic trade-offs
   - The NACA 0010 airfoil, camber line and thickness distribution
   - Emitter and collector topologies, and the two-stage configuration of four sets of parallel electrotrodes
   - Investigation of trade-offs in a 3D printed hollow NACA 0010 airfoil
4. Introduction to parallel computing
   - Multicore and multinode parallel computing topologies
   - Introduction to the Message Passing Interface (MPI) for parallel computing using ethernet-connected nodes
   - The Free Software Foundation and the Debian/Linux Operating System
   - Investigation of a 3D printed multinode parallel computer assembly and frame
5. Introduction to mechanical engineering
   - Introduction to FreeCAD and 3D surface modeling and rendering
   - Developing a 3D model of a hollow lightweight NACA 0010 airfoil segment
   - Designing the frame assembly of the electroaeroplane prototype
   - Developing a full 3D model of the electroaeroplane design
6. Midterm
   - Midterm interim report (compilation of assigned Problem Sets and technical reports up to middle of the semester)
   - Laser-etched printed circuit board for the electroaerodynamic 40kV propulsor
   - 3D printed multinode parallel computer frame assembly
   - 3D printed hollow NACA 0010 airfoil segment at fullsize
   - 3D printed electroaeroplane prototype at 1/10th scale

7. Introduction to computational fluid dynamics for aeroengineering
   - Introduction to mass density, flow velocity, pressure, viscosity, convection and Reynolds number
   - Introduction Navier-Stokes equation for incompressible flow
   - Investigation of computational fluid dynamics free-software applications for drag coefficient calculations
   - Introduction to electrohydrodynamics (electrofluid dynamics)
   - Standard CFD calculation for the NACA 0010 airfoil
8. Introduction to modeling and simulation of an electroaeroplane
   - Emitter-airgap-collector electrotrode trust model
   - Aircraft models for simulation and steady-state flight
   - Aircraft dynamic behavior and feedback control
   - Investigation of digital control simulation schemes
   - Investigation of adaptive control schemes
   - Investigation of strategies to launch the electroaeroplane prototype
9. Introduction to fabrication, testing and flight evaluation of an electroaeroplane
   - Major subsystem performance testing, evaluations and subsystem revisions
   - Completed 3D printed hallow and light-weight NACA airfoils
   - Wind and frame assembled holding a 2-stage configuration with 4 set of parallel electrodes
   - Integrated solid-state EAD propulsor and flight control system
   - Flight testing and measurements using video capture techniques
10. Final project
    - CFD simulation and modeling results
    - Fully assembled electroaeroplane prototype
    - Solid-state powered flight demonstration
    - Final project report (writeup of electroaeroplane demonstration) due during exam week and submitted in Technical Report format

III. PROBLEM SETS

Problem sets (including subsystem reports) are assigned as needed and tailored to the students' progress. Students generally have one week to complete any given assigned problem set.

Selected Problem Sets will be submitted in technical report format using scientific typesetting software (LaTeX). Students should be familiar with technical and scientific writing.

IV. COURSE REQUIREMENTS AND EVALUATION

Progress reports, lab assignments, written exercises, and electronics and computer problems: 30%
(e.g. usually assigned Tuesday and due the following Sunday)
Midterm interim report: 30%
Final project report: 30%
Class participation: 10%

V. METHOD OF INSTRUCTION

- Scientific and engineering presentations
- Internet-based video teleconference
- Mathematica demonstrations
- Class discussions
- Weekly office hours following the class end and can be scheduled on a weekly basis by e-mail request

VI. RESOURCES

- Journal articles:

1. Haofeng Xu et al., "Flight of an aeroplane with solid-state propulsion," Nature, Vol. 563 (23 November 2018) pages 532–535.
2. Kento Masuyama and Steven R. H. Barrett et al., "On the forces of electrohydrodynamic propulsion," Proceedings of the Royal Society A, 469:20120623 (2013).
3. Christopher K. Gilmore and Steven R. H. Barrett et al., "Electrohydrodynamic thrust density using positive corona-induced ionic winds for in-atmosphere propulsion," Proceedings of the Royal Society A, 471:20140912 (2015).

There is no assigned textbook for this course.

- Additional reference book:

  Brian L. Stevens, Frank L. Lewis, Eric N. Johnson, "Aircraft control and simulation," 3rd Edition, Wiley (2016)

- Wikipedia provides many helpful overviews, including for the respective lectures presented in the course:

  1. Electric charge
  2. Ion
  3. Ion wind
  4. Voltage multiplier
  5. Cockcraft-Walton generator
  6. Resonant converter
  7. Boost converter
  8. Power inverter
  9. Navier-Stokes equations
  10. Fluid dynamics
  11. Ion-propelled aircraft
  12. Thrust vectoring
  13. Aircraft flight mechanics

- Mathematical physics developments will be provided in class tailored to the skill of the students and the complexity of the project.

VII. DISABILITY STATEMENT

1. If you have a disability and have not voluntarily disclosed the nature of your disability and the support you need, you are invited to contact Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833.

2. Reasonable accommodations will be provided for students with documented physical, sensory, systemic, cognitive, learning and psychiatric disabilities. If you believe you have a disability requiring accommodations, please notify Lisa Deneen - Disabilities Coordinator at 984-3227 or Telecommunication Device for the Deaf (TDD) 984-3325 or the Text Telephone (TT) replay service at 643-8833. The Disabilities Coordinator will verify your disability and provide the course instructor with recommendations for appropriate accommodations.