

Mechanical Engineering Courses Syllabi

THE FU FOUNDATION SCHOOL
OF ENGINEERING
AND APPLIED SCIENCE



Columbia University

This list is tentative and provided for reference only. Actual course schedule may change.

Course Name	Dept	Number	Instructors	F21	S22	F22	S23	F23	S24	F24	S25	F25 Est
Intro to Machining	MECE	1008	Vukelic/Stark/Garcia	36	36	48	48	45	49	48	48	48
Mechanical Engineering Lab I	MECE	3018	Kysar/Yesilveskiy/Hone	79		82		70		58		58
Mechanical Engineering Lab II	MECE	3028	Lin/Howard/Hone		76		79		70		83	
Intro to Mechanics of Fluids	MECE	3100	Kasza/Vedula	77		87		70		60		60
Mechanics, I	ENME	3105	Hone/Kougioumtzoglou/Kasza		69		71		57		58	
Dynamics and Vibrations	ENME	3106	A. Smyth									
Mechanics of Solids	ENME	3113	Betti	110								
Thermodynamics	MECE	3301	Vukelic/Narayanaswamy	85		80		64		65		65
Heat Transfer	MECE	3311	Burke		86		81		77		84	
Mechanics of Machines	MECE	3401	Lipson/Lin									
Computer Graphics and Design	MECE	3408	Vukelic	45	44	42	43	37	48	44	51	48
Machine Design	MECE	3409	Yesilveskiy	57		77		80		75		75
Review of Fundamentals	MECE	3411	Vukelic		20							
Mechanics of Solids for Mechanical Engineers	MECE	3414	Ateshian/Myers			50		85		72		72
Engineering Design Concept	MECE	3420	Yesilveskiy	60	51	77		79		70		85
Engineering Design	MECE	3430	Yesilveskiy				77		79		67	
Computer Aided Design	MECE	3450	Ateshian		19		40	32				
Introduction to Continuous Control Systems (w/	EEME	3601	Beigi/ Agrawal	65		75			80		82	80
Materials and Processes in Manufacturing	MECE	3610	Yao/Vukelic		78		86				82	
Mechatronics	MECE	4058	Zordan	44	24	22	28	18	38	27	18	27
Internet of Mechanical Things (IoMT)	MECE	4078	Yev			Yev?						
Mechanics of Fluids	MECE	4100	Kasza/Vedula		18		12		XX		XX	
Human-Centered Design & Innovation	IEME	4200	West	49			103				110	
Energy Infrastructure & Planning	MECE	4210	Modi									
Energy Sources and Conversion	MECE	4211	Modi	39		58		22		40		40
MEMS	MECE	4212	Schuck	20		31		20		28		28
Lab-on-a-Chip and Microbotic Devices (was: I	MECE	4213	Lin						10		19	20
MEMS Sensors & Systems	MECE	4214	Hilton		14		10		20		14	
Advanced Thermodynamics	MECE	4302	Narayanaswamy		25		14		22		27	
Turbomachinery	MECE	4304	Nolan				3		13		22	
Mech & Thermodynamics of Propulsion	MECE	4305	Bradshaw		17		15		8		X	
Intro to Aerodynamics	MECE	4306	LeVoci		36		19		28		40	
Solar Thermal Engineering	MECE	4312	Naraghi			10						
Decarbonizing Buildings Studio:Energy	MECE	4313	Zuluaga				15		13		34	
Energy Dynamics of Green Bldgs	MECE	4314	Naraghi		29		25					
Intro to Combustion	MECH	4320	Burke	26		26		13		19		19
Thermofluid Systems Design	MECE	4330	Bradshaw	17								
Building Energy Modeling and Simulation	MECE	4350	Howard			20		20		16		16
Kinematics of Machines and Robots	MECE	4401	Lin								7	
Automotive Dynamics	MECE	4430	Browne				20				26	
Space Vehicle Dynamics	MECE	4431	Longman									
Modeling & ID of Dynamic Systems	MEBM	4439	Chbat					14				14
Mechanics of Elastomeric Materials	MECE	4460	Boyce							13		13
Materials Selection for Mechanical Design	MECE	4461	Boyce								23	20
Optimization of Dynamic Systems	MECE	4490	Agrawal									
Frontiers of Tough Tech	IEME	4505	West									20
Evolutionary Computation & Design Automation	MECS	4510	Lipson	111		61		59				
Data Science for Mech. Engineers	MECE	4520	Changyao Chen	154	100?	151		100		140		140
Continuous Control Systems (was: Introduction	MEEE	4600	Beigi/Dadgar/Chbat									85
Discrete Control Systems (was: Digital Control	EEME	4601	Beigi		28		32				24	
Intro to Robotics	MECE	4602	Ciocarlie/Agrawal	101		110		85		101		101
Applied Robotics	MECS	4603	Ciocarlie			Sabbatical		62		74		
Product Design for MFG	MECE	4604	Walker	58		N/A						
Digital Manufacturing	MECE	4606	Lipson		122		103		81			
Computer Aided Manufacturing	MECE	4609	Walker			N/A						
Adv. Manufacturing Processes	MECE	4610	Vukelic	27		36	Sabbatical	29		37		37
Robotics Studio	MECE	4611	Lipson	71	75	84	70	73	78	90	67	90
Sustainable Manufacturing	MECE	4612	Vukelic				31		28		53	
Industrial Automation	MECE	4613	Dadgar							24		24
Morphogenesis: Biol Mat Shp/Str	MEBM	4710	Kasza		9				17			17
Intro to Human Space Flight	IEME	4810	Massimino				22		20		19	
Aerospace Human Factors	MECE	4811	Massimino	14		19		19		20		20
Adv. Mechanics of Fluids	MECE	6100	Ateshian	23		45		36		37		37
Computational Heat Trnsfr -Fluid Flow	MECE	6102	Demetriou/Vedula				6				10	
Case Studies-CFD	MECE	6104	Henry									
FEM for Fluid Flow and FS	MECE	6106	Vedula	4			XX			13		13
Nanoscale Actuation and Sensing	MECE	6137	Schuck		34		47		8		19	
Turbulence	MECE	6200	Low									
Mixture Theories for Biol Tissues	MEBM	6310	Ateshian									
Advanced Heat Transfer	MECE	6313	Narayanaswamy		19		13		15		16	
Multiscale Phenomena in Gases	MECE	6320	Burke				5					
Advanced Machine Dynamics	MECE	6400	Chbat		41		17		27		19	
Intro-Theory of Elasticity, I	MECE	6422	Myers/Kysar/Tepole	15		21		29		17		17
Intro-Theory of Elasticity, II	MECE	6423	Kysar									
Vibrations in Machines	MECE	6424	Chakrabarti									
Small-Scale Mech Behavior	MECE	6432	Kysar	?		4						
Intro to Control Theory (deprecated)	EEME	6601	Longman/Chbat	104		116		73		85		85
Nonlinear and Adaptive Control	MEEE	6610	Beigi									30
Adv Topics in Robotics	MECE	6614	Agrawal		19		30				31	
Robotic Manipulation	MECE	6615	Ciocarlie			Sabbatical	Sabbatical					
Robot Learning	MECS	6616	Ciocarlie		123	Sabbatical	85		73		119	
Adv Kinematics/Dynamics	MECE	6617	Agrawal									
Applied Signal Recognition	MECE	6620	Beigi									
Advanced Continuum Mechanics	MECE	8501	Myers		7				8		8	

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[MEBM E4710: Morphogenesis: shape and structure in biological materials](#)
[MEBM E6310: Mixt Theories for BIOL TISSUES](#)
[MECE E3408: Computer Graphics and Design](#)
[MECE E3409: Machine Design](#)
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[MECE E6102: Computational Heat Transfer and Fluid Flow](#)
[MECE E6106: Finite Element Method for Fluid Flow and Fluid-Structure Interactions](#)
[MECE E6313: Advanced Heat Transfer](#)
[MECE E6400: Advanced Machine Dynamics](#)
[MECE E6422: Intro-Theory of Elasticity I](#)
[MECE E6423: Introduction to the Theory of Elasticity II](#)
[MECE E6617: Advanced Kinematics, Dynamics, and Control in Robotics](#)
[MECE E6620: Applied Signal Recognition and Classification](#)
[MECH E4320: Introduction to Combustion](#)
[MECS 4510: Evolutionary Computation and Design Automation](#)
[MECS E6616: Robot Learning](#)
[MEEE E4600: Continuous Control Systems](#)
[MEEE E6610: Nonlinear and Adaptive Control](#)
[MEEC E6600: Mathematics of Machine Learning, Signals, and Control](#)
[MEIE E4810: Intro to Human Space Flight](#)
[MEEM E6432: Small Scale Mechanical Behavior](#)

EEME E3601: Introduction to Continuous Control Systems

Course Number: EEME E3601
Course Title: Introduction to Continuous Control Systems
Lecture Hours: 2.5
Credits: 3

Instructor: Homayoon Beigi <hb87@columbia.edu>
Prerequisites: Linear Algebra, Ordinary Differential Equations

Textbooks:

Required:

Farid Golnaraghi and Benjamin C. Kuo, "Automatic Control Systems," 10th Edition, McGraw Hill, New York, 2017.

Reference:

Homayoon Beigi, "Fundamentals of Speaker Recognition", Springer, New York, 2011.

Thomas E. Fortman and Konard L. Hitz, "An Introduction to Linear Control Systems," Control and Systems Theory Vol. 5, Marcel Dekker, Inc, New York, 1977.

Grading:

Homework (30%): - Problems solving and coding assignments.

Midterm Exam – In-Class (30%)

Final Exam – In-Class (40%)

Course Description:

Introduction to continuous systems with the treatment of classical and state-space formulations. Mathematical concepts, complex variables, integral transforms and their inverses, differential equations, and relevant linear algebra. Classical feedback control, time/frequency domain design, stability analysis, Laplace transform formulation and solutions, block diagram simplification and manipulation, signal flow graphs, modeling physical systems and linearization. state-space formulation and modeling, in parallel with classical single-input single-output formulation, connections between the two formulations. Transient and steady state analysis, methods of stability analysis, such as root locus methods, Nyquist stability criterion, Routh Hurwitz criterion, pole/zero placement, Bode plot analysis, Nichols chart analysis, phase lead and lag compensators, controllability, observability, realization of canonical forms, state estimation in multivariable systems, time-variant systems. Introduction to advanced stability analysis such as Lyapunov stability and simple optimal control formulation. May not take for credit if already received credit for MEEE E4600.

Note:

More advanced Lyapunov and optimal treatment and solutions are left to more advanced courses: see MEEE 6610 Nonlinear and Adaptive Control. A full treatment of discrete control systems will be covered in a subsequent course: see EEME E4601 Discrete Control Systems. Matlab will be used for simulations and the coding assignments.

Lectures:

Week 1

Introduction to Control Theory

Terminology

Types of Control Systems

Sample Plants and Suitable Associated Control Systems

Nonlinear Systems, Linear Time-Variant and Time Invariant Systems

General Mathematical Forms

Block Diagrams

Sensor Data Collection Examples

Week 2

Control Problem Components

Review of Linear Algebra Concepts

Week 3

Review of Complex Variable Theory

Continuity and Analyticity

Power Series Representation – Taylor and Laurent

Review of Function Relations

Week 4

Laplace Transform and Laplace Inversion
Partial Fraction Expansion

Week 5

Review of Linear Differential Equations
Dynamic and Electrical System Plant Formulation
Simple Block Diagrams
Proportional Control
Integral Control and steady state response

Week 6

Derivative Control and transient response
PI, PD, PID Control
State-Space Representation
Controllability Canonical Form
Series Solutions for Scalar First Order ODEs
Series Solutions for Matrix First Order ODEs and the Matrix Exponential

Week 7

Block Diagram Manipulation and Signal Flow Graphs
Routh-Hurwitz Criteria for Stability
Bode Diagrams
Laplace and Fourier Transform Visualization

Week 8

Midterm (First half of class)
Root Locus Plot – Rules and Examples

Week 9

Root Locus Plot – Rules and Examples (continued)
Nyquist Stability Criterion
Nichols Chart

Week 10

Phase Lead/Lag Compensator
Eigenvalue-Eigenvector Formulation
Generalized Eigenvalue problem formulation and solution
Transformations – ie, Similarity Transform
Jordan Block Form
Eigenvector Solution to the General Controllable Canonical Equations

Week 11

Controllability, Observability, and Realizability
Second Order System Examples
Formulating External Disturbances
Formulating State Observer and State Feedback
Luenberger Observer

Week 12

Time-Variant Systems
Nonlinear Systems
Linearization
Lyapunov Stability Analysis

Week 13

Kalman Filtering
Optimal Control Set-up

Final Exam

EEME E4601: Discrete Control Systems

Course Number: EEME E4601
Course Title: Discrete Control Systems
Lecture Hours: 2.5
Credits: 3
Instructor: Homayoon Beigi <hb87@columbia.edu>
Prerequisites: EEME E3601 or MEEE E4600

Textbooks:

Required:

Charles L. Phillips, "Digital Control System Analysis & Design," Pearson-Prentice Hall, New York, 2015, ISBN: 9780132938310.

Reference:

Homayoon Beigi, "Fundamentals of Speaker Recognition", Springer, New York, 2011, ISBN: 9780387775913.
Thomas E. Fortman and Konard L. Hitz, "An Introduction to Linear Control Systems," Control and Systems Theory Vol. 5, Marcel Dekker, Inc, New York, 1977.

Grading:

- Homework – 30%
 - Small Problems and/or Coding Assignments
- Midterm – 20%
 - Problems and/or Coding Assignments
- Project Proposal – 10%
 - 2-page proposal, including state of the art and proposed methodology – 5-10%
 - Up to 5% class participation
- Class Participation – 5%
- Final Project – 35%
 - 10% – Code
 - 25% – 6-page IEEE Style Report of the methodology and result +
3 minute Video Presentation

Up to 5% for class participation may be based on average participation in class. If most of the class is present, an attendance may not be taken, in which case the whole 10% will be counted toward the project proposal, otherwise, random attendance may be taken to assess class participation.

Course Description:

The course studies control strategies and their implementation in the discrete domain. Introduction with examples; review of continuous control and Laplace Transforms; review of continuous state-space representation and Solutions; review of difference equations, discretization in time and frequency, the WKS (aka Shannon) sampling theorem, windowing, filters, Transforms: Fourier series, Fourier transform, z-transform and their inverses; Ideal sampler, Sample-and-hold devices, zero, one, polygonal, and slewer hold; Transfer functions, block diagrams, and signal flow graphs for discrete systems; Discrete State-Space transformation, controllability, observability, and stability in the state-space domain. Discrete time and z domain analysis, steady state analysis, discrete-time root-locus, and pole-zero placement; Discrete Nyquist stability criterion, Bode plot, Gain and Phase Margin analysis, Nichols chart, bandwidth and sensitivity analysis; Design criteria, self-tuning regulator, Kalman filter, and simulation, followed by advanced stability analysis such as Lyapunov stability; Overview of the discrete Euler-Lagrange equations, discrete maximum and minimum principle, optimal linear discrete regulator design, optimality and dynamic programming.

Note:

More advanced Lyapunov and optimal treatment and solutions are left to more advanced courses: see MEEE E6610 Nonlinear and Adaptive Control.

Lectures:

Week 1

Introduction with examples

Week 2

Review of Mathematical Concepts

Review of continuous control

Laplace Transform

Week 3

Review of continuous state-space representation and Solutions

Week 4

Review of difference equations
Discretization in time and frequency
The WKS (aka Shannon) sampling theorem

Week 5

Windowing, filters
Transforms:
 Fourier series
 Fourier transform
Discrete Time Fourier Transform
Discrete Fourier Transform
Short Time Discrete Time and Discrete Fourier Transform

Week 6

z-transform
Inverse z-transform
Problem solving in z-Domain

Week 7

Ideal sampler, Sample-and-hold devices, zero, one, polygonal, and slewer hold;
Transfer functions, block diagrams, and signal flow graphs for discrete systems;

Week 8

Midterm (First half of class)
Discrete State-Space transformation, controllabililty, observability, and stability in the state-space domain.

Week 9

Discrete State-Space transformation, controllabililty, observability, and stability in the state-space domain (continued)
Discrete time and z domain analysis
steady state analysis

Week 10

Discrete-time root-locus and pole-zero placement
Discrete Nyquist stability criterion
Bode plot, Gain and Phase Margin analysis
Nichols chart

Week 11

Bandwidth and sensitivity analysis
Design criteria

Week 12

Self-tuning regulator
Kalman filter, and simulation, followed by advanced stability analysis such as Lyapunov stability

Week 13

Overview of the discrete Euler-Lagrange equations
Set up of the following:
 Discrete maximum and minimum principle
 Optimal linear discrete regulator design
 Optimality and dynamic programming

Final Projects are due

EEME E6601 Introduction to Control Theory Syllabus

Professor:

Primary contact: Email RWL4@columbia.edu

1. Course Description:

This is a self-contained graduate level introduction to linear feedback control systems. It does not assume any previous course in control. The course covers both classical control design methods, and modern or state variable control methods for designing automatic control systems. It is appropriate to take this course even if you already have seen classical control in another course, because it covers a much broader set of material, and does so on a 6000 level expecting more sophistication of understanding.

2. Prerequisites:

The course makes substantial use of ordinary equations, matrix differential equation, linear algebra, similarity transformations, Laplace transforms. The course is self-contained with respect to these topics, presenting what you need to know or need to remember in these fields, but previous familiarity with these topics is very helpful.

3. MS/PhD Programs

Control systems and control system concepts are used in many fields, so the course can be relevant to students in many departments. The course designator EEME indicated that it is particularly appropriate for people in Electrical Engineering and in Mechanical Engineering, including the fields that merge the two, Mechatronics and Robotics.

Feedback control is fundamental to Aeronautics and to Astronautics, to Chemical Process Control, to Nuclear Engineering, Automotive Engineering, and gets used in various ways in Civil Engineering for structural control and structural health monitoring. It also gets used beyond engineering, in Business and in Economics – aiming to optimally manage economic growth of an economy.

4. Required Textbook:

Required Textbook, *Modern Control Engineering*, by Ogata, 5th Edition, ISBN- 13: 978- 0136156734.

Topics from throughout the book are covered, but the lecture topics can come from many places through the book in any order. Some homework assignments are from the book.

There are also a number of handouts specifically prepared for the class on various useful topics.

5. Grading:

One Midterm Exam	45%,
Final (cumulative) Exam	45%,
Homework	10%.

6. Assignments:

Approximately weekly homework assignments. These are important, you need to struggle with the material in order to digest it, and also to be able prepared for the exams.

7. Exam Schedule:

There are weekly 3-hour lectures. The midterm exam is usually given after the 8th lecture or the 7th lecture. Midterm exam is 3 hours.

Final exam is normally scheduled after all lectures have been viewed, usually scheduled by the registrar.

EEME E6601 Schedule of Lectures, Homework Assignments, and Exams

The following list of topics is a representative list, but topics can be different or in a different order for any given year. And homework assignments may be different and due at different times.

LECTURE 1:

Classical control feedback loop, scalar differential equation models, Laplace transforms and transfer functions, state variable models, state observers, and modern control feedback structure. ***Related Handouts***

- BasicStructure
- ControlDesignAndODE
- LaplaceTransforms ***Homework***

Homework #1 Relates to this lecture Due at Lecture 4

LECTURE 2:

Response to command, to disturbances, to initial conditions. Solution of homogeneous differential equations. Stability, time constants, settling time, overshoot, desired pole locations for good performance. Solution of homogeneous state space equations. **Related Handouts**

- TransFnsAndBlockDiag
- HomogEqSol
- HomogEqSolAsTransients **Homework**

Homework #2 Relates to this lecture Due at Lecture 4

LECTURE 3:

Particular solutions. Annihilator method. Effect of controller gains on particular solutions. Impulse response, unit step response. Number of zeros vs. number of poles. Related **Handouts**

- ParticularSolutions **Homework**

Homework #3 Relates to this lecture Due at Lecture 5

LECTURE 4:

State variable models, multi-input, multi-output. Controllable and observable canonical form. Similarity transformations and conversions of state variables. Numerical solution of ODE's. **Homework**

Homework #4 Relates to this lecture Due at Lecture 6 Homeworks 1 and 2 due

LECTURE 5:

Response of classical control laws to commands, disturbances, and initial conditions. **Related Handout**

- RoutineControlLaws **Homework**

Homework #5 Relates to this lecture Due at Lecture 7 Homework 3 due

LECTURE 6:

Routh Criterion with special rules, use for range of stable gains, for gains producing desired settling times. Pole placement controller design for state variable models. No Handouts – Refer to Text **Homework**

Homework 4 due

LECTURE 7:

Observable canonical form and designing Luenberger observers by pole placement. Converting observable to controllable form. The separation theorem for controller and observer design, and closed loop stability. The Kalman filter observer. **Related Handout**

- QuadraticCostKalman **Homework**

Homework #6 assigned Due at Lecture 8 (one week) Homework 5 due

LECTURE 8:

Kalman filter. Exponential of a matrix, the state transition matrix. Diagonalization. **Homework 4** assigned

MIDTERM EXAM

(3 hours, closed book. Laplace tables supplied in case wanted) **Related Handout**

- WhatToKnowForMidterm

LECTURE 9:

Generalized eigenvectors. Jordan canonical form and exponential of matrix. Nilpotent matrix. Root locus plots for varying one parameter. **Related Handouts**

- RootLocus

LECTURE 10:

Root locus rules. Tuning more than one gain with root locus. Root locus vs. pole placement. **Related Handouts**

- RootLocus

LECTURE 11:

More root locus rules. Root finding. Frequency response. **Related Handouts**

- RootLocus
- FrequencyResponse **Homework**

Homework #7 due at Lecture 13

LECTURE 12:

Nyquist and Bode plots of frequency response. Bode plot superposition and linear approximations. Use for response to command and bandwidth, for response to disturbances. Nyquist stability criterion. Gain and phase margin measures of degree of stability. **Homework**
Homework 8, do not need to turn in

LECTURE 13:

Controllability. Rank of square and rectangular matrices. Observability. Controller design by Linear Quadratic Regulator. **Related Handouts**

- QuadraticCostPagesFromOgata
- QuadraticCostKalman **Homework**

Homework #7 Due

FINAL EXAM

(3 hours, closed book. Laplace tables supplied in case wanted) Scheduled by Columbia Registrar **Related Handout**

- WhatToKnowForFinal

MEBM E4439 – Modeling and Identification of Dynamic Systems

Professor: Nicolas W. Chbat, PhD

Teaching Assistant: Cheng Bi

Week	Topic	Hours
1	Fluid Systems, Physical Laws	3
2	Generalized Dynamics System Modeling, Linear Systems, Convolution, Impulse and Step Responses, State-Space Matlab/SIMULINK*	3
3	Nonlinearities, 3 rd and higher order systems	3
4	Thermal Systems, Mechanical Systems	3
5	Mechanical Systems (cont'd)	3
6	Electrical and Diffusive Systems	3
7	Hybrid Systems, Transformers, Gytrators	3
8, 9	Classical & Non-parametric System Identification, Z-transform	6
10, 11	Stochastic signals, Parametric System Identification	6
12, 13	Kalman Filter, Observer-Kalman Identification (OKID)	6
Extra	Lab session: Matlab's System ID Toolbox*, Review	2

Grade:

Homework: 40%
 Exam 1: 25%
 Exam 2: 35%
Total: 100%

There will be ~10 homework sets and 2 exams. Exam1 is a modeling project.

Textbooks (suggested – also on reserve in library):

1. Rowell, Wormley *System Dynamics, An Introduction*
2. Chow, Frederick, Chbat *Discrete-Time Control Problems using Matlab*
3. DiStefano III *Dynamic System Biology Modeling and Simulation*
4. Iserman, Munchhof *Identification of Dynamic Systems, Introduction with Applications*

Rationale: Articulating real-world dynamics mathematically, i.e. modeling, is often half of the battle in solving engineering problems. Understanding different modeling approaches (based on data, rules, physics, or probabilities) and their applicability is an invaluable tool to the practicing engineer. Quickly obtaining ordinary differential equations of a dynamic system and estimating its parameters from experimental data (system id or parameter estimation), sets the engineer apart. A model thus obtained can be readily used for prediction, diagnosis, or controller design.

MEBM E4710 Morphogenesis: Shape and Structure in Biological Materials

Office Hours Prof. Kasza: TBA, Mudd 220C (and by appointment, karen.kasza@columbia.edu)

Prerequisites

Courses in mechanics, thermodynamics, and ordinary differential equations (for example ENME 3113, MECE E3301, and MATH UN3027) at the undergraduate level or instructor's permission.

Description Introduction to how shape and structure are generated in biological materials using an engineering approach that emphasizes the application of fundamental physical concepts to a diverse set of problems. Mechanisms of pattern formation, self-assembly, and self-organization in biological materials, including intracellular structures, cells, tissues, and developing embryos. Structure, mechanical properties, and dynamic behavior of these materials. Course uses textbook materials as well as a collection of research papers.

Textbooks For course readings, I am requiring:

- *Mechanisms of Morphogenesis*, 2nd Edition, Jamie Davies (required)

Other texts that may be helpful:

- *Biological Physics of the Developing Embryo*, 1st Ed., by Forgacs and Newman, Cambridge University Press, 2005.
- *Molecular Biology of the Cell*, 6th Ed., by Alberts et al., Garland, 2014.
- *Physical Biology of the Cell*, 2nd Ed., by Phillips, Kondev, Theriot, and Garcia, Garland Science, 2012.
- *Mechanics of Motor Proteins and the Cytoskeleton*, by Jonathan Howard, Sinauer, 2001.

Course structure

The course will consist of lectures and in-class discussions of research papers. For in-class discussions, you should read the papers well ahead of time and prepare a "reading memo" that will help you prepare for the discussion (details to follow).

Homework

Homework and paper readings will be assigned every one or two weeks.

Homework and reading memos must be submitted electronically via Courseworks as a pdf file.

You are encouraged to discuss with the TA and the instructor. You may discuss with classmates, but the work you submit should be your own. Copying homework from other students is unacceptable, against University regulations, and will be dealt with according to University policy. **You may not consult solutions from past years, online, or from textbook solutions.**

Final presentation Each student will read and present a research paper to the class. I will post suggested papers. You are encouraged to use one of these papers for your presentation, but if you have another paper you would like to present, you may propose it to me for approval.

Phones Cell phone use is not allowed during class.

Grading

- 35% Homework
- 25% Reading memos
- 15% Participation in in-class discussions
- 25% Final presentation

Important Note I would like to notify all individuals with access to the MEBM E4710 course materials that the course material is copyrighted and is not to be freely distributed/posted online without the written consent of the professor. I explicitly deny consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Canvas (a.k.a Courseworks2). Notice has been provided directly to Course Hero that they are not to accept any course content from this course for the current and for the past semesters. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

MEBM E6310 MIXT THEORIES FOR BIOL TISSUES

Notice:

I would like to notify all individuals with access to the MEBM E6310 course material that the course material for MEBM E6310 is copyrighted and is not to be freely distributed/posted online without the written consent of the professor. I explicitly deny consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Courseworks. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

Academic Integrity

The follow constitutes cheating:

- Copying assignments from others.
- Consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by the instructor.
- Completing individual assignments in a group, when permission not explicitly granted by the instructor.
- Plagiarizing the work of others.
-

Cheating may lead to the following consequences:

- Students receive a failing grade for a specific assignment.
- Students receive a failing grade for an entire course.
- Students may be expelled from the university.
- The Department of Mechanical Engineering adheres to Columbia's policies on academic integrity, see <http://www.college.columbia.edu/academics/integrity>.

Student Bill of Rights

- Academic integrity policies clearly explained at start of semester
- Course requirements/grading policies/etc. must be clearly stated at the start of the semester.
- Textbook/reference book usage must be clarified at the start of semester.
- Homework assignments will be graded on a weekly basis (unless a valid explanation is provided).
- Midterm exams will be graded within two weeks of the test (unless a valid explanation is provided).
- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedures for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

Honor Code

- Honor code: <https://www.cc-seas.columbia.edu/integrity> (<https://www.cc-seas.columbia.edu/integrity>)
- Also review the guidelines posted here:
<http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>
(<http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>)
- All coursework is to be done by the student working alone. For homework assignments, you may consult other students for general guidelines or to review and discuss material covered in class, but homework assignments must be completed individually.
- No external aids or electronic devices are allowed in exams.
- Do not look up homework solution sets posted from previous years or posted elsewhere.
- Consult the instructor if you require clarifications regarding the honor code.

Course Grading

- Homeworks 30%
- Midterm Exam 30%
- Final Exam 40%

Chapter 1: Mixture Theory

- History
 - The theory of mixture
 - Mixture theory for biological tissues
- Basic definitions in mixture theory
 - Apparent and true mass densities
 - Molar concentration
- Simplifying assumptions for biological tissues
 - Intrinsic incompressibility of constituents
 - Electroneutrality
 - Isothermal conditions

- o Constrained mixtures of solid constituents
- o Negligible fluid viscosity and solid viscoelasticity

Chapter 2: Tissues Modeled as a Mixture of a Solid and a Fluid

- Introduction
- Governing equations of a solid-fluid (biphasic) mixture
 - o Overview
 - o Mass balance
 - o Stress tensor of mixture constituent
 - o Momentum balance
 - o Energy balance
 - o Entropy inequality
 - o Kinematics of the continuum
 - o Constitutive assumptions
 - o Implications for momentum balance
 - o Frictional drag between fluid and solid constituents
 - o Linear isotropic elastic solid
 - o Summary of governing equations
- Boundary conditions
 - o Mass jump across an interface
 - o Momentum jump across an interface
 - o Energy jump across an interface
 - o Summary of boundary conditions
- Permeation
 - o Steady-state permeation
 - o Transient response
- Confined compression
 - o Creep
 - o Stress-relaxation
- Unconfined compression
 - o Solution by the method of Laplace transform
 - Initial and equilibrium responses
 - Transient response
- Transport across thin membranes

Chapter 3: Solute Transport in Biological Tissues

- Introduction
- Governing equations for a solid-solvent-solute mixture
 - o Constitutive assumptions
 - o Implications for momentum balance
 - o Frictional drag
 - o Chemical potential of ideal solutions
 - Fluid mixtures
 - Solid-fluid mixtures
 - o Chemical potential of non-ideal solutions
 - o Solubility and partition coefficient
 - o Diffusion coefficients and Fick's laws for dilute solutions
- Summary of governing equations
- Boundary conditions
- FEBio tutorial

Course Summary:

Date	Details	Time
Wed Jan 29, 2020	HW 01 https://courseworks2.columbia.edu/courses/95904/assignments/404587	4:10 pm
Wed Feb 5, 2020	HW 02 https://courseworks2.columbia.edu/courses/95904/assignments/408288	4:10 pm
Wed Feb 19, 2020	HW 03 https://courseworks2.columbia.edu/courses/95904/assignments/413051	4:10 pm
Wed Feb 26, 2020	HW 04 https://courseworks2.columbia.edu/courses/95904/assignments/415759	4:10 pm
Wed March 4, 2020	HW 05 https://courseworks2.columbia.edu/courses/95904/assignments/417622	4:10 pm
Wed Apr 1, 2020	Midterm Examination https://courseworks2.columbia.edu/courses/95904/assignments/421604	4:10 pm
Wed Apr 15, 2020	HW 06 https://courseworks2.columbia.edu/courses/95904/assignments/432255	4:10 pm

Wed May 13, 2020	Final Examination https://courseworks2.columbia.edu/courses/95904/assignments/4430297 pm	
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MECE E3408 COMPUTER GRAPHICS & DESIGN

INSTRUCTOR: Sinisa Vukelic E-mail: sv2147@columbia.edu OFFICE HOURS:
TBD, by appointment, and any time you see me in the office

TA OFFICE HOURS:
TBD

Location: ENGINEERING TERRACE, ET 252, COMPUTER LABORATORY

LECTURES:
SECTION 1:

Mondays and Wednesdays 8:40 pm –9:55 pm

Location: ENGINEERING TERRACE, ET 252, COMPUTER LABORATORY

SECTION 2:

Mondays and Wednesdays 10:10 pm – 11:25 am

Location: ENGINEERING TERRACE, ET 252, COMPUTER LABORATORY

RECITATIONS

First part of the semester (classes up to the midterm): Zoom recordings.

Second part of the semester (Labs): Zoom recordings and in-person sessions. These recitations will be primarily used as help room for SolidWorks assignments, and You are welcome to come to the recitations to work on your lab/homework assignments. Course assistants (CAs) will be around to help you, if needed. Please note that CAs will leave if no one shows up for recitation by 20 minutes after the session has started. In case you plan to come later, please communicate this matter in advance with CAs via email.

REQUIRED TEXTBOOK

SolidWorks 2025 Tutorial, by David C. Planchard, SDC Publications (older editions should be fine as well)

RECOMMENDED TEXTBOOKS

Fundamentals of Graphic Communication by Gary R. Bertoline and Eric N. Wiebe Engineering Design Graphics, by James M. Leake and Jacob L. Borgerson

GRADING:

- Homeworks and Labs combined 25%
- Midterm #1 20%
- Midterm Project 20%
- Final Project 30%
- Professionalism 5%

COURSE OBJECTIVES

- Develop understanding of technical drawings as means of communication of technical ideas in mechanical engineering design and products.
- Understand how to read technical drawings
- Be able to use and create technical drawings to communicate technical ideas
- Learn the terms, standards, and conventions used in modern engineering drafting.
- Develop sketching and visualization skills.
- Be able to sketch and visualize mechanical components and assemblies
- Become proficient in using a CAD package
- Create a complete set of working drawings for an existing engineering design.

COURSE DESCRIPTION

Lectures will focus on development of visualization skills and the principles of technical drawing applied in the form of engineering graphics. Lectures will include but are not limited to pictorial views, multiview drawings, dimensioning and tolerancing, section and auxiliary views, assemblies and working drawings. In addition, students will master solid modeling skills and produce engineering drawings through learning to use the chosen CAD software. At the end of the semester a reverse engineering design project will be assigned to test mastery of solid modeling techniques. Additional time outside of the class will be required to master the material.

COURSE POLICY

- Attendance: Due to current situation the attendance policy is amended. Attendance is strongly suggested. However, it is understood that we are currently facing enormous challenges and thus mandatory attendance is waived.

- Professionalism: Professional behavior is expected in all aspects of the course. This includes, but is not limited to, timely arrival for class and appointments, undistracted attention during class and timely communication of special circumstances such as illness or personal issues that interfere with this course.

ACADEMIC HONESTY POLICY

The academic honesty policies for the Mechanical Engineering Department are listed at:

<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at:

<http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at

<http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at: <http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Furthermore, in this course the follow constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by the instructor.
- Completing individual assignments in a group, when permission not explicitly granted by the instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university. Student rights:
- Academic honesty policies clearly explained at start of semester
- Course requirements and grading policies must be clearly stated at the start of the semester.
- Textbook and reference book usage must be clarified at the start of the semester.
- Homework assignments will be graded on a weekly basis (unless clear explanation provided).
- Midterm exams will be graded within two weeks of the test (unless clear explanation provided).
- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedures for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

Consult the instructor if you require clarifications regarding the honor code.

MECE E3409 Machine Design

Instructor:

Dr. Yevgeniy Yesilevskiy E-mail: yy3040@columbia.edu
Office: 232A Mudd inside the Mechanical Engineering Office
Office Hours: TBD

Office Hours Zoom link: By request for special circumstances (e.g. illness, religious holiday, job interview, or another legitimate reason)

Teaching Assistants:

TBD

Class times:

Tuesday, Thursday: 10:10am – 11:25am

Optional Textbooks:

Machine Design an Integrated Approach by Norton.
Design of Machinery by Norton
The Fundamentals of Machine Component Design, by Juvinall and Marshek
Shigley's Mechanical Engineering Design by Budynas and Nisbett
Mechatronics and Measurement Systems by Alciatore

Course Syllabus

Course Description

The goal of the course is to teach students the fundamentals and principles behind both mechanical and electromechanical systems. By the end of the course, students will be able to utilize these fundamentals to design, build, and analyze simple mechanical systems and their constituent components.

Credits

This is a 3-credit course.

Learning Objectives

After taking this course, students will

1. Be able to describe and explain mechanical components, mechanisms, and electromechanical components/systems.
2. Design and precisely manufacture an electro-mechanical system that interfaces with existing hardware in order to achieve a goal. As part of this goal, students will learn to make manufacturing/design tradeoffs, and be able to choose standard off-the-shelf parts that meet their design/performance criteria.
3. Perform analysis of mechanisms and electromechanical systems to see if they meet desired design criteria.
 - a. This analysis will take place through modeling as well as virtual prototyping methods.
4. Prepare detailed engineering drawings and manufacturing plans to precisely manufacture parts that have the correct geometry, loading characteristics, and tolerances.
5. Build and assemble electro-mechanical systems using machine shop tools and electrical elements.
6. Test and evaluate the performance of mechanical systems, and redesign as necessary to improve the performance.
7. Understand safety considerations in mechanism design.
8. Communicate design and manufacturing choices and their rationale orally and in writing.

Course Requirements and Expectations

- 1) Attendance expected.
- 2) Complete all homework assignments.
- 3) Complete the project (project requirements and expectations to be given in a separate document).
- 4) Take the exam(s)

Homework

Homework will be assigned regularly. It is always due by the posted time. Due dates will be posted with each assignment. All assignments are to be completed on your own. While students may consult with course instructors and other students during the conceptualization of a problem, all submitted work should be done by you alone. Additionally, students are not allowed to use, in any way, pre-existing solutions (either former students' work, solutions from the publisher, or from any former instructor). Again, all assignments should reflect your own work. Violation of this policy will initiate action according to the Academic Integrity Violation and Sanction Classification Rubric.

Late Submission Policy

Unless the lateness is excused, there is a penalty of 10% off of the assignment per late day (if the submission is an hour late on the due date, that will count as the first late day). Once the answer key to the homework is posted, no more submissions are allowed and all credit for that assignment will be lost.

Grading

Outcome will be determined based off of the following percentages:

- Project 50%
- Peer Evaluation 10%
- Homework assignments 20%
- Exam 20%

NOTE: If your peer evaluations indicate that you did little to no work on the project, you will receive a greatly reduced project score.

Academic Honesty Policy

The academic honesty policies for the Mechanical Engineering Department are listed at:
<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at:
<http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at
<http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at:
<http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment. It is the responsibility of each student to read and understand these policies.

For this course, ChatGPT and similar AI tools will NOT be used unless explicitly allowed. It will be considered a violation of the academic honor code if it is used to complete assignments.

Attendance Policy

Class and lab attendance is mandatory. Unexcused missed class will result in grade reduction. Discuss with the instructor any potential conflict or illness with the instructor well before the session.

Disability-related Academic Accommodations

In order to receive disability-related academic accommodations for this course, students must first be registered with their school Disability Services (DS) office. Detailed information is available online for both the Columbia and Barnard registration processes. Refer to the appropriate website for information regarding deadlines, disability documentation requirements, and drop-in hours (Columbia)/intake session (Barnard). Students registered with the Columbia DS office can refer to the Master TARF section of the DS Testing Accommodations page for more information regarding disability-related academic accommodations for this course

MECE E3420 Senior Design

Instructors:

Dr. Yevgeniy Yesilevskiy E-mail: yy3040@columbia.edu
Office: 232A Mudd inside the Mechanical Engineering Office

Office Hours: TBD

Office Hours Zoom link: By request for special circumstances (e.g. illness, religious holiday, job interview, or another legitimate reason)

Teaching Assistant:TBD

Class times:

Monday, Wednesday: 1:10pm – 3:40pm

Course Syllabus

Course Description

The goal of the course is to guide students through the first portion of an iterative design cycle focused on need-based problem solving. Students will be taught ideation techniques, develop problem choices, conduct interviews, develop solutions, and create low-fidelity proof-of-concept prototypes. Students will also frequently present in the course and receive presentation critique.

Credits

This is a 3-credit course.

Learning Objectives

After taking this course, students will

1. Be able to develop an engineering solution that meets a need.
2. Be able to use ideation techniques to develop a problem and solution space.
3. Understand how to utilize end-users and research to guide the design process.
4. Be able to confidently and cogently present their project ideas.
5. Be able to use low-fidelity prototypes to iterate towards a finalized design.
6. Understand the design process.

Course Requirements and Expectations

- 1) Attendance expected.
- 2) Complete all assignments.
- 3) Develop a proof-of-concept prototype.
- 4) Present in all presentations.

Assignments

Team assignments will be given regularly to check-in on progress with class goals. It is always due at the start of class. Due dates will be posted with each assignment. All assignments are to be completed as a team, with a single submission per team. While students may consult with course instructors and other students during the conceptualization of the assignment tasks, all submitted work should be done by the team alone. Additionally, teams are not allowed to use, in any way, pre-existing materials (either former students' work or from any former instructor). You may reference materials using appropriate citation techniques. Again, all assignments should reflect your team's own work. Violation of this policy will initiate action according to the Academic Integrity Violation and Sanction Classification Rubric.

Project Requirements

The project chosen by each team must solve a well-articulated need. Note, this need requirement should not be limiting. Needs can include anything from solving pollution problems to bringing joy in the form of a kinetic art installation. The possible categories for project choice fall into the following three categories:

- 1) Invention/Product: The product should serve a need for a customer. The prototype is a demonstration of the operation of the product.
- 2) Analytical: Address an engineering problem in one of the mechanical engineering disciplines. These projects will necessarily require a more significant level of engineering analysis, modeling, and simulation.
- 3) Experimental: Design an experimental apparatus to test a hypothesis.

Aside from falling into one of the above categories, the project must also meet the following requirements:

- 1) There must be a significant physical and/or simulation component related to mechanical engineering design.
- 2) The prototype and/or simulation must have a mechanical function (it cannot be, for example, just a case that holds a sensor).
- 3) The solution must be the right one for the problem. If in the course of solving a problem, a team finds that the best solution is not a mechanical engineering one, the team will modify their problem rather than “force” a mechanical engineering solution onto their current problem.
- 4) The project must be of proper scope, neither too small or too big. As such, it must receive approval by the instructors.
 - a. The goal of the course is to do a full-year design sequence. This is not a place to continue existing projects. It is a place to find a problem, develop a solution, and refine on that solution.
- 5) It must be novel.
- 6) The project cannot be tied to a Columbia club
 - a. The intent is to go through a full design sequence, not iterate slightly on an existing part.
 - b. Funding from clubs cannot be used for Senior Design projects

Teams

Project teams should consist of 4 members, though they may have as many as 5. Enthusiasm is key in forming teams! You will necessarily have to learn new skills for your project, and the enthusiasm to learn these skills to meet your project goals is a necessity.

Late Submission Policy

Unless the lateness is excused, there is a penalty of 10% off of the assignment per late day (if the submission is an hour late on the due date, that will count as the first late day). Once the answer key to the homework is posted, no more submissions are allowed and all credit for that assignment will be lost.

Grading

Outcome will be determined based off of the following percentages:

- | | | |
|---------------------------------------|-----|-----|
| • Assignments | | 15% |
| • Performance in weekly meetings | 15% | |
| • Peer Evaluation | | 10% |
| • Presentations | | 30% |
| • Proof-of-concept Prototype | 25% | |
| • Return of all tools in Machine Shop | 5% | |

Note: if your peer evaluations indicate you did little to no work, your scores across all other areas will see a significant reduction.

Academic Honesty Policy

The academic honesty policies for the Mechanical Engineering Department are listed at:
<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at:

<http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at
<http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at:

<http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Attendance Policy

As noted above, attendance is expected. In general, for the Monday slot of the course the first hour will typically have an instructional component, followed by group meetings. During this time, the instructor will be available to help answer questions and address issues. During the Wednesday slot, you will again have group time where the instructors will be available.

Disability-related Academic Accommodations

In order to receive disability-related academic accommodations for this course, students must first be registered with their school Disability Services (DS) office. Detailed information is available online for both the Columbia and Barnard registration processes. Refer to the appropriate website for information regarding deadlines, disability documentation requirements, and drop-in hours (Columbia)/intake session (Barnard).

Students registered with the Columbia DS office can refer to the Master TARF section of the DS Testing Accommodations page for more information regarding disability-related academic accommodations for this course.

MECE E3430 Senior Design

Instructors:

Dr. Yevgeniy Yesilevskiy

E-mail: yy3040@columbia.edu

Office Hours: TBD

Office Hours Zoom link: By request for special circumstances (e.g. illness, religious holiday, job interview, or another legitimate reason)

Teaching Assistants:

TBA

TA office hours, they will be held in the machine shop. Hours TBD

Monday -

Tuesday-

Wednesday-

Thursday-

Friday -

When you are ready to place an order, begin by filling out the spreadsheet here:

<https://docs.google.com/spreadsheets/d/1mJ32zk01fCvC4jzfc0OOR5MiqL4CIJht215hauza3hs/edit?usp=sharing>

Then e-mail your corresponding TA and cc me as well to tell us that you've updated the order sheet. Once you've done that, the order will be placed soon after. When it arrives, your TA will get the package and put it in your plastic bin in the machine shop.

Class times:

Tuesday, Thursday: 1:10pm – 3:40pm

Tentative Presentation Dates:

- Week 6 (2/24 - 2/28)
- Week 11 (3/31 - 4/4)
- o Spring Break is 3/17 – 3/21
- Week 15 (4/28 - 5/2)

Course Syllabus

Course Description

The goal of the course is to guide students through the second portion of an iterative design cycle focused on need-based problem solving. Students will build on the progress from their low-fidelity, proof-of-concept prototypes created in the first semester of Senior Design to create refined prototypes. The design choices in these refined prototypes will be based on analysis and the incorporation of engineering standards to meet realistic constraints. Students will also frequently present in the course and receive presentation critique.

Credits

This is a 3-credit course.

Learning Objectives

After taking this course, students will

1. Have a knowledge of engineering standards.
2. Be able to define realistic constraints that guide the refinement of their proof-of-concept prototypes.
3. Be able to use analysis techniques from earlier course work in combination with engineering standards to design a prototype that meets those realistic constraints.
4. Be able to confidently and cogently present their analysis and resulting design choices.
5. Develop refined prototypes.
6. Summarize their analysis and design choices in a conference-style paper.

7. Develop a video summarizing their problem, solution, and key design features.

Course Requirements and Expectations

- 1) Attendance is not mandatory, with the exception of presentation days, but strongly encouraged.
- 2) Complete all assignments.
- 3) Develop a refined prototype.
- 4) Present in all presentations.
- 5) Submit an analysis report.

Assignments

Team meetings will be regularly scheduled to check-in on progress with class goals. While students may consult with course instructors and other students during the conceptualization of their tasks, all submitted work should be done by the team alone. Additionally, teams are not allowed to use, in any way, pre-existing materials (either former students' work or from any former instructor). You may reference materials using appropriate citation techniques. Again, all assignments should reflect your team's own work. Violation of this policy will initiate action according to the Academic Integrity Violation and Sanction Classification Rubric.

Project Requirements

The project chosen by each team must solve a well-articulated need. The possible categories for project choice fall into the following three categories:

- 1) Invention/Product: The product should serve a need for a customer. The prototype is a demonstration of the operation of the product.
- 2) : Address an engineering problem in one of the mechanical engineering disciplines. These projects will necessarily require a more significant level of engineering analysis, modeling, and simulation.
- 3) Experimental: Design an experimental apparatus to test a hypothesis. The experiment should be constructed in such a way that it has teaching value, and can be used in future undergraduate courses for laboratory experiments.

Aside from falling into one of the above categories, the project must also meet the following requirements:

- 1) There must be a physical prototype
- 2) The prototype must have a mechanical function (it cannot be, for example, just a case that holds a sensor).
- 3) The solution must be the right one for the problem. If in the course of solving a problem, a team finds that the best solution is not a mechanical engineering one, the team will modify their problem rather than "force" a mechanical engineering solution onto their current problem.
- 4) The project must be of proper scope, neither too small nor too big. As such, it must receive approval by the instructors.
- 5) It must be novel.

Teams

Project teams should consist of 4 members, though they may have as few as 3 and as many as 5. Enthusiasm is key in forming teams! You will necessarily have to learn new skills for your project, and the enthusiasm to learn these skills to meet your project goals is a necessity.

Late Submission Policy

Unless the lateness is excused, there is a penalty of 10% off of the assignment per late day (if the submission is an hour late on the due date, that will count as the first late day). Once the answer key to the homework is posted, no more submissions are allowed and all credit for that assignment will be lost.

Grading

Outcome will be determined based off the following percentages:

- Peer Evaluation 10%
- Individual progress during weekly check-ins 10%
- Presentations 30%
- o Design Review I
- o Design Review II

o	Final Presentation		
•	Refined Prototype	20%	
•	Analysis Report		25%
•	Website	2.5%	
•	Project Video		2.5%

Note: if your peer evaluations indicate you did little to no work, your scores across all other areas will see a significant reduction.

Academic Honesty Policy

Under no circumstances is it acceptable to copy text from another source without proper acknowledgement. It is the responsibility of each student to read and understand these policies.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at <https://bulletin.engineering.columbia.edu/academic-integrity-and-discipline>

Resources for help can be found here: <https://www.cc-seas.columbia.edu/integrity>

Attendance Policy

As noted above, attendance is not mandatory, with the exception of presentation days, but strongly encouraged.

Disability-related Academic Accommodations

In order to receive disability-related academic accommodations for this course, students must first be registered with their school Disability Services (DS) office. Detailed information is available online for both the Columbia and Barnard registration processes. Refer to the appropriate website for information regarding deadlines, disability documentation requirements, and drop-in hours (Columbia)/intake session (Barnard).

Students registered with the Columbia DS office can refer to the Master TARF section of the DS Testing Accommodations page for more information regarding disability-related academic accommodations for this course.

MECE E3610: Materials and Processes in Manufacturing

INSTRUCTOR: Sinisa Vukelic E-mail: sv2147@columbia.edu Office: 122B Mudd

TEACHING ASSISTANT(S):
TBD

OFFICE HOURS:
TBD, by appointment, and any time you see me in the office

LECTURES:
Mondays and Wednesdays 1:10 pm –2:25 pm
Location: 602 Hamilton Hall

TEXTBOOK

- Kalpakjian, S. and Schmid, S. R., Manufacturing Engineering and Technology, 6th Ed., Prentice Hall, 2010

REFERENCE TEXTBOOK

- Smith, W. F. and Hashemi, J., Foundations of Materials Science and Engineering, 5th Ed., McGraw Hill, 2010

COURSE DESCRIPTION:
Introduction to microstructures and properties of metals, polymers, ceramics and composites; typical manufacturing processes: material removal, shaping, joining, and property alteration; behavior of engineering materials in the manufacturing processes.

GENERAL TOPICS

- Properties of Materials
- Structure of materials
- Structure of Metals
- Phase Diagrams
- Heat Treatment
- Ferrous and nonferrous metals and alloys
- Metal casting processes
- Bulk and sheet metal forming processes
- Metal removal processes
- Nontraditional machining processes
- Polymer materials
- Shaping and forming polymers
- Powder metallurgy, additive processes
- Ceramic materials and processing
- Composite materials and processing

GRADING:

- Homework Assignments (15%)
- Midterm Exam (25%)
- Midterm Project (25%)
- Final Project/Exam (35%)

COURSE POLICY

- Attendance: Attendance is mandatory.
- Professionalism: Professional behavior is expected in all aspects of the course. This includes, but is not limited to, timely arrival for class and appointments, undistracted attention during class and timely communication of special circumstances such as illness or personal issues that interfere with this course.

ACADEMIC HONESTY POLICY
The academic honesty policies for the Mechanical Engineering Department are listed at:
<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at: <http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at <http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at: <http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Furthermore, in this course the follow constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university.

Student rights:

- Academic honesty policies clearly explained at start of semester
- Course requirement and grading policies must be clearly stated at start of semester.
- Textbook and reference book usage must be clarified at start of semester.
- Homework assignments will be graded on a weekly basis (unless clear explanation provided).
- Midterm exams will be graded within two weeks of test (unless clear explanation provided).
- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedure for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

Consult the instructor if you require clarifications rega

ME E4058 - Mechatronics & Embedded Microcomputer Control

Instructor: Dr. Enrico Zordan
E-mail: ez2287@columbia.edu

TA / Course Assistants (CA) (for both Lab Sessions):

tbd tbd@columbia.edu
tbd tbd@columbia.edu
tbd tbd@columbia.edu

Mechatronics Class Hours: Maximum Lab Enrollment 30

Lecture:	Thursday	4:10 – 6:40	Mudd 337
Lab:	Thursday	7:00 – 9:30	MechTech ET 273

Course Description:

What constitutes a successful mechanical product design in today's world where electronics and computers are found everywhere? This course addresses this question. Mechatronics, as an engineering discipline, is the synergistic combination of mechanical engineering, electronics, control engineering, and computer software, all integrated through the product design process. Starting at concept and continuing through manufacture, mechatronic designs optimize the available mix of technologies to produce quality precision products and systems in a timely manner with features that the customer wants. If successful product designs are to be produced in today's environment, it is imperative that electronics and computer software be included in the design process when the basic product functions and properties are defined. The real benefits to industry of a mechatronic approach to product design are shorter development cycles, lower costs, and increased quality, reliability, and performance. This course covers mechatronic system design, analysis of dynamic systems, control sensors and actuators, analog and digital control electronics, interfacing sensors and actuators to a microcomputer, discrete and continuous controller design, and real-time programming for control. These are the fundamental areas of technology that determine successful mechatronic designs. Emphasis is placed on physical understanding and design issues rather than on mathematical formalities. Throughout the coverage, the focus is kept on the role of each of these areas in the overall design process and how these key areas are integrated into a successful mechatronic system design.

Course Layout:

Mechatronics Syllabus

This course is organized in a combined lecture / laboratory format. Lectures are designed to introduce the material and to show how the course material can be used to solve real world design problems. Laboratory sessions address case studies in mechatronic product design. Rather than concentrating on a single product, the case studies deal with general techniques which can be applied in a wide variety of product areas.

Prerequisites:

Basic Knowledge of:

- Dynamic Systems Analysis
- Circuits, Electronics and Instrumentation
- C Programming

Course Objective:

Product design is one of the few engineering activities that have not been outsourced to countries outside the United States. The "mechatronics engineer" is that rare individual who has a genuine interest and ability to span a wide range of technologies, and who takes delight in working across disciplinary boundaries. The mechatronics engineer can identify and use the particular blend of technologies which will provide the most economic, elegant, and appropriate solution to the product design problem at hand. To be able to evaluate concepts generated during the design process, without building and testing each one, the mechatronics engineer must be skilled in the modeling, analysis, and control of dynamic systems and understand the key issues in hardware implementation. This course studies, in depth, the key areas of technology on which successful mechatronic designs are based and thus lays the foundation for the students to become true mechatronic engineers.

The objective of this course is for the student to be competent in the following areas:

- Mechatronic System Design Principles (discussed throughout the course)
- Analysis of Dynamic Physical Systems (discussed primarily in lecture)
- Embedded Microcomputer Control System Design
- Analog and Digital Control Electronics
- Digital Data Acquisition and Waveform Generation

- Control Sensors and Actuators
- Interfacing Sensors and Actuators to Microcomputers
- Real-Time Programming in Assembler and Embedded C
- Advanced Concepts (e.g. fuzzy logic control, active materials as sensors and actuators)

In addition, this course:

1. provides students with industrial design experience. Students learn product design by experience, implementing solutions for case studies on real world design problems. Each case study contains a specific set of design objectives that must be met.

Mechatronics Syllabus

2. fosters team building. Students are divided into two-person lab teams. Case studies require significant work extending over several weeks. Assignments require the planning, delegation of tasks, coordination and communication required of a team effort.
3. enhances student skills related to all elements of engineering design methodology, including analysis, modeling, simulation, experimentation and satisfying design constraints.
4. has each team of students execute several engineering design projects using embedded microcomputer control.
5. teaches the application of analog and digital electronics, microcomputers, and control sensors and actuators through laboratory experimentation. All case studies involve electronic feedback control of mechanical systems requiring the integration of electronic, computer, control and mechanical components.

Textbook:

Course notes written by the instructor serve as the textbook for the course. These will be supplemented with sections from various published sources and information from internet locations.

References: (not to be purchased)

Mechatronics

1. *The Art of Embedded System Design*, Ganssle, J., Newnes, 2nd edition, Butterworth-Heinemann, 2008. (on reserve in the library)
2. *Art Of Electronics*, Horowitz, P. and Hill, W., 3rd edition, Cambridge University Press, 2015. (on reserve in the library)
3. *Mechatronics with Experiments (Coursemart)*, Centinkunt, S., 2nd edition, 2015. (on reserve in the library)
4. *Mechatronics: an Integrated Approach*, de Silva, C. W., CRC Press, 2005. (on reserve in the library)
5. *Introduction to Mechatronic Design*, Carryer, J.E., Ohline, R.M., & Kenny, T.W., Prentice Hall, 2011.
6. *Getting Started in Electronics*, Mims, III, F.M. 1997 (on CourseWorks)
7. *Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering*, Bolton, W., 5th Edition, Addison Wesley Longman.
8. *Introduction to Mechatronics and Measurement Systems*, 2nd edition, Alciatore, D. & Hestand, M. McGraw Hill, 2003.
9. *Dynamic Modeling and Control of Engineering Systems, Second Edition*, Shearer, J.L., Kulakowski, B.T. & Gardner, J.F., Prentice Hall, 1997.
10. *Modeling and Analysis of Dynamic Systems, Second Edition*, Close, C. & Frederick, D., Houghton Mifflin Co., 1993
11. *Control Sensors and Actuators*, C.W. deSilva, Prentice-Hall, 1989. (on reserve in the library)
12. *Mechatronics System Design*, Shetty, D. and Kolk, R., PWS Publishing Co., 1997.
13. *Design with Microprocessors for Mechanical Engineers*, A.K. Stiffler, McGraw-Hill, 1992.
14. *Measurement Systems*, E.O. Doebelin, 4th Edition, McGraw-Hill, 1990.

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15. *Feedback Control of Dynamic Systems*, Franklin, G., Powell, J., and Emami-Naeini, A., 7th Edition, Addison-Wesley, 2014.
16. *Control System Design: An Introduction to State-Space Methods*, Friedland, B., Dover Books, 2005

C Programming

1. *The C programming Language*, Kernighan, B. W. & Ritchie D. M., Prentice Hall, 1988. (on reserve in the library)
2. *C Language for Programmers*, Pugh, K., QED Information Sciences, 1989. (on reserve in the library)

Lecture Topics: Topics are covered using both Lecture and Case-Study. Case Studies emphasize a Problem-Solving Approach with Hands-on Laboratory Exercises and Hardware Demonstrations.

1. Introduction to Mechatronics
2. Mechatronic System Design (discussed throughout the course)
3. Digital Electronics (digital logic, timing circuits and state machines)
4. Analog Electronics (op amps and filters)
5. Data Acquisition Systems
6. Laboratory Equipment (mixed signal oscilloscope, power supplies, function generator, digital multimeter)
7. Embedded Microcomputer Architecture & Microcomputer Development Systems
8. Control System Design (use of MATLAB) 9. Control Sensors and Actuators
10. Interfacing Sensors, Actuators to Microcomputers
11. Real-Time Programming in Assembler and Embedded C
12. Advanced Concepts (e.g. electromagnetic levitation, fuzzy logic control, active materials)

Laboratory Exercises and Case Studies:

Laboratory sessions involve completing exercises and case studies. Exercises are one week sessions intended to develop specific skills. These are not graded but must be completed and demonstrated to the instructor or teaching assistant.

Mechatronics is primarily taught through the use of case studies. Case studies are graded and span multiple weeks. The purpose of these case studies is to help develop in each student the experience of designing real world mechatronic products. The key issues of software simulation, hardware implementation, and comparison of analysis and experiments are investigated. The *defining quality* of a mechatronics engineer is the ability to work competently in the three areas of engineering: analysis, design and experimentation.

Hands-on hardware exercises include:

1. Laboratory Equipment
2. Microcomputer Development Systems

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3. C Programming

Case studies include:

1. Digital Electronics and Logic Systems
2. Analog Electronics, OpAmps and Filters
3. Electromagnetic Levitation
4. Interfacing Microcontrollers
5. Programming Microcontrollers in Assembly and C
6. Digital Input / Output System (Solenoid) - - On / Off Control, Timing Control
7. Stepper Motor - - Open-Loop Position Computer Control, State Machines
8. DC-Motor - - Closed-Loop Velocity Control

Students will conduct laboratory exercises in 2 person teams. A set of questions will be provided with each laboratory exercise to be answered during the session and submitted for grading. These questions are meant to emphasize key points of the exercise and to provoke thought about possible extensions to the work. For each microcomputer case study, question sets will be graded and will count 5% of the final grade. One set of questions will be turned in for each lab team. In addition, programs written in Assembler and C will be turned in electronically (either by email or diskette) and will count 45% of the grade. Grades for programs will be based on following the firmware standard, program content, program organization, speed of execution and the use of comments to document the code. Finally, the laboratory team must demonstrate the operation of the embedded program to the instructor. The system must perform all the requirements set forth in the case study and operate reliably. In some case studies, specific programming techniques will be required. Operation of the system will count 50% of the case study grade.

The programming case studies will use several microcomputers from Microchip Corporation. Microchip is the largest manufacturer of microcomputers for mechatronic applications. Devices include internal timers, counters, analog-to-digital (A/D) converters and pulse width modulators (PWM), which are all useful for controlling mechanical systems. Ports can be configured for different purposes under software control. The microcomputers from Microchip are Very Long Instruction Word (VLIW), Harvard architecture Reduced Instruction Set Computers (RISC). Since programming is first done in Assembler, students learn microcomputer operation at the register / bit level. With this background, their embedded C programs are much more efficient.

Homework Assignments:

Homework will be not be specifically assigned. However, students are expected to review all distributed material outside of class since this material cannot be covered completely in lecture. Further, case studies have to be completed in the scheduled time and student teams are expected to complete case study assignments outside of lab time if they cannot be completed in the required period. Arrangements can be made with the instructor and TA to complete case studies outside class time.

The microcomputer development system is available online at www.microchip.com; the C compiler is available as a 1-month demo from Microchip. Much of the work on the case studies can be accomplished outside of lab.

Mechatronics Syllabus

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Exams:

There will not be a final assignment in this course. There is also no mid-term exam.

Quizzes:

Brief on-line quizzes will be conducted during the course. The quizzes are meant to test whether the course material is understood and to gauge the effectiveness of course notes. Quizzes will count 10 % of the final grade.

Class Attendance and Participation:

Attendance at **all** classes is mandatory and participation in class is strongly encouraged. An effort will be made to make all classes interactive and thus greatly enhance the learning process. In addition, the instructor will consider preparation and participation in class, lateness and attendance, as well as professional behavior, for all students in the final grade. This evaluation will be used by the instructor to either raise or lower the student's overall letter grade in marginal cases.

Course Conduct:

Student-teacher relationships are built on trust. Acts, which violate this trust, undermine the educational process. For example, students must trust that teachers have made appropriate decisions about the structure and content of the courses they teach, and teachers must trust that the assignments that students turn in are their own work.

In this class, all assignments that are turned in for a grade must represent the student's or the laboratory team's own work. Collaboration with other members of the class is encouraged since this aid in the learning process. However, each laboratory team is expected to submit a unique assignment that is representative of their work. Submission of any assignment that is in violation of this policy will result in a penalty of zero for that particular assignment. If you have any questions concerning this policy before submitting an assignment, please ask for clarification. Also, any cheating on an electronic quiz or exam will result in a grade of zero for that particular quiz or exam. In addition, students are expected to conduct themselves in a professional manner at all times.

Grade Summary:

Case Studies		90%
Digital Logic	5%	
On / Off Control	25%	
Other Case Studies	20%	
Electronic Quizzes		10 %
Total		100 %

Grade Appeal:

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Students are encouraged to discuss their grades with the instructor as frequently as needed. The student is always given the benefit of the doubt in all grade discussions and every effort will be made to find ways to help a student improve his/her grade throughout the semester.

MECE E4100 Mechanics of Fluids Course Meeting Times

Lectures: 1 session / week, Wed 4:10-6:40pm at Mudd 227.

Office Hours

Prof. Vedula: Friday 2-3pm, Mudd 220BA (and by appointment, vv2316@columbia.edu)
Course Assistant: Daniel Klass (dk3109@columbia.edu)

Prerequisites

MECE E3100 or equivalent

Description

This is an intermediate-level fluid dynamics course, which introduces and develops the fundamental principles governing the flow of fluids. Topics include basic continuum mechanics, transport theorem and control volume analysis, the Navier-Stokes equations, dimensional analysis, flows at low and high Reynolds numbers, boundary layers, introduction to transition and turbulence, vorticity dynamics, ideal/potential flows, and additional selected topics.

Textbooks

For course readings I am strongly recommending:

- P.K. Kundu, I.M. Cohen, & D.R. Dowling, Fluid mechanics. 6th ed. Academic Press, 2015.
- Panton, Incompressible Flows, 4th ed., Wiley, 2013.

Recommended additional reading:

- Milton van Dyke, An Album of Fluid Motion, Parabolic Press, 1982.
- G. K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press.
- F. White, Fluid Mechanics. McGraw-Hill, 2015.
- L. D. Landau and E. M. Lifshitz, Fluid Mechanics, 2nd ed. Course of Theoretical Physics, Vol. 6, Elsevier.
- Sir Horace Lamb, Hydrodynamics, 6th ed., Cambridge University Press.
- Theodore von Kármán, The Wind and Beyond, Little Brown and Company, 1967 (for fun and historical perspective of classical physics).

Certain books and journal articles will be recommended for specific topics during the course.

Grading

- Homework (40%)
- Exam I (25%)
- Exam II (35%)

Syllabus

Week 1:

- Overview of fluid mechanics
- Intro to key concepts
- Brief introduction to dimensional analysis

Week 2:

- Review of mathematical concepts
- Classical Thermodynamics
- Simplified one-dimensional derivation of conservation of mass and linear momentum
- Intro to kinematics: Lagrangian and Eulerian descriptions

Week 3:

- Control volume analysis
- Reynolds Transport Theorem (RTT)
- RTT applications
- Dynamics of inviscid flows
- Bernoulli's principle

Week 4:

- Streamline coordinates
- Euler-s and Euler-n equations
- Applications of control volume analysis and Bernoulli's Momentum theorem, jets and jet pumps, wakes, sudden expansions, etc. • Moment of momentum theorem (lawn sprinkler example)

Week 5:

- Effects of compressibility

- Unsteadiness (unsteady Bernoulli) o Pipe connected to a large tank o Bubble expansion in an infinite fluid (Rayleigh's equation)

Week 6:

- Introduction to viscous effects
- Couette flow, plane Poiseuille flow
- Unsteady flows (Rayleigh's 1st and 2nd flows, Womersley flow)
- Introduction to Navier-Stokes equations

Week 7:

- Derivation of Navier-Stokes equations
- Non-dimensionalization
- Dimensional analysis (Buckingham Pi-theorem)
- Inertia-free flows (lubrication, Stokes flow)

**Week 8: Exam I
Spring Recess**

Week 9:

- Viscous boundary layers
 - o The idea
 - o Boundary layer equations
 - o Boundary layer solutions (Blasius, Falkner-Skan)
 - o Falkner-Skan similarity solutions
 - o Momentum integral equation (von-Kármán – Pohlhausen's approach)

Week 10:

- Secondary flows
- Stability and transition o Introduction to linear stability analysis
 - o Kelvin-Helmholtz instability
 - o Stability analysis for nearly parallel viscous flows (Orr-Sommerfeld equation)
 - o Inviscid instability (Rayleigh's and Fjortoft's criteria)

Week 11:

- Introduction to Turbulence
 - o Characteristics
 - o Governing equations (RANS)
 - o Closure problem
 - o Correlations, mean and turbulent kinetic energy
 - o Energy cascade, Kolmogorov's theory

Week 12:

- Vorticity dynamics
 - o Helmholtz's decomposition
 - o Vorticity transport equation
 - o Significance of vortex stretching
 - o Kelvin-Helmholtz circulation theorem
 - o Biot-Savart law

Week 13:

- Potential flows o Mathematical formulation of ideal flows
- Classical examples (plane flows, source/sink, vortex, dipole, cylinder in uniform stream)

Week 14:

- Introduction to aerodynamics o Conformal mapping o Two-dimensional airfoil theory o Finite wing theory, drag due to lift (induced drag)

Last day of classes

Week 15 (Study Week):

Week 16: Exam II

All exams will be held during regular class hours in the classroom.

MECE E4210 Energy Infrastructure Planning

Professor: Michael Waite
Office Hours: Mondays 1:30-2:30pm
Location: Mudd 134F

Teaching Assistant: Terry Conlon
Office Hours: Tuesdays noon-1:30pm, Fridays noon-1:30pm
Location: MECE TA Room, Mudd 122B

Prerequisites: Programming experience in Python, Matlab or R; concepts of thermodynamics and energy sources; some linear algebra and statistics is ideal

Course Structure: Approximately the first half of the course will consist of (a) lectures on energy systems engineering considerations, with a focus on integration of variable renewable energy (VRE, wind and solar) and (b) developing data-driven computation models to analyze energy infrastructure under such scenarios. Project assignments will reflect these subjects. The second half will introduce thermal loads, energy districts and integrated energy system planning. Much of the student effort will involve a final district design and data-driven modeling project with an intermediate “milestone” assignment.

Assignments: Assignments will primarily be data-driven analysis projects that will require computational/programming models developed in, e.g., Python, Matlab or R. Regular reading assignments will also be assigned. Straightforward quantitative assignments may also be given in the second half of the course intended to assist in the design project.

Final Design Project: More detail will be provided approximately midway through course, but a long-term project will focus on the analysis and design of a grid-connected community energy system / microgrid / energy district in the context of greater penetration of VREs and local growth in demands. Through the “milestone”, this will be a structured assignment with the remainder of the project requiring you to present and analyze a design for the community energy system. A final project presentation with feedback from instructors will precede submission of a final report.

Quizzes: Two quizzes, about one hour each, covering readings and lectures.

Grading: Projects 1-3 – 30% (12.5% each)
Quizzes – 25% (12.5% each)
Design project milestone – 12.5%
Final project/report – 17.5%
Final presentation and class participation – 7.5%

Course Schedule and Topics

(May change given guest lecture availability and class/professor interests and schedule)

Date	Lecture Topics	Assignments
1/22	- Course introduction/overview - Building demands and diesel/fossil generators	
1/29	-Solar PV and battery storage - Economic calculations, levelized cost of electricity	
2/5	Grid integration of variable renewable energy (VRE); Challenges and solutions in different regions	Project 1 due
2/12	Electricity grid formation; load balancing; central on-demand generation; generator types/roles	
2/19	1 st half: Deep renewable penetration scenarios and implications 2 nd half: Working session for Project 2	
2/26	Electricity markets; location-based marginal pricing; ancillary services	Project 2 due
3/5	Quiz 1 (First half of class) Lecture: Baseload generation; nuclear and hydro considerations	
3/12	<i>Spring break week – no class</i>	
3/19	Flexible generator/hydro operation; grid-connected storage 2 nd half: Project 3 review and working session	
3/26	Thermal loads; greenhouse gas emission; space heating equipment; heat pumps vs. fossil fuel boilers/furnaces	Project 3 due

4/2	Continuing with thermal loads; district energy demands (base electric, cooling, heating); delivered energy cost components	
4/9	Computing greenhouse gas emissions for different end use equipment and electricity generators; thermal system design and operation effects on energy, costs, emissions; milestone review	
4/16	Campus energy systems; combined heat and power (CHP); integrated district energy solutions	Final project milestone due
4/23	Electricity transmission and interconnected energy systems; reliable system operation; energy decarbonization studies	
4/30	Quiz 2 (First half of class) Second half: In-class consultation/working time on final project	
5/7	Final project presentations <i>5/7 is expected final date</i>	Final project report due 5/9

MECE E4211 Energy Sources and Conversion

Prerequisite: ME 3301 THERMODYNAMICS or Equivalent.

use background Undergraduate Thermodynamics
Familiarity with ideal gas behavior, properties
(Ideally familiar with Rankine, Brayton, Otto cycles)

Solar No need to purchase
Renewable and Efficient Electric Power Systems- Masters
2nd edition chapters will be posted

Wind Power

Manwell and McGowan, Wind Energy Explained, (online edition CLIO)
No need to buy above unless you want to go deep into wind(beyond class)

Other useful references

William Bathie Fundamentals of Gas Turbines 1996. (online thru CLIO)

Lumley, J. L., Engines, Cambridge, 1999. (will provide notes)

Chemistry of the environment by Spiro and Stigliani. Prentice Hall, 2003.
Third edition (International edition)

Van Wylen/Sonntag/Borganakke, Funda. Classical Thermodynamics, any edition, Wiley

Class Mondays 4:10 to 6:10 pm
Friday 2:00 to 4:00 pm
Room TBD Additional Office Hours: TBD

Week

- 1 Introductory
Primary sources of energy
Energy and Power, Units
Energy carriers, Services
Fossil Fuels, Renewables, what does efficiency mean
Direct energy conversion vs Thermal Energy Conversion
DEC- other than Carnot limits
- 1 Recitation Review of basic data analysis tools
time series data, excel/Python
- 2 Energy in context of decarbonization
Energy system includes end-use, buildings, mobility, industry
Recitation Review of basic data analysis tools
- 3 Wind Energy- Characterizing resource, distributions, data-driven
- 4 Betz Limit - performance limits from fluid mechanics
- 5 First order design- rotor rpm, blade chord and twist variation
- 6 Solar radiation, Sun-earth Geometry
Characterizing the resource, clear sky and DHI/DNI/GHI
- 7 Direct conversion technologies - why c-Si dominates
- 8 Combining resource and conversion techs
- 9 Stand-alone captive power, minigrids,
Entire System: solar/storage or solar/storage/dispatchable
- 10 Heat to Power cycles, Rankine, Brayton, Otto/Diesel, P-V, T-s for ideal gases
- 11 Engines, ideal, real-gas, indicator, and other losses
Engines vs Turbines: comparative perspective, CAES
- 12 Turbomachines - compressor/turbine blade design
compressor/turbine temperature and pressure changes

Journals of interest for research and reading:

Nature Energy
Nature Sustainability
Joule
PNAS
Energy Policy
Applied Energy
Science

MECE 4212 Microelectromechanical Systems

Scheduled meeting time: Weds 4:10-6:40PM

Instructor: Prof. Jim Schuck

Office: Mudd 1009 NWC; Office Hours: Thursday 10:30-11:30PM Email: pjs2191@columbia.edu

Teaching Assistant: Emanuil Yanev

Office: TBD; Office Hours: TBD Email:

Course Materials:

(Required) Practical MEMS, Ville Kaajakari, Small Gear Publishing, 2009 (Recommended) Microsystems Design, Stephen Senturia, Kluwer, Boston, 2001.

Course Objective: To explore the exciting physics and engineering at small – order of micrometers (10^{-6} m) or less – length scales. This covers an appreciation of micro- and nano-fabrication technologies, dynamics and structural mechanics, actuation and detection of motion, and fluids at these length scales. The structure of this course will combine lectures, case studies, a team-level design project, and hands-on laboratory experiences.

Course Description and Bulletin: This is an exciting interdisciplinary course covering the physics, engineering, and design of microsystems, ranging from micro- and nano- fabrication, mechanics, fluid dynamics, electronics and optics with special emphasis on small length scale devices. This subject presents an introduction to micro- and nano-scale devices, using examples from micro- and nano-electromechanical real-world applications. Emphasis of the class will be on the design modeling and simulation of such devices. Lectures during the first half of the term will cover physics and engineering on these length scales: such as mechanics and dynamics, actuation and sensing methods, optics, heat transfer, fluids and device fabrication. During the second half, we will explore specific micro- and nano-scale design projects, and device case studies, with a section where students will get actual hands-on experiences with sample microdevices.

Assignments:

For the **Lecture** portion of the course (~ first seven weeks), each student will be responsible for the material covered in class and reading assignments from the *Practical MEMS* textbook (Kaajakari). Homework will be assigned weekly and a midterm exam will be held on the eighth week. Collaboration on the homeworks is encouraged. Collaboration is not allowed on the midterm exam.

For the **Design** portion of the course (~ the next seven weeks: mid-Oct to mid-Dec), students will be assigned into groups to pursue a MEMS design project. The design projects will cover state-of-the-art research. A group written report and presentation on the design project will be held at the end of the semester.

In parallel, for the **Laboratory** portion of the course (mid-Oct to mid-Dec), each student will be able to use a set of virtual tools to design/model a widely used MEMS device. Each group of students will then have the opportunity to work with an actual MEMS device for characterization.

Grading: Student grades will be determined from the midterm exam, homework, design project and laboratory characterization scores as follows:

Lecture: Midterm Exam – 30% and Homework – 20%

Design: Design Project (written report and presentation) – 30%
(20% written report and 10% presentation)

Laboratory: MEMS Characterization – 20%.

Microelectromechanical Systems

MECE 4212 Outline

Week	Lecture topic	Laboratory Activity
1 (9/6/17)	Introduction, Scaling, MEMS Markets and Applications (Kaajakari-Chap. 1, Senturi-Chap. 1-2, Device Electronics for Integrated Circuits, Muller Chapter 1-2) MEMS Materials and Fabrication: General Concepts Silicon, Semiconductor Physics and Silicon Micromachining (Senturia-Chap. 3)	
2 (9/13/17)	MEMS Materials and Fabrication (cont.): Silicon and Silicon Micromachining (Senturia-Chap. 3)	Process simulation: basic lithography, deposition, and etching processes Continuation of week 2 activities
3 (9/20/17)	MEMS Materials and Fabrication (cont.) MEMS Mechanics: a) Statics (Kaajakari-Chap 4; Senturia-8.1-8.4, 9.1-9.6,10.4)	

4 (9/27/17)	MEMS Mechanics: a) Dynamics (Kaajakari: Chap 12, Appendix B; Senturia: 7.1 - 7.2), Lumped Element (Chap. 5) MEMS Sensing Mechanisms: a) Piezoresistive Sensing (Kaajakari: Chap 5; Senturi: 18.2)	Process simulations: integrated process simulation of a pressure sensor
5 (10/4/17)	Piezoresistive Signal Conditioning: Operational Amplifiers, (Kaajakari: Chap 8-9) MEMS Limits of Operation: Noise (Kaajakari: Chap 2), Dissipation, and Nonlinearity (Kaajakari: Chap 11) MEMS Sensing Mechanisms: a) Capacitive Sensing (Kaajakari: Chap 6) MEMS Actuation: b) Capacitive Actuation - Electrostatics (Kaajakari Chap. 15)	Continuation of week 4 activities a) Capacitive Sensing (Kaajakari: Chap 6) Piezoelectric Sensing (Kaajakari: Chap 7; Senturia 21.4-21.5)
6 (10/11/17)	MEMS Sensing Mechanisms: a) Piezoelectric Sensing (Kaajakari: Chap 7; Senturia 21.4-21.5) MEMS Actuation: a) Piezoelectric Actuation (Kaajakari Chap 16) b) Thermal Actuation (Kaajakari Chap 17)	Continuation of week 4 activities
7 (10/18/17)	MEMS Devices: Case Studies of Resonators and/or Gyros FEA Modeling of MEMS - COMSOL Laboratory Introduction Lecture: Labs: Pressure Sensor (Piezoresistive) (Kaajakari: Chap 13), Micro-Mirror (Electrostatics), Quartz Resonator (Piezoelectric)	Form groups and define topic for MEMS / NEMS design projects
8 (10/25/17)	Midterm Exam	Define specifications for MEMS / NEMS design project
9 (11/1/17)	DESIGN: MEMS / NEMS Project	LABORATORY: Part 1
10 (11/8/17)	DESIGN: MEMS / NEMS Project	LABORATORY: Part 2
11 (11/15/17)	DESIGN: MEMS / NEMS Project	LABORATORY: Part 3
12 (11/29/17)	DESIGN: MEMS / NEMS Project	LABORATORY: Part 4
13 (12/6/17)	Design Project Group Presentations; Laboratory report due	
14 (12/13/17)	Final Projects Due	

References:

Books:

- Kaajakari, Ville. *Practical MEMS*. 2009.
- Senturia, Stephen. *Microsystem Design*. 2001.

Journals:

- Sensors and Actuators A & B (Elsevier).
- IEEE Microelectromechanical Systems (MEMS)

Databases (Best Search Tools, Access through Columbia Library Website)

- Science Direct
- IEEE Xplore <http://ieeexplore.ieee.org/Xplore/home.jsp>
- Web of Science

Conferences:

- IEEE MEMS, <http://www.mems2017.org/>
- IEEE Transducers, <http://www.transducers2017.org/>
- IEEE Eurosensors
- Solid-State Sensors, Actuators and Microsystems Workshop. Hilton Head, NC

Other Resources:

<http://www.mems.sandia.gov/> SANDIA National LABS MEMS
Projects

<https://www.mems-exchange.org/> Microsystems foundry and device
Prototyping

<http://mail.mems-exchange.org/mailman/listinfo/mems-talk> E-list for
MEMS folks building devices

www.darpa.mil/mto DARPA/MTO: Follow link under MEMS to see
Projects

www.mosis.org The website with user foundries for integrated
Circuits

<http://www.memscap.com/products/mumps> MUMPS process flow
Foundry

www.smalltimes.com A trade journal with useful info about MEMS
and NEMS

MECE E4213 Bio-Microelectromechanical Systems (BioMEMS): Design, Fabrication and Analysis

MECE E4213 3 Points,
Course Homepage: <https://courseworks.columbia.edu/>

Lectures: Mondays 4:10 – 6:40 pm 307 Pupin Laboratories

Instructor: Professor Qiao Lin
Office: 236 Mudd
Phone: 4-1906
Email: qlin@columbia.edu
Office hours: TBD

Objectives

This course is intended to introduce students to the emerging field of bio-microelectromechanical systems (BioMEMS), with an emphasis on design, fabrication and analysis aspects. BioMEMS devices and systems hold great promise in a wide range of applications in biology and medicine. Class material will discuss relevant fundamental principles and technologies for BioMEMS. These include various aspects in the design, fabrication, and analysis of BioMEMS.

Outline

Through a combination of lectures, literature research and design projects, the following topics will be broadly covered in the course:

1. Micro- and nanofabrication techniques: silicon micromachining, polymer microfabrication, nanofabrication, and system integration.
2. Fundamentals of microfluidics: hydrodynamic and electrokinetic microfluidic devices
3. Fundamentals of MEMS biosensing and detection: *in vivo* and *in vitro* MEMS sensors, transduction principles, noise analysis, and wireless transmission
4. Biocompatibility and surface modification of MEMS devices
5. Microfluidic devices and systems (e.g., sample preparation, separations, reactions, molecular and cellular manipulation, and drug delivery)
6. Micro and nano-biosensors

Course Mechanics

The course will consist of lectures, a reading project and a design project. There will be no regular homework assignments or exams. However, exercise problems will be handed out when appropriate to enhance understanding of class material.

Lectures. Lectures will cover technology and physical principles that BioMEMS devices and systems are based upon. Emphasis will be placed on using fundamental engineering principles to understand, analyze and design microfluidic devices. Case studies involving detailed modeling, simulation and design of select microfluidic devices will be included.

Reading Project. Students will be divided into teams to research the microfluidic literature. Each team will select a topic with guidance from the instructor and learn and study the topic by reading relevant books and research papers. Each team will be required to submit a report and make a presentation in class. Examples of information that should be covered in the report and presentation include the background and significance of the topic, fundamental concepts and principles, methods and technology, and a review of representative research efforts for the topic selected.

Design Project. Students will, divided into the same teams as for the reading project, perform a design project. Each team will select an application and design a device for the application. Alternatively, in lieu of a device design, the project may involve an in-depth analysis of a chosen device, provided the analysis has not been reported in the literature. Each team will be required to submit a report on their design or analysis.

If the project addresses a design, the report should clearly present the following for the device: (1) background and significance; (2) device concept, design and operating principle; (3) detailed analytical and/or numerical calculations predicting the device performance; (4) fabrication processes including microfabrication techniques needed; and (5) photomask layout if appropriate. If the project addresses an analysis, the report should include a description of the device concept, details of a physical model for the device, solution procedure, and figures that present analysis results and discussions that give insights into the device.

Recommended References

- S.D. Senturia, *Microsystem Design*, Springer, 2000.
- N.-T. Nguyen and S.T. Wereley, *Fundamentals and Applications of Microfluidics*, 2nd edition, Artech House, 2006.

Course Grading and Project Timeline

Final grades will be given based on the reading (50%) and design projects (50%). Exercise problems will not be included in final grading. The grading criteria and tentative schedule for the projects are as follows.

Tentative Date	Reading Project (50 points)	Design Project (50 points)
Monday, 9/16	Team formation	
Monday, 9/30	Reading topic selection: 5-minute, 1-slide PPT presentation of the selected topic, and the scope of the literature study (5 points)	
Monday, 10/7		Design topic selection: 5-minute, 1 or 2-slide PPT presentation of the selected topic, and the scope of the design or analysis (5 points)
Monday, 10/21	Reading project outline: 10-minute PPT presentation on a detailed outline of references to be reviewed (10 points)	
Monday, 10/28		Design project outline: 10-minute PPT presentation on a detailed project outline (10 points)
Monday, 11/11	Reading project review: complete draft of PPT slides due (10 points)	
Mondays, 11/18, 11/25, 12/2	Reading project presentations by individual teams (15 points)	
Monday, 12/2		Design project review: complete draft of PPT slides due (10 points)
Monday, 12/9		Design project presentations by individual teams (15 points)
Monday, 12/16	Reading project report and PPT slides due (10 points)	Design project report and PPT slides due (10 points)

Percentage grades will be converted into letter grades based on the following chart:

90 or above:	A
80 or above (below 90):	B
70 or above (below 80):	C
60 or above (below 70):	D
59 or less:	R

MECE E4214 MEMS Sensors and Systems

Course Material:

MEMS Sensors and Systems takes the study of MEMS transducers to the next logical step: how transducers are packaged and then integrated into larger systems. Intended as a follow-on to an introductory MEMS course which covers MEMS fabrication and transduction methods, this class covers both fundamental issues associated with analog instrumentation and practical issues encountered in the use of packaged MEMS transducers. Class instruction consists of lectures, homeworks, take-home hands-on projects, and a final exam.

The class connects hands-on sensor problems to a thorough study of analog instrumentation. Single-board computers with both digital and analog inputs are employed to teach critical sensor implementation skills, and help students make hands-on comparisons between pre-packaged digital IoT sensors and built-to-specification analog sensing systems. A series of lectures and homeworks follows the path of the analog signal chain: transduction, signal conditioning, filtering, analog to digital conversion, noise sources and noise coupling methods.

The traditional lecture material is supplemented with information related to MEMS sensor packaging and manufacturing. Commercialized, packaged pressure sensors will be studied and compared to learn how instrumentation issues arise in practice and how they are commonly addressed. The sensor packaging section of the class also works to tie sensor design to use cases in application areas such as Aerospace Test and Robotics. Measurement specifications will be explored for example cases, and we will show how end-use drives variations in the design of the overall signal chain, and therefore of the integrated sensors. Sensor integration is addressed both from the point of view of hardware and data analysis such as uncertainty.

Having taken the class, students will be able to understand both detailed technical issues associated with sensors as well as “big-picture” problems of sensing applications. The students should be able to understand, debug, and design sensing systems for use in realistic engineering environments.

Expectations

- Attend each class
- Be mentally present and academically prepared
- Participate in discussions
- Complete homeworks on time
- Read assigned pages ahead of class

Course Objective:

The objective of the course is to prepare students for MEMS Instrumentation applications. This might include jobs in the private sector (Instrumentation Engineer, Test and Operations Engineer, Sensor Design Engineer, etc.) or in academia. At the end of the course, students will be prepared to use MEMS transducers, diagnose problems, and relate the performance of transducers to their design and manufacturing.

Preliminary Schedule for the Class:

Week Topic

1. Introduction
2. Wheatstone Bridges, etc.
3. Comparative Packaging: Piezoresistive Sensors
4. PR Sensors
5. Noise in Sensors
6. Analog to Digital Conversion
7. Cabling and Grounding
8. Amplification & Signal Conditioning
9. Filtering, Comparative Packaging: Piezoelectric Sensor

10. Comparative Packaging: Piezoelectric Sensors, more Packaging
11. Microfluidics
12. Uncertainty and Integration
13. Dynamic Signals, Capacitive Sensor Teardown
14. Guest Lecture
15. Homework Review / Final Exam / Etc.

Basis for Grading

20% Class Participation

40% Homeworks

10% Exam

30% Take-Home Projects

Other Class Policies

- Homeworks will be penalized 10% for every day late
- Class will be in-person, unless the instructor has a need for a remote session (illness, travel, etc.)
- Students can request classes be recorded and made available

Textbooks

I have placed a few recommended textbooks in the Textbooks section of Courseworks. These are on reserve in the Science and Engineering Library but I will use excerpts from them as needed during the semester.

MECE E4302: Advanced Thermodynamics

Time: Thursday 4:10 pm-6:40 pm

Place: 644 Mudd Building

Instructor:

Prof. Michael P. Burke

Email: mpburke@columbia.edu

Office Hours: Friday 2:00-3:00 pm

Office Hours Location: Mechanical Engineering Conference Room

Grader/Course Assistant:

TBD

Email: TBD

Required Textbook:

C. Borgnakke, R.E. Sonntag, *Fundamentals of Thermodynamics*, 8th Ed., 2013.¹

¹on course reserve: NW Corner Building Library

Other Useful Textbooks:

M.J. Moran, H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 6th Ed., 2008.¹

C. Kittel, H. Kroemer, *Thermal Physics*, 2nd Ed., 1980.¹

S.R. Turns, *Introduction to Combustion: Concepts and Applications*, 3rd Ed., 2011.¹

C.K. Law, *Combustion Physics*, Cambridge University Press, 2006.²

¹on course reserve: NW Corner Building Library

²on course reserve: e-reserve

Course Description:

Advanced classical thermodynamics: exergy, Maxwell relations, equations of state and properties for ideal and non-ideal gases, generalized behavior, mixtures and solutions, phase and chemical behavior, combustion, compressible flow, applications to power generation and refrigeration systems.

Course Prerequisites:

Introductory thermodynamics at the undergraduate level or instructor's permission.

Course Objectives:

After completion of the course, the students will be able to

1. Demonstrate a firm understanding of core thermodynamic concepts and foundations. 2. Perform thermodynamic analyses (energy, entropy, exergy, etc.) of complex, integrated thermodynamic systems. 3. Be comfortable with and effectively utilize thermodynamic relations for various substances. 4. Calculate heat release, final temperatures, and equilibrium composition of final products in reactive systems. 5. Apply knowledge and concepts to various application domains (power systems, refrigeration systems, etc.)

Attendance Policy:

Students are expected to attend all lectures and to come prepared. Students are responsible for any material covered during absences.

Grading Policies:

30% Homework 35% Midterm examination 35% Final Examination

Midterm exam date:

Thursday, March 12 in class

Final exam date:

Finals period at official time scheduled by registrar

Homework Policies:

You may work together on homework sets while exploring and discussing general concepts and methods, but all work you submit must be completed and written up by yourself individually and must represent your level of knowledge and understanding of the subject.

Academic Honesty Policies:

The academic honesty policies for the Mechanical Engineering Department are listed at:

<http://me.columbia.edu/academic-honor-code>

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at:

<http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at

<http://www.college.columbia.edu/academics/academicdishonesty>

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at:

<http://www.college.columbia.edu/academics/dishonesty-plagiarism>

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Furthermore, in this course the follow constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university.

Student rights:

- Academic honesty policies clearly explained at start of semester
- Course requirement and grading policies must be clearly stated at start of semester.
- Textbook and reference book usage must be clarified at start of semester.
- Homework assignments, midterm exams, and final exams will be graded in a timely manner.
- Instructor and teaching assistants must provide office hours or otherwise explain procedure for meeting with students.
- Instructors will provide pertinent information on assignments in a timely manner.

Tentative schedule

Class #	Date	Topic
1	Jan. 23	Introduction, Definitions, and Foundations
2	Jan. 30	Foundations
3	Feb. 6	Foundations
4	Feb. 13	Exergy
5	Feb. 20	Thermodynamic relations
6	Feb. 27	Thermodynamic relations
7	Mar. 5	Mixtures
8	Mar. 12	MIDTERM EXAMINATION
9	Mar. 19	NO CLASS – SPRING RECESS
10	Mar. 26	Mixtures
11	Apr. 2	Chemical reactions
12	Apr. 9	Chemical reactions
13	Apr. 16	Chemical and phase equilibria
14	Apr. 23	Chemical and phase equilibria
15	Apr. 30	Compressible flow basics
16	May 7	NO CLASS – STUDY DAYS
17	Finals period	FINAL EXAMINATION

MECE E4304: Turbomachinery

Summary of the course: This course will introduce you to the basics of theory, design, selection and applications of turbomachinery. Turbomachines are widely used in many engineering applications such as energy conversion, power plants, air-conditioning, pumping, refrigeration and vehicle engines, in the forms of pumps, blowers, compressors, gas turbines, jet engines, wind turbines etc. The class will use examples drawn from energy conversion technologies, HVAC, and propulsion.

Prerequisites: MECE E3100 and MECE E3301, or equivalent, or permission of the instructor

MECE E4304: Turbomachinery

Instructor: Sean Nolan, Ph.D.
Email address: sn3063@columbia.edu
Saturdays, Noon - 2:30PM at 333 Uris Hall

Textbooks:

1. Aircraft Engines and Gas Turbines (2nd ed.), Jack Kerrebrock
2. Internal Flow: Concepts and Applications, E. M. Greitzer, C. S. Tan, and M. B. Graf (available on GoogleBooks)

Prerequisites: MECE E3100 (Intro to Mechanics of Fluids) and MECE E3301 (Thermodynamics), or equivalent, or permission of the instructor

Learning Objectives:

1. Evaluate turbomachinery components, and describe the physical principles informing relevant design parameters based on the specific application. [SYNTHESIS, EVALUATION]
2. Given a set of requirements, design and create a model for turbo component. [SYNTHESIS]
3. Evaluate limitations of models of varying fidelity, as they apply to above learning objectives. [SYNTHESIS]

Measurable Outcomes:

1. Draw velocity triangles and apply control volume analysis for a compressor or turbine stage. Calculate corresponding aero loads (absolute forces and loading parameters), velocity ratios, pressure ratios, temperature ratios, and reaction. [APPLICATION, EVALUATION]
2. Calculate geometric parameters (e.g., span, aspect ratio, chord, camber angles, taper ratio, twist, hub/tip ratio, etc.) [KNOWLEDGE, COMPREHENSION, APPLICATION]
3. Model the relationship between design and performance of the turbomachinery components and cycle performance in propulsion and HVAC applications. [COMPREHENSION,]
4. Explain and quantify sources of loss and blockage in turbo components. [APPLICATION, ANALYSIS]
5. Explain the role of unsteadiness in turbomachinery, both in an ideal model and as relates to real world effects. [COMPREHENSION, APPLICATION, ANALYSIS]
6. Calculate/model effectiveness of different methods of turbine cooling for gas turbine application. [APPLICATION, ANALYSIS]
7. Explain mechanisms associated with compressor instability, and calculate mode of instability (rotating stall or surge) for a compressor. [APPLICATION]
8. Demonstrate how to match compressor and turbine of a gas turbine. [APPLICATION]
9. Demonstrate matching stages in multi-stage compressors, and design variable geometry and/or spool architecture to maintain acceptable matching at off-design conditions. [COMPREHENSION, APPLICATION, ANALYSIS]
10. Explain causes for performance degradation and typical maintenance procedures for components in gas turbines. [KNOWLEDGE, COMPREHENSION]

Schedule:

Week 1 Turbomachinery applications. Review of useful fluid mechanics and thermodynamics concepts.
Week 2 Reynold's Transport theorem. Control volume analysis. Steady-flow energy equation. Euler turbine equation.
Week 3 Non-ideal Brayton cycle. Reverse Brayton cycle. Component efficiency. Boundary layers in pressure gradients.
Week 4 Centrifugal and axial compressors. Velocity Triangles. Diffuser and nozzle modeling.
Week 5 Compressor design parameters (e.g. Tipspeed, solidity, aspect ratio, reaction, etc.)
Compressor maps. Appropriate non-dimensional parameters. Loss sources.
Week 6 Turbine mapping and design parameters. Turbine cooling.
Week 7 Polytropic efficiency. Importance of unsteadiness for energy exchange.
Week 8 Midterm
Week 9 Spring recess. No class.
Week 10 Multistage turbomachinery. Stage matching. Off-design operation.

Week 11 Component matching. Gas generator considerations. Propulsor considerations.
Week 12 Characteristics of external turbomachinery (propellers and wind turbines). Actuator disk theory.
Week 13 Vorticity and circulation, and application to turbomachinery understanding.
Week 14 Structural considerations, including HCF, Campbell diagrams, and rotor dynamics.
Week 15 Operational considerations. Lifing. Dirt separation. Field diagnostics. MRO.
Week 16 Final Exam

Grading:

Home Work:		1/3
Midterm Exam:	1/3	
Final Exam:		1/3

MECE E4305: Mechanics and Thermodynamics of Propulsion

Course Description

This course introduces the basic principles of propulsion, including a review of the mechanics and thermodynamics of fluid flow. Thermodynamic cycle and component analysis of air-breathing propulsion systems, including turbojet, turbofan, turboprop, and ramjet engines are covered. Elementary rocket performance principles are introduced.

Classes: Saturday, 9:40am-12:00pm in Seeley W. Mudd 627

Lecturer: Professor Sean Bradshaw (sb3964@columbia.edu)

Email: sb3964@columbia.edu

Bio: <http://me.columbia.edu/sean-bradshaw-0>

Course Assistant: Elon Gordon

Email: eg2876@columbia.edu

Prerequisites: Thermodynamics MECE E3301, Heat Transfer MECE E3311, Turbomachinery MECE E4304 (or instructor approval)

Grading:

Your class grade will be based a mid-term exam and a final term project.

Mid-Term Exam: 50% Final Term Project: 50%

Term Project: The final term project, which consists of 50% of your class grade, will be due on the last day of class, April 28, 2018. The final term project consists of two components: a written report and an MS PowerPoint presentation.

Textbooks:

1. "Aircraft Engines and Gas Turbines", J. Kerrbrock, MIT Press, 1992.
2. "Mechanics and Thermodynamics of Propulsion", P. Hill and C. Peterson, Addison-Wesley, 1992.

Lecture Schedule, Topics, and Reading Material

Lecture #	Lecture Topic	Reading Material	Date
1	Introduction to Aircraft Propulsion	"Aircraft Engines and Gas Turbines," Chap. 1	20-Jan
2	Mechanics & Thermodynamics of Fluid Flow	"Aircraft Engines and Gas Turbines," Chap. 1	27-Jan
3	Propulsion Systems Analysis	"Aircraft Engines and Gas Turbines," Chap. 11	3-Feb
4	Ideal Cycle Analysis	"Aircraft Engines and Gas Turbines," Chap. 2	10-Feb
5	Non-Ideal Cycle Analysis	"Aircraft Engines and Gas Turbines," Chap. 3	17-Feb
6	Turbomachinery	"Aircraft Engines and Gas Turbines," Chap. 5,6	24-Feb
	Mid-Term Exam		3-Mar
7	Combustion Systems	"Aircraft Engines and Gas Turbines," Chap. 4	10-Mar
	No Class/Spring Break		17-Mar
8	Introduction to Rocket Propulsion	"Mechanics & Thermodynamics of Propulsion," Chap. 10	24-Mar
9	Rocket Performance	"Mechanics & Thermodynamics of Propulsion," Chap. 10	31-Mar
10	Rocket Nozzle Aerodynamics & Heat Transfer	"Mechanics & Thermodynamics of Propulsion," Chap. 11	7-Apr
11	Rocket Nozzle Aerodynamics & Heat Transfer	"Mechanics & Thermodynamics of Propulsion," Chap. 11	14-Apr
12	Guest Lecture: Exhaust		21-Apr

	Systems Aerodynamics		
	Final Term Projects Due		28-Apr

Modern Commercial Jet Engines

General Electric Aircraft Engines:

LEAP Engine

<https://www.cfmaeroengines.com/engines/leap/>

CF34 Engine

<https://www.geaviation.com/commercial/engines/cf34-engine>

GE90 Engine

<https://www.geaviation.com/commercial/engines/ge90-engine>

Pratt & Whitney Aircraft Engines:

PW1000G Geared Turbofan Engines

http://www.pw.utc.com/PurePowerPW1000G_Engine

V2500 Turbofan Engine

http://www.pw.utc.com/V2500_Engine

PW4000 Engine

http://www.pw.utc.com/PW4000112_Engine

Rolls Royce:

Trent 7000

<https://www.rolls-royce.com/products-and-services/civil-aerospace/airlines/trent-7000.aspx#/>

Trent XWB

<https://www.rolls-royce.com/products-and-services/civil-aerospace/airlines/trent-xwb.aspx#/>

RB211

<https://www.rolls-royce.com/products-and-services/civil-aerospace/airlines/rb211-535e4.aspx#overview>

General

The course aims at providing the student with an understanding, from first principle, of lifting force and flow properties as seen through development and use of the governing equations for inviscid two-dimensional flow about an object, such as an airfoil. Concepts of viscous flow, for an understanding of drag, and three-dimensional flow, as an introduction to the finite wing, are introduced throughout the course. To provide an aircraft-level appreciation for the core material, aspects of flight test engineering, flight performance, and aircraft stability & control are also introduced.

Method of Instruction

As listed by the Office of the Registrar, the course is In-Person.

Time and Location

- As published under “Directory of Classes.” The class meets once per week for 2 hours and 30 minutes on Saturdays, 1500-1730 ET.
- **NOTE:** On rare occasions the Saturday lecture may need to be moved due to travel. If this occurs, a zoom lecture will be given during the week to make up for a lost Saturday lecture.
- At this time the following conflicts are noted: **None**.

Instructor

Peter A. LeVoci, Ph.D.
248B Mudd
pal27@columbia.edu
Office hours: immediately after class or by appointment

Textbooks

<u>Title:</u>	<u>Priority:</u>	<u>Location:</u>
Fundamentals of Aerodynamics, Fifth (or Sixth) Edition by John D. Anderson, Jr.	Primary: Required	Bookstore
Introduction to the Aerodynamics of Flight, NASA SP-367	Secondary: Purchase not required.	In public domain: posted on Courseworks (see file “Papers and Articles”)
Introduction to Flight, by John D. Anderson, Jr.	Secondary: Purchase not required.	On reserve: Science & Engineering Library [NWC Building]

Homework

- Due prior to next class – **electronic upload required**
- Solutions will be posted after the homework is submitted.

Exams

- Midterm: date: as scheduled below
- Final: date: as scheduled below

Grades

- 20% - Homework
- 30% - Midterm Exam
- 50% - Final Exam

Course Material – Outline

- **NOTE:** On rare occasion the Saturday lecture may need to be moved due to travel. If this occurs, a zoom lecture will be given during the week to make up for a lost Saturday lecture.

Weekly Lecture	Course Material	Homework
L1 1/25	<ul style="list-style-type: none"> · Aircraft Level – Introduction <ul style="list-style-type: none"> o Coordinate System o Electronic Flight Control Systems (Fly-By-Wire) introduction · Elements of flight test engineering 	No HW issued
L2 2/1	<ul style="list-style-type: none"> · Thermodynamics Review <ul style="list-style-type: none"> • Equation for the speed of sound 	HW-1 issued
L3 2/8	<ul style="list-style-type: none"> · Object in Flow <ul style="list-style-type: none"> o Shock waves (normal, oblique) <ul style="list-style-type: none"> § Aircraft Level - impact <ul style="list-style-type: none"> · Flight performance · Stability & control • Newtonian sine-squared law • Shock waves: re-entry vehicle problem 	HW-2 issued <i>HW-1 DUE</i>

<p>L4</p> <p>2/15</p>	<ul style="list-style-type: none"> · Airfoil and wings: <ul style="list-style-type: none"> • Force and moment systems for an airfoil • Center of pressure 	<p>HW-3 issued</p> <p><i>HW-2 DUE</i></p>
<p>L5</p> <p>2/22</p>	<ul style="list-style-type: none"> · Basic variables · Dimensional analysis <ul style="list-style-type: none"> o Dimensionless coefficients · Hydrostatic equation <ul style="list-style-type: none"> o International Standard Atmosphere o Buoyancy force 	<p>HW-4 issued</p> <p><i>HW-3 DUE</i></p>
<p>L6</p> <p>3/1</p>	<ul style="list-style-type: none"> · Aircraft Level – Introduction to Flight performance <ul style="list-style-type: none"> o 1g straight & level flight vs. accelerated flight <ul style="list-style-type: none"> § Lift curve – airspeed relation to angle of attack § Stall speed o Maximum speed o Lift to drag ratio 	<p>HW-5 issued</p> <p><i>HW-4 DUE</i></p>
<p>L7</p> <p>3/8</p>	<ul style="list-style-type: none"> · Creation of lift · Viscous flow and drag · Selected videos <ul style="list-style-type: none"> § Laminar- turbulent transition § Smoke flow visualization for airfoil specimen § Trailing cone (flight test instrumentation) 	<p>No HW issued</p> <p><i>HW-5 DUE</i></p>

<p>Midterm Exam</p> <p>3/15</p>	<p style="text-align: center;"><u>Midterm Exam</u></p>	<p>No HW issued</p> <p>HW DUE: none</p>
<p>No Lecture</p> <p>3/17 to 3/22</p>	<p style="text-align: center;">Spring Break</p>	<p>N/A</p>
<p>L8</p> <p>3/29</p>	<ul style="list-style-type: none"> · Vector calculus review <ul style="list-style-type: none"> o Scalar fields, vector fields and vector multiplication o Gradient o Divergence of a vector field o Integrals: line, surface, volume o Useful theorems: Stokes, divergence, gradient 	<p>HW-6 issued</p> <p>HW DUE: none</p>
<p>L9</p> <p>4/5</p>	<ul style="list-style-type: none"> · Continuity equation · Momentum equation 	<p>HW-7 issued</p> <p><i>HW-6 DUE</i></p>

L10 4/12	<ul style="list-style-type: none"> · Momentum equation: wind tunnel example · Substantial derivative · Equation of a streamline 	<p>HW-8 issued</p> <p><i>HW-7 DUE</i></p>
L11 4/19	<ul style="list-style-type: none"> · Energy equation · Introduction to Computational Fluid Dynamics · Vorticity, strain · Circulation 	<p>HW-9 issued</p> <p><i>HW-8 DUE</i></p>
L12 4/26	<ul style="list-style-type: none"> · Coanda effect <ul style="list-style-type: none"> o NOTAR example · Stream function · Velocity potential · Bernoulli's equation · Argument for the Kutta-Joukowski theorem 	<p>HW-10 issued</p> <p><i>HW-9 DUE</i></p>
L13 5/3	<ul style="list-style-type: none"> · Laplace's equation · Some basic flows: uniform flow; source flow · Flow synthesis: flow over a semi-infinite object · Introduction to finite wings 	<p>No HW issued</p> <p><i>HW-10 DUE</i></p>
Final Exam 5/10	<p><u>Final Exam</u></p>	<p>No HW issued</p> <p>HW DUE: none</p>

MECE E4401 Introduction to Kinematics of Machines and Robots

Syllabus:

This course introduces fundamental mechanisms theory. Material covered will focus on kinematics concepts and theories of rigid bodies and rigid body linkages, which represent machinery and robotic mechanisms encountered in practice. An outline of the course material is given below.

- Concept of planar displacements and linkages
- Four-bar linkages
 - Graphical synthesis for rigid body guidance
 - The dyad and decomposition of four-bar linkages into dyads
 - Analytical synthesis of four-bars for rigid body guidance; Burmester theory
 - Computation of four-bar trajectories
 - Grashof criterion
 - Planar motion of rigid bodies
- Planar displacement representations
 - Operations on planar displacements
 - Uses of planar rigid transformations
 - Change-of-frame considerations
 - Pole of a planar displacement
- Spherical motion of rigid bodies
 - Description of spherical displacements by proper orthogonal matrices
 - Euler's theorem
 - The 3D rotation matrix: Cayley's formula and Rodriguez's formula
 - Euler angles
- Three-dimensional motion of rigid bodies
 - 3D formulation by generalization of planar rigid body motion
 - Chasle's theorem; screw motion and screw parameters
 - Rodriguez's generalized displacement equation
 - Application to forward kinematics of robot manipulators
- Rigid body velocities and wrenches
 - Rotational rigid body velocities
 - General rigid body velocities - "body", "spatial", and "hybrid" velocities
 - Rigid velocities as instantaneous screw motions
 - Wrenches on a rigid body
 - Screw coordinates for wrenches and Poincot's theorem
 - Application to forward kinematics of robot manipulators

Textbook: There is no textbook for this course, since no textbook is currently available to provide the desired coverage of all class material. Lecture notes and handouts will be provided to cover the material taught.

MECE E4430: Automotive Dynamics

Course Description

Prerequisites: ENME 3105; recommended: ENME 3100, 3106. "This course reviews the fundamentals of vehicle dynamics. A systems-based engineering approach is used to explore the following areas: tire characteristics, aerodynamics, stability and control, wheel loads, ride and roll rates, suspension geometry, and dampers. A high-performance vehicle (racecar) platform will be used as an example throughout the course to review these topics.

Course Texts

Required:

- "Race Car Vehicle Dynamics," Milliken and Milliken (RCVD)

Supplemental:

- "Fundamentals of Vehicle Dynamics," Thomas Gillespie;
- Sustainable Energy – without the hot air, David MacKay, 2009,
 - o <https://www.withouthotair.com/download.html> (Links to an external site.)

Recommended:

- Other articles and texts throughout the semester as appropriate

Grading

- Pop quizzes based on lecture materials, general engineering knowledge, and weekly readings – 25%
- Homework – 20%
- Mid-term & Final – 30%
- Final paper / project – 25%

Course Schedule - Wednesdays, 4:10 PM - 6:40 PM

Lecture #1, Sept 5: Introduction

Lecture #2, Sept 12: Lateral load transfer distribution

Lecture #3, Sept 19: Springs and Anti-Roll Bars, Ride rates, roll rates, motion ratios, roll stiffness calculation

Lecture #4, Sept 26: Suspension geometry I

Lecture #5, Oct 3: Applied example w/tire data

Lecture #6, Oct 10: Continue worked example, Damping calculations, shock absorbers

EXAM: Oct 17: Midterm

Lecture #7, Oct 24: Project updates, Vehicle system and damper data analysis

Lecture #8, Oct 31: Data acquisition & analysis

Lecture #9, Nov 7: Intro. to steady state stability and control (i.e. 'handling')

Guest Lecture, Nov 14: Guest Lecture Dr. Edward Kasprzak - Tires, tire testing, tire modeling

Lecture #10, Nov 28: Stability derivatives, compliance, Guest Lecture Chris Woodward -Toyota Racing Development - CFD

Lecture #11: Dec 5: Final Exam & project updates (preliminary results)

Project report due Dec. 22 by midnight (last day of finals)

MECE 4431 Space Vehicle Dynamics

- 1. Credits:** 3 Credit Hours
2. Contact Hours: TBD
3. Instructor: Professor
4. Textbook Information: None

a. Other Supplemental Material

Writeups supplied as handouts on many topics in the course

b. List of Reference Books:

Peter C. Hughes, Spacecraft Attitude Dynamics, J. Wiley, 1986 (2004 edition, Dover publications, Mineola, New York) S.W. McCuskey, Introduction to Celestial Mechanics, Addison-Wesley, 1963 John E. Prussing, Bruce A. Conway, Orbital Mechanics, New York: Oxford University Press, 1993
Marshall Kaplan, Modern Spacecraft Dynamics and Control, Wiley, 1976
Bong Wie, Space Vehicle Dynamics and Control (AIAA Education Series), AIAA (American Institute of Aeronautics & Ast.), 1998 Hanspeter Schaub, John L. Junkins, Analytical Mechanics of Space Systems (AIAA Education Series), AIAA, 2003
Thomas Kane, Peter W. Likins, David A. Levinson, Spacecraft Dynamics, McGraw-Hill Company, 1983

5. Specific Course Information

- a. Course Description:** Space vehicle dynamics, rocket equations, satellite orbits, initial trajectory designs from earth to other planets, satellite attitude dynamics, gravity gradient stabilization of satellites, spin-stabilized satellites, dual-spin satellites, satellite attitude control, modeling, dynamics, and control of large flexible spacecraft.
b. Prerequisites: MECE E3105 or ENME E3105 and ENME E4202 ENME E4202 recommended
c. Co-requisites: None
d. Course Required or Elective: Elective Course

6. Specific Goals for the Course

- a. Specific Outcomes of Instruction:** Satellite orbits, transfer orbits, patched conics, kinematics and dynamics of rigid satellite rotational motion
b. Student Outcomes Addressed by Course: This course addresses the following student outcomes; a, c, k, l and m,

7. Brief List of topics covered:

Overview of course topics
Projectiles. Rocket equation.
Coordinate transformations.
Direction cosine matrices.
Euler Angles.
Spherical triangles.
Great circle.
Kepler's laws.
Derivatives of vectors.
Differential equation of orbits.
Parabolas, hyperbolas, elliptical orbits.
More orbits.
Orbital parameters.
Transfer orbits.
Angular velocity.
Rendezvous equations.
Attitude motion of spacecraft.
Sensors and actuators.
Angular momentum.
Angular momentum equation.
Dyadics.
Inertia matrix.
Euler's equations.
Momentum and energy ellipsoids.
Kinetic energy of rigid body.
Kinematics of rotations.

Equations of rotational motion with kinematic equation choices.
Numerical solution of ode's.
Gravity gradient attitude stabilization, flexible spacecraft, grand tour.

MECE E4507: Fundamental Design Tools

Instructor:

Dr. Yevgeniy Yesilevskiy E-mail: yy3040@columbia.edu
Office: 232A Mudd inside the Mechanical Engineering Office
Office Hours: TBD

Office Hours Zoom link: By request for special circumstances (e.g. illness, religious holiday, job interview, or another legitimate reason)

Teaching Assistants:

TBD

Office Hours: TBD

Office Hours Zoom link: By request for special circumstances (e.g. illness, religious holiday, job interview, or another legitimate reason)

Class times:

Tuesday, Thursday – 10:10am – 11:30am

Optional Textbooks:

SolidWorks 2023 Tutorial (older editions are nearly identical), by David C. Planchard, SDC Publications
Fundamentals of Graphic Communication by Gary R. Bertoline and Eric N. Wiebe
Engineering Design Graphics, by James M. Leake and Jacob L. Borgerson
Machine Design an Integrated Approach by Norton.
Design of Machinery by Norton
The Fundamentals of Machine Component Design, by Juvinall and Marshek
Shigley's Mechanical Engineering Design by Budynas and Nisbett
Mechatronics and Measurement Systems by Alciatore

Course Syllabus

Course Description

The course covers fundamental engineering design tools for creating and testing physical products. Topics will include basics of computer-aided design, circuit design and use of microcontrollers, Internet of Things, and computational modeling and simulation. Students will also gain hands-on exposure to tools for high-fidelity physical prototyping in our world-class Makerspace including 3D printing, laser cutting, prototyping electronics, and others.

Credits

This is a 3-credit course.

Learning Objectives

After taking this course, students will

1. Be able to describe and explain mechanical components, mechanisms, and electromechanical components/systems.
2. Design and precisely manufacture an electro-mechanical system that interfaces with existing hardware in order to achieve a goal. As part of this goal, students will learn to make manufacturing/design tradeoffs, and be able to choose standard off-the-shelf parts that meet their design/performance criteria.
3. Perform analysis of mechanisms and electromechanical systems to see if they meet desired design criteria.
 - a. This analysis will take place through modeling as well as virtual prototyping methods.
4. Prepare detailed engineering drawings and manufacturing plans to precisely manufacture parts that have the correct geometry, loading characteristics, and tolerances.
5. Build and assemble electro-mechanical systems using machine shop tools and electrical elements.
6. Test and evaluate the performance of mechanical systems, and redesign as necessary to improve the performance.
7. Understand safety considerations in mechanism design.
8. Communicate design and manufacturing choices and their rationale orally and in writing.
9. Learn to use rapid prototyping tools such as 3D printers, laser cutters, and electronics.

Course Requirements and Expectations

- 1) Attendance expected.
- 2) Complete all homework assignments.
- 3) Complete the project (project requirements and expectations to be given in a separate document).

Homework

Homework will be assigned regularly. It is always due by the posted time. Due dates will be posted with each assignment. All assignments are to be completed on your own. While students may consult with course instructors and other students during the conceptualization of a problem, all submitted work should be done by you alone. Additionally, students are not allowed to use, in any way, pre-existing solutions (either former students' work, solutions from the publisher, or from any former instructor). Again, all assignments should reflect your own work. Violation of this policy will initiate action according to the Academic Integrity Violation and Sanction Classification Rubric.

Late Submission Policy

Unless the lateness is excused, there is a penalty of 10% off of the assignment per late day (if the submission is an hour late on the due date, that will count as the first late day). Once the answer key to the homework is posted, no more submissions are allowed and all credit for that assignment will be lost.

Grading

Outcome will be determined based off of the following percentages:

- Project 60%
- Peer Evaluation 10%
- Homework assignments 30%

NOTE: If your peer evaluations indicate that you did little to no work on the project, you will receive a greatly reduced project score.

Peer Evaluation will also only be relevant if project is done in teams. If it is done individually, the 10% will be put into the project.

Academic Honesty Policy

The academic honesty policies for the Mechanical Engineering Department are listed at:

<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at:

<http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at

<http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at:

<http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

For this course, ChatGPT and similar AI tools will NOT be used unless explicitly allowed. It will be considered a violation of the academic honor code if it is used to complete assignments.

Attendance Policy

Class and lab attendance is mandatory. Unexcused missed class will result in grade reduction. Discuss with the instructor any potential conflict or illness with the instructor well before the session.

Disability-related Academic Accommodations

In order to receive disability-related academic accommodations for this course, students must first be registered with their school Disability Services (DS) office. Detailed information is available online for both the Columbia and Barnard registration processes. Refer to the appropriate website for information regarding deadlines, disability documentation requirements, and drop-in hours (Columbia)/intake session (Barnard).

Students registered with the Columbia DS office can refer to the Master TARF section of the DS Testing Accommodations page for more information regarding disability-related academic accommodations for this course.

MECE-E4440: Optimization of Dynamic Systems

Summary of the course: Fundamentals for optimizing performance of dynamic systems described by a set of ordinary differential equations based on the theory of variational calculus. Systematic methods to solve the optimization problems using numerical methods. Topics covered include: Static Optimization of systems with equality and inequality constraints, Numerical Methods to solve static optimization problems, Theory of calculus of variations, Application of calculus of variations to solve dynamic optimization problems with equality and inequality constraints, Direct and indirect numerical methods to solve dynamic optimization problems, Finite-time linear systems, Steady state linear systems, Multi degree-of-freedom robotic systems.

Prerequisites: Course on linear and/or nonlinear control theory, Introduction to Robotics, or Permission of the instructor

Notes: The course was taught as an experimental class in Fall 2019.

Time: Tuesday 4:10 pm - 6:40 pm,

Venue: Mudd Building 627

Instructor: Sunil K. Agrawal, Ph.D.

Professor of Mechanical Engg./Rehabilitation and Regenerative Medicine Office: 230 Mudd Hall

Email: Sunil.Agrawal@Columbia.edu

Textbook:

Optimization of Dynamic Systems, Authors: Sunil K. Agrawal and Brian C. Fabien, Kluwer Academic Publishers, ISBN 0-7923-5681-0

Prerequisites: MECEE 4602 or Instructor's Permission

Schedule:

9/03 Chapter 1: Static Optimization
9/10 Chapters 1 Contd. and Chapter 2: Numerical Methods
9/17 Chapter 2 Contd. - Numerical Methods
9/24 Chapter 3: Calculus of Variations
10/1 Chapter 4: Dynamic Optimization
10/8 Chapter 4 Contd. - Dynamic Optimization
10/15 Chapter 5: Dynamic Optimization – Direct Solution
10/22 **Mid-Term Project Report Due**
10/29 Chapter 6: Dynamic Optimization – Indirect Solution
11/5 University Holiday
11/12 Chapter 7: Finite time linear Systems
11/19 Chapter 8: Steady State Linear Systems
11/26 Chapter 9: Multi-degree-of-Freedom Systems
12/3 **Final Project Presentation**

Grading:

Homework: 20%

Mid-Term Project: 30%

(Includes presentation/Technical report)

Final Project 50%

(Includes presentation/Technical report)

Other Course Details:

- (i) **Homework** will be assigned after the completion of a topic. These will be due in a week after the assigned date. The problems will require programing, simulation, and animation using MATLAB.
- (ii) **Mid-Term Project:** The students will work in assigned groups of 2. Define a single- degree-of-system that you will like to optimize the performance. Motivate this system from a practical application. Please discuss your project with the Instructor/TA.
Prepare 6 Powerpoint slides that include the following: Problem statement, Your solution approach, Results, Conclusions and Future Extensions. Write a 3-page technical report in word (2 column 10 point) using the typical format of an IEEE paper (you can use the template of ICRA paper).
- (iii) **Final Project:** The students will work in self-selected groups of 2. Define a two or more degree-of-freedom system that you will like to optimize using the principles that you have studied in this course. Motivate this system from a practical application. Please discuss your project with the Instructor/TA.
Presentation - Prepare 6 PowerPoint slides that include the following: Problem statement, Your solution approach, Results, Conclusions and Future Extensions. *Technical Paper* - Write a 3-page technical report in word (2 column 10 point) using the typical format of an IEEE paper (you can use the template of ICRA paper).

- (iv) **Course Ethics:** Discussion of the lecture material among students is encouraged. However, home-works must be performed individually.

MECE-E4520 DATA SCIENCE OR MECHANICAL SYSTEMS

Class format: A series of guest lectures (14 total), Homework, Final Project/Paper

Textbook: None; topic readings assigned for each lecture

Bulletin Description: Introduction to the practical application of data science, machine learning, and artificial intelligence. A review of relevant Python tools necessary for applying data science is reviewed, as well as a detailed review of data infrastructure and database construction for data science. A series of detailed industry case studies from experts in the field of data science will be presented.

Rationale: Data science curriculum generally maintains a strong focus on machine learning, and more broadly, AI fundamentals. A gap exists between academia and the practical application of data science methods in industry. Beyond machine learning and AI in general, a strong basis in Python and a nuanced understanding of the challenges of building appropriate data pipeline and database architecture are foundational requirements for building successful data science programs. This course aims to fill this gap.

Full Description: This seminar-based course will consist of case studies in the field of data science. The course is primarily aimed at engineering students with an interest in data science. The goal of this course is to provide an initial look at a broad range of 'real world' data science applications. Each lecture will provide a background review of current data science methods, followed by an applied example based on current projects at Rho AI. The case studies will generally focus on engineering problems across the waste, water, and energy industries. In addition to AI and machine learning, this class will review data infrastructure and more generally, "DevOps," as a critical component to successful deployment of AI-based solutions.

Grading and requirements: Overall grades calculated as follows: 20% class participation, 30% homework, 50% final project. Attendance is mandatory, as class participation is a critical element of the curriculum (1 letter grade penalty per unexcused absence). Students will be expected to arrive for each lecture on time and participate in the discussion. Readings will mostly consist of relevant industry and research papers relating to practical data science applications for mechanical systems. Readings will be assigned prior to the week's lecture and students will be expected to come to class prepared to discuss assigned readings in the context of that day's lecture material. Homework will be assigned throughout the semester and the penalty for late homework will 10% of the total grade for that assignment per day late. Each student will be required to complete a final project that is based on the class material, but that takes the class material beyond its introductory stage and reports on a recent application of data science for industrial and/or mechanical system processes. Projects can be completed individually or in groups of 2-3, and an idea must be formulated early on in the semester in coordination with the instructor(s).

Lecture #1 (1/22/20) - Introduction to data science, machine learning, and Artificial Intelligence

- Lecture Goal: Understand what machine learning, data science and artificial intelligence are, how they relate to topics you might be familiar with, how they are being applied.
 - o What is machine learning?
 - o How can you understand it based on current coursework?
 - o Techniques / overview
 - o Why do we care / why is it hot
- Required reading: selected overviews of key introductory articles and chapters regarding the role of AI and Machine Learning as being applied to business today.
- Homework: run a complete machine learning example focused on the Boston Housing data set. Preliminary analytical approaches will be provided, and students will be encouraged to expand upon these tools to increase the accuracy of the prediction method.

Lecture #2 (1/29/20) – Python 101

- Lecture Goal: Review the foundations of Python programming within the context of data science
 - Required reading and other prep:
 - o Download Miniconda (version 3+, accept default
- options): <https://conda.io/miniconda.html> (Links to an external site.)
- o Download a text editor (e.g. Sublime Text, Atom)
 - o Download git: <https://git-scm.com/downloads> (Links to an external site.)
 - o Read A Whirlwind Tour of Python
- (<https://github.com/jakevdp/WhirlwindTourOfPython> (Links to an external site.)): Sections 3-5, 7-10, 13, 15
- Lecture Flow:
 - o Why use Python?
 - o Different ways to interact with Python
 - o Write simple scripts using common data science tools
 - Homework: TBD

Lecture #3 (2/5/20) - Databases, databases, and databases

- Lecture Goal: provide an appreciation for the wide array of available database "makes and models", along with why their relative strengths/weaknesses are critical to understand in the world of data science.
- Required reading: selected overviews of key database classes (specifically, the difference between relational and non-relational) and commonly used databases in each category (e.g. MySQL/Postgresql, Redis, Elasticsearch, Arango)
- Lecture Flow:
 - o High level overview of relational databases.
 - Describe the core concepts of tables, normalization, etc.
 - Describe the SQL query language
 - Show different examples of relational database options such as MySQL, Postgresql, etc.
 - o Overview of non-relational databases
 - Describe core concepts, which are far more varied than relational
 - Show examples of different query languages for databases
 - Show two examples of non-relational databases (e.g. elasticsearch and arango)
 - o Real-world example/demonstration
 - Pit Rho using Postgres for core relational models and Redis for high speed caching during real-time events
 - o Interactive example of the steps involved in the database selection process
 - Provide a use case example
 - Walk through selection process with students, showing techniques for weighing pros/cons of different options.
 - o Homework: design a system with the most efficient use of databases based on a provided scenario.
 - o References / reading materials:
 - <https://github.com/dhamaniasad/awesome-postgres#readme> (Links to an external site.)
 - <https://github.com/sindresorhus/awesome#back-end-development> (Links to an external site.)

Lecture #4 (2/12/20) - Data Pipelines for ML

- Lecture Goal: provide an understanding on how to collect, move and analyze data for ML.
- Lecture flow:
 - o Overview of methodologies for collecting data (open data vs. proprietary data)
 - o Overview of data ingestion pipelines:
 - Ingesting, little, but specialized data
 - Ingesting big data
 - Ingesting time-series data
 - Real-time vs batch processing
 - o Overview of tools for data analysis and manipulation:
 - Jupyter notebooks
 - Data scaling and transformation
 - Plotting for visual analysis
 - o Homework:
 - Pick a real-world problem and design data ingestion pipeline for it

Lecture #5 (2/19/20) - Introduction to Neural Networks and Deep Learning

Class Description:

- Lecture goal: Introduce the neural network, survey the landscape of specialized architectures and their respective fields of applicability and open the discussion of 'deepness' and why these algorithms have been so successful.
- SWBAT: Describe a deep neural network as a series of concepts, highlighting the hierarchical nature of the algorithm.
- Lecture flow:
 - o Expose students' perception of neural networks/deep learning
 - o Early applications & Successes of deep learning
 - o Fundamentals towards a basic neural network
 - Nonlinearity, logistic regressions, and layering
 - o Neural network
 - Stitching together logistic units
 - The costs of model complexity & backpropagation through calculus
 - o Why are deep learning models so useful?
 - Review of some theories
 - Leveraging Hierarchy
 - o Modern deep learning architectures & applications:
 - How can we ensure translational invariance? Convolutional NN
 - How can we encode temporal dependencies? Recurrent NN

- How can we create, rather than predict? Generative Adversarial Networks

Lecture #6 (2/26/20) - Reinforcement learning

- Lecture goal: An overview of the reinforcement learning problem and applications in engineering. This includes tie-ins with techniques from supervised learning, and recent successes with deep neural networks as environment models, value function approximators, and policy estimators.
- Lecture flow:
 - o Brief intro to Markov decision processes (MDPs)
 - o Definition of reward, state, actions, value, and policy
 - o Modeling the environment
 - Examples
 - o Modeling the value function
 - Deep Q learning successes (e.g. Atari games)
 - o Policy gradient methods
 - Deep learning policy gradient methods
 - A3C algorithm and AlphaGo
 - o Review some specific engineering applications
- (Possible HW):
 - o Use Open AI Gym and ML library of choice to get a Q-Learning ML agent working on an Atari game
- Reference: Reinforcement Learning, An Introduction (Links to an external site.)

Lecture #7 (3/4/20) - Intersections of data science and software engineering

- Lecture Goal: provide a guide for successful collaboration between data scientists and software engineers.
- Required reading: selected overviews of different workflow and project management methodologies (e.g. waterfall vs agile vs purely exploratory vs ...) to highlight how there are multiple methods available for successfully planning and managing projects - and each has its own timelines, expectations, and paths to the end goal.
- Lecture Flow:
 - o High level overview of what industry expects from “data scientists” vs “software engineers”
 - o Examples of why it’s important for data scientists and software engineers to work together and find a common language (e.g. some fun examples of where things went wrong and why)
 - o Timeline expectations - examples of typical development cycles between the two competencies (specifically highlighting how expectation setting is important and describing why timeline expectations are different)
 - o Natural divisions of labor and how to speak each other’s language
 - o Recipes for success - ensuring ML work can make it to a production application and ‘play nice’ in demanding environments (e.g. memory, processor, disk, network concerns)
 - o Applied example of weekly cross-domain coordination on Pit Rho product, include here not only the roles of software developers and data scientists, but also analysts and domain experts

Lecture #8 (3/11/20) - From Research to Reality

Lecture Goal: To provide insight into the research world, start-up life, and industry, with regards to data science.

Lecture Flow: Case Studies in Academia, Start-Up, and Industry.

- Academia: A deep dive into an academic research problems and their solutions
- Start-Up: Understanding the start-up lifestyle and responsibilities
- Industry: The challenges of applying data science in industry

Lecture #9 (4/1/20) - Machine learning for chemistry and materials science 1: an overview

- Lecture goal: provide an overview of ML applications in materials and chemicals design and discovery, including discussion of successful and unsuccessful efforts
- Required reading:
 - o *Materials Genome Initiative white paper* (https://www.mgi.gov/sites/default/files/documents/materials_genome_initiative-final.pdf (Links to an external site.))
 - o *Accelerating the discovery of materials for clean energy in the era of smart automation* (<https://www.nature.com/articles/s41578-018-0005-z> (Links to an external site.))
- Lecture flow:
 - o Overview of computational materials science techniques and how they have evolved in the last few decades: going from solving the H atom to modern-day Kohn-Sham DFT
 - o Frame the problem of materials/chemicals discovery: when intuition is poor,

humans result to guessing. When screening materials there is a speed vs accuracy trade-off - for certain problems you need speed and can sacrifice accuracy (especially when material space is large)

- o Discuss ML approach and how this is different/similar from existing approaches
- o Provide examples, discuss companies doing this
- o Begin discussion of technical issues
- Homework (one assignment for both lectures): ~1000-word paper discussing how ML could apply to your individual engineering field of interest. Think beyond “how do we answer questions” and delve into “why do we want to answer this question”? This is the domain where ML shines. Highlight cases where the conventional wisdom/approaches have been unsuccessful and cite work when possible. This may help you see your field in a new light.

Lecture #10 (4/8/20) - Machine learning for materials science 2: deep dive in batteries

• Lecture goal: provide a real-life example of how ML can accelerate materials development by discussing Austin’s work in batteries

• Required reading:

- o *Holistic computational structure screening of more than 12,000 candidates for Li-ion conductor materials* (<http://pubs.rsc.org/en/content/articlehtml/2017/ee/c6ee02697d> (Links to an external site.))
- o *Machine learning-assisted discovery of many new solid Li-ion conducting materials* (<https://arxiv.org/abs/1808.02470> (Links to an external site.))

• Lecture flow:

- o Continue discussion of technical issues around ML: this is small data and we have to be careful not to overfit at all costs
- o Begin with a dive into battery science
- o Discuss Austin’s battery paper to highlight the technical issues around ML for materials
- o End with class discussion of other directions in hard science where this approach may be valuable

• Homework: Continue writing assignment from previous week

Lecture #11 (4/15/20) - Transfer learning and AutoML

• Lecture goal: Provide an introduction to the importance of transfer learning in industry, science, and engineering, with the focus on the applications of image recognition, self-driving cars, and physics models.

• Lecture flow:

- o Description of transfer learning, why it's useful, how it relates to human reasoning (reading ([Links to an external site.](#)))
 - Successes in image recognition (reading ([Links to an external site.](#)))
 - Example applications in self driving cars (segmentation), engineering problems with small datasets (car/airplane model prediction)
 - Example applications in physics and materials science
- o General description of AutoML (meta-learning)
 - Why is it needed, what are recent developments
 - The CNN/RNN loop
 - Applications to hyperparameter tuning, data processing pipelines, state of the art results in a variety of applications ([reading 1 \(Links to an external site.\)](#), [2 \(Links to an external site.\)](#))

Lecture #12 (4/22/20) - Applied example, Pit Rho

• Lecture Goal: Review how data science and machine learning are used for in-race strategy, with an application to NASCAR.

• Required reading: introductory presentation

• Lecture Flow:

- o High level overview of NASCAR and NASCAR strategy
- o Overview of how technology drives decision-making in NASCAR
- o The case for real-time strategy tool
- o Key strategy considerations
- o How it plays out in a race
- o Lessons to be more broadly applied

• Homework: Continue the homework from week one.

Lecture #13 (4/29/20) - [topic TBD] -

MECE E6614: Introduction to Robotics

Meeting Time: Tuesday 4:10 pm - 6:40 pm, Venue: Fayewether 310

Instructor: Sunil K. Agrawal, Ph.D.
Professor of Mechanical Engg./Rehabilitation and Regenerative Medicine
Office: 230 Mudd Hall
Email: Sunil.Agrawal@Columbia.edu

Office Hrs: Tuesday 2:00 – 3:00 pm, 230 Mudd Hall
TA: Haohan Zhang: hz2347@columbia.edu
Antonio Prado: jap2254@columbia.edu

Textbook: Robot Dynamics & Control, M. W. Spong and M. Vidyasagar, Wiley 1989
Prerequisites: All students must have taken introductory classes in Dynamics/Control

Schedule:

9/6 Introduction to Robotics: Chapter 1
9/13 Rigid Motions and Homogeneous Transformations: Chapter 2
9/20 * Work in Groups: Project 1
9/27 Angular Velocity and Linear Velocity: Chapter 2 Contd.
10/4 Forward Kinematics: Chapter 3
10/11 Inverse Kinematics: Chapter 4
10/18 Velocity Kinematics – Jacobians: Chapter 5
10/25 Dynamics: Chapter 6
11/1 * **Mid-Term Exam**
11/8 **University Holiday- Election Day**
11/15 Dynamics: Chapter 6 Contd.
Independent Joint Control: Chapter 7
11/22 Independent Joint Control: Chapter 7 Contd.
11/29 * Work in Groups: Final Project
12/6 **Final Project Presentation**

Grading:

Homework: 20%
Project 1 10%
Mid-Term Exam: 30%
Final Project 40% (Includes presentation/Technical report)

Other Course Details:

- (i) **Homework** will be assigned after the completion of a topic. These will be due in a week after the assigned date.
- (ii) **Project 1:** These will be performed in assigned groups of 4. You choose a paper from ICRA 2015 or 2016 Proceedings on a topic of interest to you and obtain permission from Instructor/TA to work on it. You may be able to pick papers based on sub-disciplines of robotics or application areas. Prepare 6 PowerPoint slides that include the following: Problem statement, Prior research, Solution approach, Results, Conclusions and Future Extensions.
- (iii) **Mid-Term Exam:** This exam will be based on material of Chapters 1-6
- (v) **Final Project:** The students will work in self-selected groups of 4. Define a problem that involves novel design, analysis, simulation, etc. using the principles that you have studied in this course. The problem should have a good motivation and should be approved by the Instructor/TA.

Presentation - Prepare 6 PowerPoint slides that include the following: Problem statement, Your solution approach, Results, Conclusions and Future Extensions. *Technical Paper* - Write a 4-page technical report in word (2 column 10 point) using the typical format of ICRA paper.

- (v) **Course Ethics:** Discussion of the lecture material among students is encouraged. However, home-works must be performed individually.

MECE-E4603 Applied Robotics: Algorithms and Software

Course Designator: MECE

Course Prefix: E

Course Number: 4603

Course Semester: x

Title: Applied Robotics: Algorithms and Software

Lecture Hours: standard (13/14 lectures)

Lab Hours: 0 **Points:** 3

Instructor: Matei Ciocarlie

Prerequisites: Fundamental programming skills (e.g. COMS W1002 or COMS W1004 or COMS W1005 or ENGI E1006 or equivalent).

Corequisites: none

Program Restrictions: none

Textbook: none

Evaluation: Applied projects (70%), quizzes (30%)

Bulletin Description: The science and systems aspects of Robotics taught from an applied perspective, focusing on algorithms and software tools. Spatial reasoning; tools for manipulating and visualizing spatial relationships. Analysis of robotic manipulators; numerical methods for kinematic analysis. Motion planning, search-based and stochastic approaches. Applications for force and impedance control. Grading based on a combination of exams and projects implemented using the Robot Operating System (ROS) software framework and executed on real and simulated robotic manipulators.

Notes: This course can be taken individually or simultaneously with MECE E4602 (Introduction to Robotics). This course can also be used to satisfy the requirements of the Robotics and Control concentration of the Mechanical Engineering Master of Science program.

Rationale: The Robotics industry is booming, with new application domains ranging from logistics and e-commerce to the hospitality industry and even the home, and unprecedented investment from both start-ups and major technology companies such as Amazon or Google. This course teaches the combined science and systems aspects needed for a roboticist to hit the ground running in this new ecosystem. It presents the core aspects of mobility and manipulation using modern tools such in both software (the Robot Operating System) and hardware (the Baxter robotic manipulator). While theoretical concepts are presented as needed, the focus is on learning the practical application of these concepts in assignments executed on real robots.

Syllabus:

9/5	Introduction
9/7	Introduction to ROS Assignment 0 (ungraded) released: basics of ROS
9/1 2	Transforms I
9/1 4	Transforms II Assignment 1: Transform Manipulation and Visualization in ROS
9/1 9	Kinematic Chains / Forward Kinematics
9/2 1	Analytic Inverse Kinematics Assignment 2: FK and Robot Visualization
9/2 6	Differential Kinematics
9/2 8	Linear Algebra Refresher I (matrices and vector spaces, linear systems)
10/ 3	Linear Algebra Refresher II (Singular Value Decomposition) Redundant Robots
10/ 5	Cartesian Control I
10/ 10	Cartesian Control II Numerical Inverse Kinematics
10/ 12	Assignment 3: Cartesian Control and Numerical IK

Midterm review
10/ 17 Midterm quiz
10/ 19 CTV Robotics Symposium
10/ 24 Motion Planning I
10/ 26 Motion Planning II
10/ 31 Motion Planning III
11/ 2 Trajectory Execution
Force Generation on Robot Arms
11/ 9 Assignment 4: Motion Planning
11/ 14 Mobile Robot Kinematics
State Estimation I
11/ 16 State Estimation II, Probabilistic Reasoning
11/ 21 State Estimation III, the Kalman Filter
11/ 28 State Estimation IV, Extended Kalman Filter, Particle Filters
11/ 30 Final review
Assignment 5: State Estimation
12/ 5 Final quiz
12/ 7 Recap and Conclusions

MECE 4606 – Digital Manufacturing

Mondays 1:10-3:40, Mudd 833

This course examines a variety of digitally-controlled manufacturing processes that convert computer models directly into physical objects. Topics include: Additive manufacturing processes, CNC, Sheet cutting processes, Numerical control, Generative and algorithmic design. Topology Optimization, Broader social, economic, legal and business implications will also be reviewed. Course involves both theoretical exercises and a hands-on project.

Staffing and office hours:

Instructor: Prof. Hod Lipson, Mudd 535F, hod.lipson@columbia.edu

Office hours: Monday 12pm-2pm.

Course assistants: TBD

Grader: TBD

Course website: All course materials and assignments will be distributed through Courseworks

Message board: Students are encouraged to use Ed Discussion (from Courseworks) for all technical questions and logistical clarification. Direct emails to the instructors should be used only for personal matters

Syllabus:

1. Overview of digital manufacturing processes
 - a. What makes a manufacturing process “digital”
 - b. The 10 disruptive principles of digital manufacturing processes
2. Additive Manufacturing processes – Engineering polymers, metals, ceramics
 - a. Stereolithography
 - b. Selective Laser Sintering
 - c. Fused Deposition Modeling
 - d. Polyjet
 - e. LENS
 - f. Layered object manufacturing
3. Additive Manufacturing processes – Advanced materials
 - a. Electronic Materials
 - b. Bioprinting
 - c. Food Printing
4. Material properties
 - a. Mechanical properties of printed materials
 - b. Post processing
 - c. Empirical and data-driven models
5. CNC
 - a. Mill
 - b. Lathe
6. 2D Cutting
 - a. Laser Cutting
 - b. Plasma Cutting
 - c. Waterjet
7. Programmable Assembly
 - a. Digital Assembly
 - b. Digital Bending
8. Fundamentals of geometric representations for digital manufacturing
 - a. Solid representations
 - b. Boundary representations
 - c. Function representations
 - d. Voxel representations

9. Algorithmic design for digital manufacturing
 - a. Parametric Models
 - b. Vibrational Geometry
 - c. Generative models
 - d. Topology optimization
10. Machine Control
 - a. Gantry positioning approaches
 - b. STL/AMF Slicing
11. Broader impacts
 - a. Safety, Liability and intellectual property
 - b. Environmental impact
 - c. On-demand fabrication models and mass customization

Textbook:

None required. A reading list will be distributed.

Grading:

Your final grade will be determined from the class activities as follows:

- Laser cutting assignment: 10% - Program a laser cutter to cut a box
- Lamp assignment: 10% - Generate a lamp shade programmatically
- Topology Optimization assignment: 10% - Optimize a desk and chair
- Digital Embroidery assignment: 10% - Design a T-shirt insignia
- Food Printing assignment: 30% - Print a dish
- Final Exam 30%

Late Submissions

You are provided 96 grace hours for late submission which you can use for any reason you like. You can earn more hours by submitting early, or use up hours by submitting late. If you have used up all your hours, there is a late penalty of 5 percent per day. Once you reach 10 days late, the penalty will remain at 50% until you submit. Last submission accepted is a week after last day of classes.

If you have a more serious situation (medical or personal) that is preventing you from completing coursework in a timely manner, and is beyond what can be addressed by grace hours, do not send medical/personal information to the instructor, TA, or grader (they are prohibited from seeing this info due to privacy). Instead, graduate students should contact deans wellness officer as listed at <https://wellness.engineering.columbia.edu/content/contact-us> and undergrads should contact their Advising Dean to discuss reasonable accommodations. For longer term situations reach out to the Office of Disability Services (<https://health.columbia.edu/content/disability-services>) and have them assess your situation. Once your situation is assessed, all faculty and course staff in all your courses will be notified of accommodations to be made. ODS is the only office allowed to make academic accommodations.

Available Resources

Makerspace (<http://make.columbia.edu>) If you are on campus, you are free to use the Makerspace (Engineering Terrace 254) to perform the assignments, as well as find basic components (e.g. fasteners and wires). Please visit the website and attend safety training.

CAD. You can use any CAD software you like, such as Creo, Fusion 360, Blender, or SolidWorks. SolidWorks for educational use is available in ET 252 computers. You can also download a copy to use on your personal computer. This is your personal copy with your UNI inside. Please do not share: <https://cwapadmin.columbia.edu/cwpackage/D94D382DA1BEA.cfm> Once you download, unzip and run *install.vbs* The 1 GB installation can take a few hours.

Getting ready

If you are interested in preparing for this course in advance, you may want to brush up on the following:

1. **CAD skills.** You should be comfortable using a 3D CAD software, such as Solidworks (provided). If you do not have much experience using CAD, you may want to install and follow online tutorials before the course begins, so that you will be ready for the course. For example, do the basic SolidWorks video tutorials for parts, assemblies and drawings.
2. **Programming skills.** You should be comfortable programming in Python, MATLAB, Java, C/C++, or any other language. If you are not comfortable in any language, we suggest you train in Python before beginning the course.
3. **3D printing and manufacturing skills.** You will need to perform some 3D printing. We suggest you get trained in the makerspace and do some 3D printing and laser cutting before the course begins. Try printing the “Benchy” sample.

Safety:

Improper, irresponsible or unsafe behavior will result in loss of laboratory privileges in MechE Lab, Makerspace, and the MechTech Lab. Due to the high fabrication content of this course, this policy will be strictly enforced. Grades may also be used to penalize safety.

When working in common areas or using shared equipment, please clean up after yourself, replace tools in their proper location and tidy the workspace. If tools or equipment have been broken, damaged, or are malfunctioning, please report this to the TA/CA immediately so that they can be repaired or replaced.

Academic Integrity

Students may NOT copy any part of someone else's design work (including from other students, external sources, previous years, the Internet, etc.), source code, CAD or written text. All text, source code, and CAD models must be created from scratch by the student(s) submitting the work. Copying is considered violation of academic integrity. Some assignments may be done in pairs, as described in the assignment briefing.

The follow constitutes cheating in this course:

- Copying assignments (in full or in part) from others.
- Consulting reports from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others without proper citation (quotes and reference).

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university.
- The Department of Mechanical Engineering adheres to Columbia's policies on academic integrity, see <http://www.college.columbia.edu/academics/integrity>.

Abide by the Honor Code

- Honor code: <https://www.cc-seas.columbia.edu/integrity>
- Also review the guidelines posted here: <http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>
- All coursework is to be done by the student working alone, except when permitted by instructor. For homework assignments, you may consult other students for general guidelines or to review and discuss material covered in class, but homework assignments must be completed individually, except when permitted by instructor.
- No external aids or electronic devices are allowed in exams, except when permitted by instructor.
- Do not look up homework solution sets posted from previous years or posted elsewhere.
- Consult the instructor if you require clarifications regarding the honor code.

Student Bill of Rights

- Academic integrity policies clearly explained at start of semester
- Course requirements/grading policies/etc. must be clearly stated at start of semester.
- Textbook/reference book usage must be clarified at start of semester.
- Homework assignments will be graded within two weeks (unless valid explanation provided).
- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedure for meeting with students.
- Instructors will provide pertinent information on assignments in a timely manner.

Students with Disabilities

If you are a student with a documented disability on record at Columbia University and wish to have a reasonable accommodation made for you in this class, please contact the instructor immediately.

Notice of copyright

All lecture notes and slides made available to students in this course are copyrighted by the instructor and third parties and are not to be freely distributed/posted online without the written consent of the instructor and those third parties. The instructor explicitly denies consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Courseworks. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

MECE E4610 Advanced Manufacturing Processes

INSTRUCTOR: Sinisa Vukelic E-mail: sv2147@columbia.edu Office: 122B Mudd

TEACHING ASSISTANT: TBD

OFFICE HOURS: TBD, by appointment, and any time you see me in the office

LECTURES:

Wednesdays 4:10 pm – 6:40 pm

Location: 1024 Seeley W. Mudd Building

PREREQUISITES

Introductory course on manufacturing processes, and heat transfer, knowledge of engineering materials, or the Instructor's permission.

REFERENCE TEXTBOOKS

Kalpakjian S and Schmid, SR, Manufacturing Engineering and Technology

Gibson, I, Rosen, DW and Stucker, B, Additive Manufacturing Technologies Rapid Prototyping to Direct Digital Manufacturing (electronically available at Columbia Library CLIO)

Hocheng, H and Tsai, H-Y Advanced Analysis of Nontraditional Machining, Springer, 2013 (electronically available at Columbia Library CLIO)

Kannatey-Asibu, Jr., E, Principles of Laser Materials Processing, Wiley, 2009 (electronically available at Columbia Library CLIO)

Steen, W, and Mazumder, J, Laser material processing, 4th ed., Springer, 2010 (electronically available at Columbia Library CLIO)

GENERAL TOPICS

- Introduction to Advanced Manufacturing Course
- Advanced Machining Processes
- Additive Manufacturing
- Fabrication of Microelectronic Devices
- Manufacturing Systems
- Quality Assurance and Robust Optimization
- Process Automation and Control

GRADING:

- Homeworks and Case Studies (25%)
- Midterm Exam (30%)
- Final Exam (40%)
- Professionalism (5%)

COURSE POLICY

- Attendance: Attendance is mandatory.

- Professionalism: Professional behavior is expected in all aspects of the course. This includes, but is not limited to, timely arrival for class and appointments, undistracted attention during class and timely communication of special circumstances such as illness or personal issues that interfere with this course.

ACADEMIC HONESTY POLICY

The academic honesty policies for the Mechanical Engineering Department are listed at: <http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at: <http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at <http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at: <http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Furthermore, in this course the follow constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Students receive a failing grade for a specific assignment.
- Students receive a failing grade for an entire course.
- Students may be expelled from the university. Student rights:
- Academic honesty policies clearly explained at start of semester
- Course requirements and grading policies must be clearly stated at the start of semester.
- Textbook and reference book usage must be clarified at the start of semester.
- Homework assignments will be graded on a weekly basis (unless clear explanation provided).
- Midterm exams will be graded within two weeks of the test (unless clear explanation provided).
- Final exams will be graded within the deadlines set by the university.
- The Instructor and teaching assistants must provide office hours or otherwise explain procedures for meeting with students.
- The instructor will provide pertinent information on assignments and lab reports in a timely manner.

Consult the instructor if you require clarifications regarding the honor code

MECE E4611 Robotics Studio

Mondays 10:10-11:25am Location 415 Schapiro

This is a studio course that will expose you to the entire robot design process from A to Z, including kinematics, industrial design, manufacturing, electronics, and programming. The project can be done individually or in pairs, for three credits. Your goal is to design and construct an organic-looking legged robot. This semester we will be building 12-motor robots similar to Boston Dynamics' Spot and ETH's ANYmal

The robot will use serial bus revolute servomotors with a 240-degree range, a rechargeable battery, and Raspberry Pi controller. It may also incorporate a touchscreen display, a camera, and an accelerometer. Your goal is to make a robot that simply moves. You can optionally make the robot do something more interesting, such as recognize objects or learn to walk. You can even use a 3D printer to make interesting textures, such as lattices, scales, fur, and any kind of alien skin.

Course staffing

- Lecturer: Prof Hod Lipson, hod.lipson@columbia.edu
- Course Assistant: TBD
- Grader: TBD

Milestones

- Week 1: Understand the basic components (see next page) and specifications. Sketch out a few potential designs in pencil and paper. Propose at least four different designs. Calculate weight and make sure motors and structure can handle the loads. For an organic look, minimize the use of straight edges, orthogonal corners, and flat surfaces. Iterate.
- Week 2: Create a rough CAD model of a selected design. Download CAD models of components (Raspberry Pi, Motors, Controller board, etc). Revise concepts if necessary.
- Week 3-4: Refine your CAD model. Include motor and PCB mounts, holes for thermoplastic screw inserts, cables and cable harnesses, covers and fairings. Revise concept if necessary.
- Week 5-6. Print portions of your robot (e.g. joints and mounts) to test form and fit, and test basic code functionality and electronic wiring.
- Week 7-8. Print and assemble your entire robot. Test motor connectivity.
- Week 9-10: Program your robot to move in a simple gait
- Week 11-12 Simulate your robot and optimize the gait.
- Week 13-14 improve, revise and adjust.
- grading
- Grading of the project is based on process and accomplishments.
- 50% Bi-weekly assignments
- 50% Final untethered walking robot performance

Academic Integrity

You are not allowed to copy code, CAD files, or design concepts from other sources. Everything you generate must be your own. However, you are allowed to reuse CAD models of subcomponents, and you may be inspired by other designs, but cite your sources.

Late Submissions

You are provided 96 grace hours for late submission which you can use for any reason you like. You can earn more hours by submitting early or using up hours by submitting late.

If you have used up all your hours, there is a late penalty of 5 percent per day. Once you reach 10 days late, the penalty will remain at 50% until you submit.

The last submission accepted is May 11.

MECE E4612: Sustainable Manufacturing

INSTRUCTOR: Sinisa Vukelic E-mail: sv2147@columbia.edu Office: 122B Mudd

TEACHING ASSISTANT: TBD

OFFICE HOURS:

TBD, by appointment, and any time you see me in the office

LECTURES:

Mondays 4:10 pm –6:40 pm

Location: 1127 Mudd

TEXTBOOKS

Green Manufacturing: Fundamentals and Applications, David A. Dornfeld (Editor), Springer, 2013. pdf version is available free of charge at Columbia Library.

COURSE DESCRIPTION:

Fundamentals of sustainable design and manufacturing, metrics of sustainability, analytical tools, principles of life cycle assessment, manufacturing tools, processes and systems, energy assessment and minimization in manufacturing, sustainable manufacturing automation, sustainable manufacturing systems, remanufacturing, recycling and reuse.

PREREQUISITE:

An introductory course in engineering materials and manufacturing processes or instructor's permission.

GENERAL TOPICS

- Introduction to Green Manufacturing
- The Social, Business, and Policy Environment for Green Manufacturing
- Metrics for Green Manufacturing
- Green Supply Chain
- Principles of Green Manufacturing
- Closed-loop Production Systems
- Environmental Implications of Nano-manufacturing
- Life Cycle Assessment Methods
- Green Energy Supply
- Packaging and Supply Chain: A Look at Transportation

GRADING:

- Homework Assignments (15%)
- Case studies: reading assignments and class participation (25%)
- Midterm Exam (15%)
- Final Exam (15%)
- Term project (25% written + 5% presentation) for a team of 2-3 students

Case Studies: Case studies are designed to reinforce lecture materials, bring in a level of realism, and develop appreciation that, in the real world, more factors come into play when sustainability is considered.

- Reading assignments and questions: Materials of each case study will be made available at CourseWorks a week prior to the class discussion of the case. A few questions will also be posed. You are expected to read the materials and provide answers to these questions prior to the class discussion.
- Class participation: During the class, the instructor will lead the discussions. Your active participation is required. You are expected to respond to questions posed by the instructor and other students. You are expected to raise your own questions and provide possible answers.

Homework Assignments: Homework assignments are designed to familiarize you with the Life Cycle Thinking and Life Cycle Assessment (LCA) methodology as implemented in LCA software. They get progressively more involved and lay groundwork for the term project.

- An individual account with LCA by Sustainable Minds (SM LCA) will be made available to each student.
- Homework assignments:

- Homework 1 : SM LCA structures, capabilities, and simple model building and analysis.
- Homework 2: Effects of materials and corresponding manufacturing processes on sustainability; material proxies; and principles of the impact assessment methodology. Bills of materials (BOM), system BOM.
- Outputting results from SM LCA to combine with cover page, overview, analysis and discussion.
- Submission of homework electronically via CourseWorks. Submit assignments on time!
- Requests for correcting possible grading errors must be submitted to the TA within one week after the work is returned with a written explanation of the correction request; no corrections are possible afterwards. If you are unsatisfied with the TA's response, you may appeal to the instructor.

Term Project:

- Term project is team based.
- The term paper should include the following sections: (1) Introduction, (2) Literature Review, (3) Method, (4) Results and Discussions, (5) Conclusion, and (6) References. An appendix can be optionally included.
- Each paper should include a literature review of at least 10 prior studies.
- Project progress will be evaluated through meetings during office hours.
- An oral presentation of your term project will be given by each team.
- Submission of term paper electronically via CourseWorks. Late submissions of the term paper are not accepted.

COURSE POLICY

- Attendance: Attendance is mandatory.
- Professionalism: Professional behavior is expected in all aspects of the course. This includes, but is not limited to, timely arrival for class and appointments, undistracted attention during class and timely communication of special circumstances such as illness or personal issues that interfere with this course.

ACADEMIC HONESTY POLICY

The academic honesty policies for the Mechanical Engineering Department are listed at:
<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at: <http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at <http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at: <http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies.

Furthermore, in this course the follow constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Students receive a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Students may be expelled from the university. Student rights:
- Academic honesty policies clearly explained at start of semester
- Course requirements and grading policies must be clearly stated at the start of semester.
- Textbook and reference book usage must be clarified at the start of the semester.
- Homework assignments will be graded on a weekly basis (unless clear explanation provided).
- Midterm exams will be graded within two weeks of the test (unless clear explanation provided).

- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedures for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

Consult the instructor if you require clarifications regarding the honor code.

MECE E4811 Aerospace Human Factors Engineering

Course Designator: MECE

Course Prefix: E

Course Number: 4811

Course Semester: Fall

Title: Aerospace Human Factors Engineering

Lecture Hours: standard (13/14 lectures)

Lab Hours:0 **Points:** 3 **Instructor:** Mike Massimino

Prerequisites: junior standing

Corequisites: none

Program Restrictions: none

Bulletin Description:

Engineering fundamentals and experimental methods of human factors design and evaluation for spacecraft which incorporate human-in-the-loop control. This course will provide a fundamental understanding of the human factors specific to space flight that must be taken into consideration in the design of spacecraft which incorporate human-in-the-loop control. Students will be taught how to design human factors experiments utilizing task analysis and user testing with quantitative evaluation metrics to develop a safe and high-performing operational space system. Topics include human-centered design, functional allocation and automation, human sensory performance in the space environment, task analysis, human factors experimental methods and statistics, space vehicle displays and controls, situation awareness, workload, usability, manual piloting and handling qualities, human error analysis and prevention, and anthropometrics.

Rationale:

As spacecraft, aircraft, and robotics become more complex, they also add complexity to the tasks of human who control and operated them. Upon completion of this course, students should be able to:

- o Understand human sensory capabilities and limitations in the space environment.
- o Properly design human factors experiments and perform related statistical analyses.
- o Perform a task analysis to derive a set of requirements for a human spacecraft interface.
- o Perform a functional analysis to properly utilize the strengths of both the astronaut and automation.
- o Design static prototypes of spacecraft displays and controls using a set of human factors heuristics.
- o Identify sources and types of human error and design controls to prevent human error in space systems operation.
- o Accommodate the full range of human anthropometrics for crew interface designs.
- o Evaluate usability, workload, and handling qualities using industry-standard quantitative metrics.
- o Combine all of these objectives in a well-written human factors test report.

Syllabus:

Part 1: Role of the Crew in Spacecraft Operation

- Functional Allocation and Group Project Outline
- Human Sensory Performance
- Task Analysis and Human Physiological Effects of Spaceflight

Part 2: Design of Displays for Spacecraft Operation

- Design of Controls for Spacecraft Operation and Human Factors Experimental Methods
- Statistics

Part 3: Workload and Related Testing Methods

- Usability and Manual Piloting
- Handling Qualities, Situation Awareness, Human Error Analysis and Prevention

Part 4: Automation and Human/Machine Collaborative Control

- Anthropometrics: Basics
- Anthropometrics: Applications

Goal

The goal of this course is to allow students to expand their professional experience by participating in an internship at an industrial or research institution outside the university.

Requirement

Students registered in this class must enroll and participate in a technical role at an external entity.

Grading

Students must submit a written report, elaborating on the internship experience, projects, and their relevance to their degree program.

The final report must be accompanied by an assessment letter written by the student's direct supervisor. The letter should be submitted directly to Melbourne Francis at mef2@columbia.edu.

Report guidelines

Your grade for MECE E4999 Fieldwork depends on the quality of the report. Hence, it is important that you describe your internship experience clearly and purposefully. Your report should contain approximately **2500 words**, plus figures, diagrams and references. Your report should contain only non-confidential information.

1. **Cover page** with the following information (only): MECE E4999 – Fieldwork, Semester, Instructor: Prof. Hod Lipson, Company/location of internship, Internship start/end date, your job title or focus area, your name, UNI, date submitted,
2. **Executive summary** (<250 words) summarizing each section below in one or two sentences.
3. **Responsibilities.** Your internship goals and responsibilities. If your internship was quantitative, please explain the concepts and clarify using equations, technical information, diagrams and photos. Clearly explain concepts, equations, symbols, abbreviations. Pretend that the audience reading your report has no knowledge of your work.
4. **Typical day:** Describe a day of this internship. Did you have routines, meetings, reports, presentations?
5. **Organization.** Explain how your work fits within the organization. How did your work contribute to the business of the organization? Who did you work with?
6. **Career contributions.** Discuss how this internship contributes to your career goals and coursework at Columbia. Include your accomplishments.

General instructions: Include page numbers. Single spacing 12pt font. Use only your own words. Do not copy content from the company website or the Internet. Proofread before submitting. Ensure supervisor is aware that they need to submit a final assessment directly to Mel in order for you to receive a grade.

Good luck!
Hod Lipson

MECE E6100 ADVANCED MECHANICS OF FLUIDS

Notice

I would like to notify all individuals with access to the MECE E6100 course material that the course material for MECE E6100 is copyrighted and is not to be freely distributed/posted online without the written consent of the professor. I explicitly deny consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Courseworks. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

Academic Integrity

The follow constitutes cheating:

Copying assignments from others. Consulting solutions sets and laboratory reports from previous years. Consulting exams from previous years that were not made available by instructor. Completing individual assignments in a group, when permission not explicitly granted by instructor. Plagiarizing the work of others.

Cheating may lead to the following consequences:

Student receives a failing grade for a specific assignment. Student receives a failing grade for an entire course. Student may be expelled from the university. The Department of Mechanical Engineering adheres to Columbia's policies on academic integrity, see <http://www.college.columbia.edu/academics/integrity>.

Student Bill of Rights

- Academic integrity policies clearly explained at start of semester
- Course requirements/grading policies/etc. must be clearly stated at start of semester.
- Textbook/reference book usage must be clarified at start of semester.
- Homework assignments will be graded on a weekly basis (unless valid explanation provided).
- Midterm exams will be graded within two weeks of test (unless valid explanation provided).
- Final exams will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedure for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

Honor Code

- Honor code: <https://www.cc-seas.columbia.edu/integrity> (<https://www.cc-seas.columbia.edu/integrity>)
- Also review the guidelines posted here:
<http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>
(<http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>)
- All coursework is to be done by the student working alone. For homework assignments, you may consult other students for general guidelines or to review and discuss material covered in class, but homework assignments must be completed individually.
- No external aids or electronic devices are allowed in exams.
- Do not look up homework solution sets posted from previous years or posted elsewhere.
- Consult the instructor if you require clarifications regarding the honor code.
-

Course Grading

- Homework 30%
- Midterm Exam 30%
- Final Exam 40%

Chapter 1: Tensors

- Indicial Notation
- Tensors

Chapter 2: Stress

- Forces and Traction
- Cauchy Stress Tensor
- Principal Stresses

Chapter 3: Balance Laws for a Continuum

- Differential Operators of Scalar, Vector and Tensor Functions
- Balance of Mass
- Balance of Linear Momentum
- Balance of Angular Momentum
- Balance of Energy
- Entropy Inequality

Chapter 4: Kinematics of the Continuum

- Motion and Path Lines
- Deformation Gradient
- Rate of Deformation
- Volume Deformation
- Velocity Gradient
- Vorticity

Chapter 5: The Viscous Fluid

- Constitutive Restrictions
- Incompressible Fluid
- Isotropic Materials
- Inviscid Fluids
- Newtonian Fluids
- Non-Newtonian Viscous Fluids

Chapter 6: Solution of Problems in Incompressible Newtonian Fluid Mechanics

- Navier-Stokes Equations
- Boundary Conditions
- Problems in Cartesian Coordinates
 - Plane Couette Flow
 - Plane Poiseuille Flow
 - Flow Near an Oscillating plate
- Problems in Cylindrical Coordinates
 - Circular Poiseuille Flow
 - Circular Couette Flow

Chapter 7: Inviscid Incompressible Flows

- Vorticity and Circulation
- Bernoulli's Equation
- Kelvin's Circulation Theorem
- Vorticity Equation

Chapter 8: Inviscid Compressible Flows

- Speed of sound in ideal gas
- Steady isentropic nozzle flow

Course Summary:

Date Details

Wed Sep 11, 2019 **Homework 1**

<https://courseworks2.columbia.edu/courses/85350/assignments/301463> due by 1:10pm

Wed Sep 18, 2019 **Homework 2**

<https://courseworks2.columbia.edu/courses/85350/assignments/301464> due by 1:10pm

Wed Sep 25, 2019 **Homework 3**

<https://courseworks2.columbia.edu/courses/85350/assignments/301465> due by 1:10pm

Wed Oct 2, 2019 **Homework 4**

<https://courseworks2.columbia.edu/courses/85350/assignments/301466> due by 1:10pm

Wed Oct 9, 2019 **Homework 5**

<https://courseworks2.columbia.edu/courses/85350/assignments/301467> due by 1:10pm

Wed Oct 16, 2019 **Midterm Examination**

<https://courseworks2.columbia.edu/courses/85350/assignments/301473> due by 3:40pm

Wed Oct 30, 2019 **Homework 6**

<https://courseworks2.columbia.edu/courses/85350/assignments/30146> due by 1:10pm

Wed Nov 6, 2019 **Homework 7**

<https://courseworks2.columbia.edu/courses/85350/assignments/301469> due by 1:10pm

Wed Nov 13, 2019 **Homework 8**
<https://courseworks2.columbia.edu/courses/85350/assignments/301470> due by 1:10pm

Wed Nov 20, 2019 **Homework 9**
<https://courseworks2.columbia.edu/courses/85350/assignments/301471> due by 1:10pm

Wed Dec 4, 2019 **Homework 10**
<https://courseworks2.columbia.edu/courses/85350/assignments/301472> due by 1:10pm

Wed Dec 18, 2019 **Final Examination**
<https://courseworks2.columbia.edu/courses/85350/assignments/301462> due by 4pm

MECE E6102 Computational Heat Transfer and Fluid Flow (Spring 2025)

Course Meeting Times and Format

Lectures: 1 session/week, Tue 4:10-6:40 pm, Kent 522A.

Office Hours

Prof. Vedula: Wed 9:30-10:30 am, or by appointment, vv2316@columbia.edu

Course Assistant: None

Course Objectives and Outcomes

- Learn techniques to numerically simulate viscous fluid flows and lay the foundation to simulate fluid flow past complex bodies.
- Gain requisite knowledge to choose the most suitable approach for developing a solver for a given flow configuration.

Prerequisites

- Any introductory fluid mechanics course (MECE E3100, MECE E4100, or equivalent).
- Any course on numerical methods (APAM E4300, E4301, or equivalent) or any course on computational fluid dynamics (CFD), including but not limited to CHEN E4150, ENME E4332, or equivalent.
- Knowledge of a programming language (C, C++, Fortran, Python, Julia, etc.). MATLAB is acceptable.
- Instructor's permission is needed if any of the above requirements are not satisfied.

Description

Solving Navier-Stokes equations for incompressible viscous fluid flows using finite differences. Foundational concepts of CFD, including discretization, stability analysis, error dynamics, and iterative methods. Special topics include methods for solving complex fluid flows, including immersed boundary methods for performing fluid-structure interaction.

Textbooks

For basic CFD and scientific computing, I'd recommend,

- Computational Fluid Mechanics & Heat Transfer (Tannehill, Anderson and Pletcher, CRC)
- Computational Methods for Fluid Flow (Peyret and Taylor, Springer)
- Numerical Computation of Internal and External Flows, vols. 1 and 2 (Hirsch, Wiley)
- Fundamentals of Engineering Numerical Analysis (Moin, Cambridge)
- High Accuracy Computing Methods: fluid flow and wave phenomena (Sengupta, Cambridge)
- Computational Methods for Fluid Dynamics (Ferziger, Peric and Street, Springer)
- Computational Fluid Dynamics (John Anderson Jr., McGraw-Hill)
- PETSc for Partial Differential Equations (Ed Bueler, SIAM)
-

Certain books and journal articles will be recommended for specific topics during the course.

Preparing for this Course

- Review the fundamentals of numerical methods and fluid mechanics.
- Because this is a computational course with assignments requiring programming, please review basic programming in a language of your choice. Install necessary software, including compilers, dependencies, packages (for Python), MATLAB, PETSc, etc.

Grading

- Homework (30%)
- Midterm (30%)
- Final Project (40%)

Late Homework Policy: Late HW is not accepted without prior permission from the instructor.

Topics Covered

- Review of discrete methods for PDE (finite differences, finite volume, and finite elements)
- Properties of the Navier-Stokes equations
- Numerical techniques for solving wave equation, linear and nonlinear Burger's equations
- Error analysis
- Solution techniques for solving the Navier-Stokes equations
- Mesh generation
- Flow simulation in complex geometries - immersed boundary methods

Academic Integrity

The strength of the university depends on academic and personal integrity. Ethical violations include cheating on exams, plagiarism, reuse of assignments (this includes copying from assignments of previous years as well as handing down assignments/exams to students who might take this course in the future), improper use of the Internet and electronic devices, unauthorized collaboration, alteration of graded assignments, forgery and falsification, lying, facilitating academic dishonesty, and unfair competition. While seeking help/advice in clarifying underlying concepts is OK, collaboration on HW assignments/projects is NEVER OK (unless specifically allowed by the instructor).

You can find more information about university misconduct policies on the web at these sites:

<https://www.cc-seas.columbia.edu/integrity>

<https://www.cc-seas.columbia.edu/integrity/policy>

MECE E6106 Finite Element Method for Fluid Flow and Fluid-Structure Interactions

Course Meeting Times and Format

Lectures: 1 session / week, Tue 4:10-6:40pm, Mudd 214 (and Zoom)

Office Hours

Prof. Vedula: Mon 3:30 – 4:30pm over Zoom or by appointment, vv2316@columbia.edu

Course Assistant: NA

Course Objectives and Outcomes

- Learn to apply the finite element method to simulate viscous fluid flows and fluid-structure interaction (FSI).

Prerequisites

- Any graduate-level fluid mechanics course (MECE E4100, MECE E6100, or equivalent).
- Any introductory course on finite element method (ENME E4332), or equivalent.
- Knowledge of high-level programming language (C, C++, Fortran, MATLAB, Python, etc.)
- Instruction's permission is needed if any of the above requirements is not satisfied.

Description

Solving convection-dominated phenomena using finite element method (FEM) including convection-diffusion equation, Navier-Stokes equation for incompressible viscous flows, and nonlinear fluid-structure interaction (FSI). Foundational concepts of FEM include function spaces, strong and weak forms, Galerkin FEM, isoparametric discretization, stability analysis, and error estimates. Mixed FEM for Stokes flow, incompressibility and inf-sup conditions. Stabilization approaches including residue-based variational multiscale methods. Arbitrary Lagrangian-Eulerian (ALE) formulation for nonlinear FSI, and selected advanced topics of research interest.

Textbooks

For the finite element method and fluid-structure interaction, I'd recommend,

- The Finite Element Method: linear static and dynamic finite element analysis (Hughes, Dover)
- Nonlinear Finite Element Methods (Peter Wriggers, Springer)
- Computational Fluid-Structure Interaction (Bazilevs, Takizawa and Tezduyar, Springer)
- The Finite Element Method for Fluid Dynamics (Zinkiewicz, Taylor and Nithiarasu, BH)

Certain books and journal articles will be recommended for specific topics during the course.

Preparing for this Course

- Review the fundamentals of finite element method (Chapters 1-3 from the book by Hughes).
- Review the basics of fluid mechanics from any graduate-level text book (e.g., Fluid mechanics by Kundu, Cohen & Dowling (Academic Press), Incompressible Flows by Panton (Wiley), etc.)
- Please note that this is a computational course with assignments requiring programming. Kindly review basic programming skills in a language of your choice. Install necessary software including compilers, dependencies, packages (for Python), MATLAB, etc.

Grading

- Homework (60%)
- Project (40%)

Late Homework Policy: Late HW is not accepted without prior permission from the instructor.

Syllabus

- Review of the basics of FEM (function spaces, strong/weak form, standard Galerkin method, isoparametric discretization)
- Convection-diffusion equation as the model problem
- Stability and Error analysis
- Stabilization methods including SUPG, variational multiscale methods
- The Stokes flow: mixed FEM, inf-sup conditions, and incompressibility
- PSPG stabilization
- Stabilization methods for the Navier-Stokes equations
- Review of nonlinear solid mechanics
- The arbitrary Lagrangian-Eulerian (ALE) formulation for FSI
- Time integration methods

- Review of linear algebra for FEM (preconditioners, direct and iterative methods)
- Advanced topics include bipartition method for incompressible flows, mixture theory-based formulation for fluid flows and FSI, and a unified formulation for fluid/solid mechanics and FSI

Academic Integrity

The strength of the university depends on academic and personal integrity. Ethical violations include cheating on exams, plagiarism, reuse of assignments (this includes copying from assignments of previous years as well as handing down assignments/exams to students who might take this course in the future), improper use of the Internet and electronic devices, unauthorized collaboration, alteration of graded assignments, forgery and falsification, lying, facilitating academic dishonesty, and unfair competition. While seeking help/advice in clarifying underlying concepts is OK, collaboration on HW assignments/projects is NEVER OK (unless specifically allowed by the inst

MECE E6313 Advanced Heat Transfer

Arvind Narayanaswamy, Department of Mechanical Engineering, Columbia University.

Topics: Review of under-graduate heat transfer (steady-state heat conduction, thermal resistances, convective heat transfer); introduction to mass transfer; transient heat conduction - separation of variables and laplace transform methods; single-phase flow through pipes; external flow over plates - boundary layer theory, similarity transforms, and integral methods; introduction to turbulent flows.

Knowledge of coding, preferably in Python, will be essential.

Grading:

Homework	(50%, approximately 5 HomeWorks for the course)
Mid-term	(25%)
Final	(25%)

Textbooks: Heat and mass transfer, by Alan F. Mills. A heat transfer textbook, by Lienhard and Lienhard (Dover Publications; pdf copy can be downloaded from Prof Lienhard's website). Heat conduction by Kakac, Yener, and Navierra-Cotta.

Sequence of topics:

Week Topic

- 1 Review of undergraduate heat transfer
- 2 Introduction to mass transfer
- 3 Mass diffusion and convective mass transfer
- 4 Transient heat conduction - separation of variables
- 5 Transient heat conduction - separation of variables and laplace transforms
- 6 Transient heat conduction - laplace transforms
- 7 Laminar flow through pipes
- 8 Laminar flow through pipes and flow over plates
- 9 Laminar flow over plates - boundary layer method - similarity transforms
- 10 Boundary layer method - natural convection - similarity transforms
- 11 Turbulent flows - introduction - law of the wall
- 12 Turbulent flows - flow through pipes
- 13 Turbulent flows - flow over flat plates

MECE E6400 – Advanced Machine Dynamics

Spring Semester 2020 – Thursday 7pm-9:30pm – Mudd 627

Professor: Nicolas W. Chbat, PhD

Teaching Assistant: Patricio Torres

Syllabus		
Section	Topic	Weeks
I	Newtonian and Euler Dynamics	7
II	D'Alembert, Lagrangian, and Hamiltonian Dynamics	5
III	Stability of Dynamic Systems	2
Detailed Syllabus		
Week	Topic	Hours
1,2	Motion Relative to a Rotating Frame	4
2,3,4	Newton-Euler Equations of Motion	7
4,5	Gyroscopic Motion	4
6	Rigid Bodies in Free Rotation, Poinot Construction	3
7	Rigid Bodies in Free Rotation	3
8	Generalized Coordinates, Constraints, D'Alembert Principle (Virtual Work)	3
9,10	Lagrange Equations for Holonomic Systems	6
11	Non-holonomic Lagrange Equations, Hamiltonian	3
12	Hamilton Equations, Legendre Transformation	3
13	Stability of Nonlinear Dynamic Systems (Lyapunov 1 st method)	3
14	Stability of Nonlinear Dynamic Systems (Lyapunov 2 nd method)	3
Extra	Lab session: Gyroscope, Free Rigid-Body Rotation	1 1/2

Grade:

Homework:	33%
Exam 1:	22%
Exam 2:	45%
Total:	100%

Textbooks (suggested – on reserve in library):

1. *Meirovitch Methods of Analytical Dynamics* (suggested – on reserve)

Rationale: Articulating real world dynamics mathematically, i.e. modeling, is often half of the battle in solving engineering problems. Understanding different classical modeling approaches (vectorial and variational mechanics) to solve complex problems is an invaluable tool for the practicing mechanical engineer. These advanced engineering approaches are useful in both industrial and academic settings.

MECEE6422: Intro-Theory of Elasticity I

Course: MECEE6422: Intro-Theory of Elasticity I
Meeting Location: XXXXX
Meeting Time: XXXX

Instructor Information

Adrian Buganza Tepole, Associate Professor of Mechanical Engineering
Office: 232 S. W. Mudd
E-mail: ab6035@columbia.edu
Office Hours: Mondays 1-5PM

CA
TBD

References:

TEXTBOOK – E-Book:

Introduction to continuum mechanics. W. Michael Lai, David Rubin, Erhard Krempf.
(<https://clio.columbia.edu/catalog/11532925>)

Website & Discussion Board

Managed through CANVAS
Corequisites: APMA E4200

TEACHING FORMAT

This class will be taught in person. I will be teaching in the classroom and my expectation is you will also be in person. Synchronous lectures will consist of live ‘chalkboard’ style lectures, where I will write equations using an ipad and stylus. Chalkboard notes will be uploaded after lecture. I will have two small breaks during the lecture to break up the time.

Method of Evaluation

Homework	15%
Midterm	35%
Final Exam	50%

Homework Policy

Please work on the homework sets by yourself. Please consult Prof. Tepole or the lead TA, before consulting your classmates.

Copyright notice

I would like to notify all individuals with access to the MECE E6422 course material that the course material for MECE E6422 is copyrighted and is not to be freely distributed/posted online without the written consent of the professor. I explicitly deny consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Courseworks. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

Academic Honesty Policies

The following constitutes cheating:

- Copying assignments from others.
- Consulting solutions sets and laboratory reports from previous years.
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university.

Student bill of rights:

- Academic honesty policies clearly explained at start of semester
- Course requirements/grading policies/etc. must be clearly stated at start of semester.
- Textbook/reference book usage must be clarified at start of semester.
- Homework assignments will be graded on a weekly basis (unless clear explanation provided).

- Midterm exams will be graded within two weeks of test (unless clear explanation provided).
- Final exams and/or projects will be graded within the deadlines set by the university.
- Instructor and teaching assistants must provide office hours or otherwise explain procedure for meeting with students.
- Instructors will provide pertinent information on assignments and lab reports in a timely manner.

The academic honesty policies for SEAS are listed at:
<https://www.cc-seas.columbia.edu/integrity>

The academic honesty policies for GSAS are listed at:
<https://gsas.columbia.edu/student-guide/research/academic-integrity-and-responsible-conduct-research>

MECE E6423 Introduction to the Theory of Elasticity II

Course:	MECE E6423: Introduction to the Theory of Elasticity II
Instructor:	Professor Jeffrey W. Kysar
Office:	244 Mudd Building
Email:	jwkysar@columbia.edu
Telephone:	212-854-7432 Office Hours: Fridays, 9:00 am – 10:00 am, or by appointment
Format:	Weekly 150-minute lecture distributed via Columbia Video Network.
Textbook:	No required textbook, but a detailed reading list will be distributed.
Homework:	Homework sets will be assigned approximately weekly.
Grading:	Several Homework Sets, 75% Final Project, 25%
Description:	Elasticity is the study of reversible deformations of materials. For materials and structures that can be treated by continuum methods, the finite element method is commonly used to calculate the stresses and deformations associated with various applied loads. However, a significant class of problems still defies ready solution with numerical methods because the stresses and strains are formally singular at a material point. In this course, we will concentrate our attention on such singular problems that include point or line loads, dislocations and cracks. In addition, we will consider the stress concentrations associated with various void shapes within an elastic solid. Further we will assume loading configurations that will lead to anti-plane deformation, plane stress and plane strain, as well as full three-dimensional deformation. We will develop solutions for both isotropic and also anisotropic elastic solids. In addition, we will introduce and employ path-independent integrals to compute effective configurational forces on the voids and singularities. Although real methods will be used for some problems, the solution methods will be predominantly complex methods including: Analytic continuation method, Hilbert–Riemann problem and Plemelj integral.
Expectations:	Students may freely discuss their work with others, but any work submitted for grading must be that of the student and must be representative of the level of understanding of the student. Under no circumstances will the copying of analysis or text from any source be tolerated.

Syllabus

1. Overview of governing equations of Elasticity
 - (a) Equations of equilibrium under infinitesimal strain
 - (b) Constitutive relations for linear elastic behavior
 - (c) Linear strain-displacement relationships
 - (d) Compatibility equations
 - (e) Tensor components described in Cartesian and cylindrical coordinate systems
2. Plane deformation states
 - (a) Anti-plane strain
 - (b) Governing equations of anti-plane strain
 - (c) Plane stress and plane strain
 - (d) Governing equations of plane stress and plane strain
3. Anti-plane strain using real methods
 - (a) Most general solution for harmonic equation with separate radial and circumferential functional dependencies
 - (b) Solution to various anti-plane problems with stress singularities
4. Overview of complex analysis
 - (a) Definition of analytic function
 - (b) Single- and multi-valued functions and branch cuts
 - (c) Laurent series
 - (d) Identity theorem and Analytic Continuation
 - (e) Entire functions and Liouville's theorem
 - (f) Harmonic functions in the complex plane
5. Anti-plane strain using complex methods

- (a) Derive governing equations expressed in terms of complex variables
 - (b) Solution to various anti-plane problems with stress singularities
 - (c) Superposition of solutions for problems with multiple singularities
6. Conformal mapping in the complex plane
- (a) Derive governing equations for use with conformal mapping
 - (b) Derive solution for stress and deformation state around an elliptical void in anti-plane strain
7. Effective forces in defects in elastic materials
- (a) Physical meaning of J-integral, L-integral and M-integral
 - (b) Path independent integrals expressed in terms of complex potentials
 - (c) Examples to calculate effective forces on defects in anti-plane strain
8. Plane stress and plane strain using complex methods
- (a) Derive governing equations expressed in terms of complex variables
 - (b) Solution to various in-plane problems with stress singularities
 - (c) Conformal mapping of in-plane problems
 - (d) Derive solution for stress and deformation state around an elliptical void for in-plane problems
9. Further overview of complex analysis
- (a) Cauchy Integral Theorem
 - (b) Principal Value of non-integrable singular integral
 - (c) Cauchy Integral Formula along contours
 - (d) Sectionally analytic functions
 - (e) Plemelj Formulas
 - (f) Jump condition across open contour
 - (g) Riemann-Hilbert problem definition
 - (h) Solution to homogeneous and heterogeneous Riemann-Hilbert problems
 - (i) Application of Riemann-Hilbert problem to solving interfacial crack problems in anti-plane strain
10. Anisotropic elasticity under anti-plane strain conditions
- (a) Review of anisotropic linear elastic constitutive behavior
 - (b) Derive conditions under which pure anti-plane deformation is admissible in crystals
 - (c) Derive governing equations for anti-plane strain in anisotropic linear elastic materials
 - (d) Solution of various problems involving singularities in anisotropic linear elastic materials

MECE E6617 Advanced Kinematics, Dynamics, and Control in Robotics

Summary of the course:

Advanced topics in robotics using fundamentals of kinematics, dynamics, and control. Topics covered include: Characterization of Orientation and angular velocity of rigid bodies, Kinematic Solutions of Planar Mechanisms, Dynamics of Closed Chains and Free-floating Bodies, Gravity Balancing of Mechanisms, Dynamics and Dependence on Inertia Redistribution, Under-actuation Systems, Feedback Linearization of SISO systems, Feedback Linearization of MIMO Systems, Design of Under-actuated Open-Chain Robots, Parallel-Actuated Robots.

Prerequisites: Course on linear and/or nonlinear control theory, Introduction to Robotics, or Permission of the instructor

Notes: The course was taught as experimental class in Spring 2016, 2017, 2019.

Instructor: Sunil K. Agrawal, Ph.D.
Professor of Mechanical Engg./Rehabilitation and Regenerative Medicine
Office: 230 Mudd Hall
Email: Sunil.Agrawal@Columbia.edu

Textbook: Lecture materials will be based on Papers/Book chapters etc.

Prerequisites: MECEE 4602 or Instructor's Permission

Schedule:

1/28 Characterization of Orientation and angular velocity of rigid bodies
2/4 No Class: Work on Technical Paper review from ICRA papers
2/11 Kinematic Solutions of Planar Mechanisms
2/18 Kinematic Solutions of Spring-loaded Planar Mechanisms
2/25 Dynamics of Closed Chains and Free-floating Bodies
3/4 Gravity Balancing of Mechanisms
3/11 Dynamics and Inertia Redistribution
3/25 **Mid-Term Project Presentation** - Design of Gravity Balanced Systems
4/1 Under-actuation Systems, Feedback Linearization, SISO systems
4/8 Feedback Linearizability: MIMO Systems
4/15 Design of Under-actuated Open-Chain Robots
4/22 Parallel-Actuated Robots
4/29 Lower Degree-of-freedom Parallel Actuated Robots
5/6 **Final Project Presentation**

Grading:

Homework:	20%
Technical Paper Review	10%
Mid-Term Project:	20% (Includes presentation/Technical report)
Final Project	50% (Includes presentation/Technical report)

Other Course Details:

- (i) **Homework** will be assigned after the completion of a topic. These will be due in a week after the assigned date. The problems will require programming, simulation, and animation using MATLAB. There will be 8 homework.
- (ii) **Technical Paper Review:** These will be performed in assigned groups of 2. You choose a paper from ICRA 2010-2018 Proceedings involving topics of 'kinematics', 'dynamics', 'closed-chain mechanisms', 'under-actuation', or other closely-related topics. Please inform and obtain permission from

Instructor/TA to work on it. Prepare 6 PowerPoint slides that include the following: Problem statement, Prior research, Solution approach, Results, Conclusions and Future Extensions.

- (iii) **Mid-Term Project:** The students will work in assigned groups of 2. Review the literature on gravity balancing and define a mechanism that you will like to design which is gravity balanced. Motivate this system from a practical application, e.g., human wearables, industrial. Please discuss your project with the Instructor/TA.

Perform the scientific analysis that will validate your design. Prepare 6 PowerPoint slides that include the following: Problem statement, Your solution approach, Results, Conclusions and Future Extensions. Write a 3-page technical report in word (2 column 10 point) using the typical format of ICRA paper.

- (iv) **Final Project:** The students will work in self-selected groups of 2. Define a problem that involves novel design, analysis, simulation, etc. using the principles that you have studied in this course. The problem should have a good motivation and should be approved by the Instructor/TA.

Presentation - Prepare 6 PowerPoint slides that include the following: Problem statement, Your solution approach, Results, Conclusions and Future Extensions. *Technical Paper* - Write a 4-page technical report in word (2 column 10 point) using the typical format of ICRA paper.

- (v) **Course Ethics:** Discussion of the lecture material among students is encouraged. However, home-works must be performed individually.

MECE6620 Applied Signal Recognition and Classification

Instructor: Prof. Homayoon Beigi <beigi@recotechnologies.com> (hb87@columbia.edu)

Textbook: H. Beigi, "Fundamentals of Speaker Recognition," Springer, New York 2011.

Grading:

Homework (20%):

- Implementation of a speech recognition engine using the VoxCeleb2 example of Kaldi or Yolov3 of Darknet

- Creation of a Flowchart with a paragraph for each block in the flowchart, describing the whole Machine Learning Process above.

- Results of the decoding.

Midterm Proposal (20%):

15% - 2-page extended abstract describing the results and proposing modifications to one specific part of the engine to increase performance (accuracy, speed, or both)
5% - 5-10-minute presentation of the above.

Final Project (60%):

45% - 6-page IEEE conference style paper describing the system and results obtained from the modification. Discussion and Implementation of an Improvement in one of the aspects of the speech recognition engine.

10% - Code and Results.

5% - 5-minute presentation of the results.

Course Description:

Applied Signal Recognition is a comprehensive course, covering all aspects of Signal Recognition from theory to practice. In this course such topics as Time and Spatial Signals (such as Audio, Image, and Vibration signals) Signal Representation, Signal Processing and Feature Extraction, Probability Theory and Statistics, Information Theory, Metrics and Divergences, Decision Theory, Parameter Estimation, Clustering and Learning, Transformation, Hidden Markov Modeling, Search Techniques, Deep Neural Networks, Support Vector Machines and other recent machine learning techniques used in signal recognition are covered in some detail. Also, applications in Machine and Structural Health analysis/prognosis, Objection Detection and Recognition, Audio Event Detection, Multimodal analysis, Image Recognition, Video Analysis are covered in detail.

Also, several open source software packages are introduced, with detailed hands-on projects using Kaldi, Darknet, and/or Caffe to produce a fully functional signal recognition engine. The lectures cover the theoretical aspects as well as practical coding techniques. The course is graded based on a project. The Midterm (40% of the grade) is in the form of a two-page proposal for the project and the final (60% of the grade) is an oral presentation of the project plus a 6-page conference style paper describing the results of the research project. The instructor uses his own Textbook for the course, Homayoon Beigi, "Fundamentals of Speaker Recognition," Springer-Verlag, New York, 2011. Every week, the slides of the lecture are made available to the students.

Research Projects:

Individual projects are done using Kaldi or Darknet, depending on the topic of interest, and picked from topics of interest to the students such as,

- Machine health prognosis and monitoring
- Structural health monitoring
- Acoustic processes
- Vibration analysis
- Sequence-to-sequence modeling
- Image processing ...

Lectures:

Week 1

Introduction (Overview of Signal Recognition and its history)

Structural health monitoring, Audio, Image, Vibration, Brain-Wave, and applications including human biometrics, imaging, geophysics, machinery, electronics, networking, sequence modeling, communications, and finance

Week 2

Signal Representation of time-dependent signals
Sampling, Quantization and Amplitude Errors
Practical Sampling and Associated Errors

Week 3

Fundamentals of Signal Processing
The Sampling Process
Spectral Analysis and Direct Method Features

Weeks 4 & 5

Signal Processing of Speech and Feature Extraction
Auditory Perception Linear Predictive Cepstral Coefficients (LPCC) Perceptual
Linear Predictive (PLP) Analysis
Alternative Cepstral-Based Features
Other Features
Signal Enhancement and Pre-Processing

Week 6

Decision Theory
Hypothesis Testing
Bayesian Decision
Theory Bayesian Classifier Decision Trees

Parameter Estimation

Maximum Likelihood Estimation (MLE, MLLR, fMLLR)
Maximum A-Posteriori (MAP) Estimation
Maximum Entropy Estimation
Minimum Relative Entropy Estimation
Maximum Mutual Information Estimation (MMIE)
Model Selection (AIC and BIC)

Weeks 7, 8, & half of 9

Neural Networks
Perceptron
Feedforward Networks
Time-Delay Neural Networks (TDNN)
Convolutional Neural Networks (CNN)
Recurrent Neural Networks (RNN)
Long-Short Term Memory Networks (LSTM)
End-to-End Sequence (Encoder/Decoder) Neural Networks
Embeddings and Transfer Learning

Weeks second half of 9 & 10

Probability Theory and Statistics
Measure Theory
Probability Measure
Integration
Functions
Statistical Moments
Discrete and continuous Random Variables
Moment Estimation
Multi-Variate Normal Distribution

Sequence Modeling
Further use of CNNs, RNNs, and TDNNs
Finite State Transducers

Week 11

Unsupervised Clustering and Learning
Vector Quantization (VQ)
Basic Clustering Techniques

Estimation using Incomplete Data

Transformation

Principal Component Analysis (PCA)

Linear Discriminant Analysis (LDA)

Factor Analysis (FA)

Probabilistic Linear Discriminant Analysis (PLDA)

Week 12

Information Theory

Sources

The Relation between Uncertainty and Choice

Discrete Sources

Discrete Channels

Continuous Sources

Relative Entropy

Fisher Information

Metrics and Divergences

Hidden Markov Modeling (HMM)

Memoryless Models

Discrete Markov Chains

Markov Models

Hidden Markov Models

Model Design and States

Training and Decoding

Gaussian Mixture Models (GMM)

Practical Issues

MECH E4320: Introduction to Combustion

MECH E4320: Introduction to Combustion

Time: Thursday 1:10 - 3:40 p.m. Place: 332 Uris Hall Instructor:

Prof. Michael P. Burke

Email: mpburke@columbia.edu Office Hours: Friday 2:00-3:00 p.m.

Office Hours Place: ME conference room (Mudd 236A)

Course Assistant:

TBD

Email: TBD

Office Hours: TBD Office Hours Place: TBD

Required Textbook:

C.K. Law, *Combustion Physics*, Cambridge University Press, 2006.1 1on course reserve: e-reserve

Other Recommended Textbooks:

S.R. Turns, *Introduction to Combustion: Concepts and Applications*, 3rd Ed., 2011.2

C. Borgnakke, R.E. Sonntag, *Fundamentals of Thermodynamics*, 8th Ed., 2013.2

M.J. Moran, H.N. Shapiro, *Fundamentals of Engineering Thermodynamics*, 6th Ed., 2008.2

M.J. Pilling, P.W. Seakins, Oxford University Press, *Reaction Kinetics*, 1995.1

J.B. Heywood, *Internal Combustion Engine Fundamentals*, 1988.2

C. Kittel, H. Kroemer, *Thermal Physics*, 2nd Ed., 1980.2

1on course reserve: e-reserve

2on course reserve: NW Corner Building Library

Course Description:

Thermodynamics and kinetics of reacting flows; chemical kinetic mechanisms for fuel oxidation and pollutant formation; transport phenomena; conservation equations for reacting flows; laminar non-premixed flames; laminar premixed flames; flame stabilization, quenching, ignition, extinction, and other limit phenomena; flame aerodynamics and turbulent flames; detonations.

Course Prerequisites:

Introductory thermodynamics, fluid mechanics, and heat transfer at the undergraduate level or instructor's permission

Course Objectives:

After completion of the course, the students will be able to

1. Calculate heat release during combustion, final temperatures, and composition of final products.
2. Perform chemical kinetic analyses and describe key features of fuel oxidation and pollutant formation chemistry.
3. Describe controlling processes in flames and determine how flame characteristics depend on the chemical and physical properties of the fuel and thermofluidic conditions.
4. Compute outcomes of combustion situations using open-source simulation codes for thermodynamics, chemical kinetics, and transport
5. Explain (and in some cases estimate) key aspects of flame stabilization, flame quenching, ignition, extinction, and other limit phenomena.
6. Understand the assumptions/limitations of the equations derived in class and apply conservation laws to derive new solutions to chemically reacting flow systems.

Attendance Policy:

Students are expected to attend all lectures and to come prepared. Students are responsible for any material covered during absences.

Grading Policies:

30% Homework
15% Quizzes
25% Midterm Examination

30% Final Examination

Exam Format and Scheduled Dates:

Midterm and Final Exams will be in-person during our class period (for the midterm) and during our registrar-scheduled final exam time (for the final).

Midterm due date: Oct. 24 Final due date: finals period

Quiz Format and Scheduled Dates:

Quizzes will be brief (~30 minute) timed quizzes administered in courseworks to be completed during a 24-hour period (outside of class time). The scheduled dates for the quizzes are:

Quiz 1: Sept. 25/26 Quiz 2: Oct. 9/10 Quiz 3: Nov. 13/14

Quiz and Exam Policies:

All quizzes and exams must be conducted completely independently. Discussing, sharing materials, or otherwise communicating with classmates – or anyone else – is not permitted.

Homework Format:

There will be approximately six homeworks consisting primarily of quantitative problems and some numerical solutions using a popular open-source combustion code, Cantera, which has a Python interface.

Homework Policies:

You may work together on homework sets while exploring and discussing general concepts and methods, but all work you submit must be completed and written up by yourself individually and must represent your level of knowledge and understanding of the subject.

ChatGPT is permitted but you must include all prompts and answers from your chat window as part of your assignment.

Academic Honesty Policies:

The academic honesty policies for the Mechanical Engineering Department are listed at:

<http://me.columbia.edu/academic-honor-code>.

The Policy on Conduct and Discipline that applies to all endeavors at the School of Engineering and Applied Science (SEAS) is described at: <http://bulletin.engineering.columbia.edu/policy-conduct-and-discipline>.

In addition, Columbia College has an extensive website devoted to Dishonesty in Academic Work at <http://www.college.columbia.edu/academics/academicdishonesty>.

Especially relevant for the writing of reports is the discussion of plagiarism and how to avoid it by proper acknowledgement of sources, as discussed in detail at: <http://www.college.columbia.edu/academics/dishonesty-plagiarism>.

Under no circumstances is it acceptable to copy text from another source without proper acknowledgment.

It is the responsibility of each student to read and understand these policies. Furthermore, in this course the following constitutes cheating:

- Copying assignments from others.
- Providing and/or consulting solutions sets from previous years.
- Consulting exams or quizzes from previous years that were not made available by instructor.
- Discussing homework solutions or exams/quizzes with previous students in the class.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others.

Cheating may lead to the following consequences:

- Students receive a failing grade for a specific assignment.
- Students receive a failing grade for an entire course.
- Students may be expelled from the university.

Student rights:

- Academic honesty policies clearly explained at start of semester
- Course requirements and grading policies must be clearly stated at the start of semester.
- Textbook and reference book usage must be clarified at the start of the semester.
- Homework assignments, midterm exams, and final exams will be graded in a timely manner.
- Instructor and teaching assistants must provide office hours or otherwise explain procedures for meeting with students.

- Instructors will provide pertinent information on assignments in a timely manner.

Tentative Schedule:

Class	Date	Topic
1	Sep. 5	Introduction, Thermodynamics Review, Stoichiometry, Heat Release
2	TBD	Chemical Thermodynamics and Equilibrium I
3	Sep. 19	Chemical Thermodynamics and Equilibrium II
4	Sep. 26	Chemical Kinetics I
5	Oct. 3	Chemical Kinetics II
6	Oct. 10	Combustion Mechanisms I
7	Oct. 17	Combustion Mechanisms II
8	Oct. 24	MIDTERM EXAMINATION – IN CLASS
9	Oct. 31	Conservation Equations
10	Nov. 7	Laminar Non-Premixed Flames I
11	Nov. 14	Laminar Non-Premixed Flames II
12	Nov. 21	Laminar Premixed Flames I
13	Nov. 28	NO CLASS – THANKSGIVING
14	Dec. 5	Laminar Premixed Flames II
15	Finals period	FINAL EXAMINATION

MECS 4510 – Evolutionary Computation and Design Automation

Evolutionary Computation and Design Automation
Wednesdays 1:10pm - 3:40pm, 142 Uris Hall

Synopsis

This course will cover topics in evolutionary algorithms and their application to open-ended optimization and design. The field of evolutionary computation tries to address large-scale optimization and planning problems through stochastic population-based methods. It draws inspiration from evolutionary processes in nature and in engineering, and also serves as abstract models for these phenomena. Evolutionary processes are generally weak AI methods that require little information about the problem domain and hence can be applied across a wide variety of applications with relatively little upfront investment. They are especially useful for open-ended problem domains for which little prior formal knowledge exists and the number of parameters is undefined, such as for the general engineering design process. This course will provide insight to a variety of evolutionary computation paradigms, such as genetic algorithms, genetic programming, and evolutionary strategies, as well as governing dynamics of co-evolution, arms races and stable states. New methods involving symbiosis models and pattern recognition will also be presented. The material will be intertwined with discussions of representations and results for design problems in a variety of problem domains including software, electronics, and mechanics.

Prerequisites

Programming experience is assumed. For example, you should be comfortable writing a breadth-first search on a binary tree. If you don't know what that means, you may need to take a Data Structures and Algorithms course first, or study a classic text book like Cormen's *Introduction to Algorithms*.

Homework assignments and projects can be done in any language of your choice, such as C++, Python, Java or Matlab. Use of efficient (compiled) language is recommended.

Staffing and office hours

Instructor: Prof. Hod Lipson, hod.lipson@columbia.edu Office House: Wed 12-1pm ET, Mudd 535F or on zoom. Office hours are walk-in and open to anyone, meaning that you can drop in and listen even if others are already there. See the Zoom link on CourseWorks. For personal matters, reach out by email to arrange a personal meeting (on zoom or in person).

- **Teach Assistant:** TBD
- **Course Assistant:** TBD
- **Grader:** TBD

Attendance

Attendance is not required nor monitored, but is highly encouraged. Students attending in class are requested to be mentally present, i.e. not working on their laptops or doing unrelated activities.

Name plates will be required for all students who are in class to encourage participation and mutual connections. Materials for making your name plate will be provided.

Curriculum

Lectures and readings will cover some or all of these topics:

1. **Optimization background and terminology:** Gradient optimization methods, sampling methods, linear programming, combinatorial optimization.
2. **Evolutionary Biology background and terminology:** Genotype and phenotype, unit of selection, genes and traits, chromosomes, alleles, diploid and haploid, fitness, mutation and recombination. Selection, variation and landscapes. The strengths and weaknesses of the evolutionary model. Inductive bias. The “No free lunch” theorem.
3. **Genetic Algorithms:** Representation, operators, and standard algorithm. The building block hypothesis and the schema theorem.

4. **Evolutionary strategies:** Evolution in continuous variables. Transformations.
5. **Genetic Programming.** Building blocks and architecture-altering operators. Libraries and Trees.
6. **Selection mechanisms:** Fitness proportionate, rank, tournament, Stochastic Universal Sampling and Boltzman selection methods. Niching methods. Spatial methods. Consequences of selection models.
7. **Artificial landscapes and test functions:** The Two-armed bandit problem. Multi-modal and deceptive functions. Royal roads. N-k landscapes. Hierarchical and fractal functions. Pareto evolution.
8. **Co-evolution:** Multiple populations and single-population co-evolution, relative and absolute fitness, engagement and gradient loss, the red queen effect. The credit assignment problem.
9. **Evolutionary dynamics and game-theoretic models:** Evolutionary stable states, cycles and chaos. The iterated prisoners dilemma. Evolution of cooperation.
10. **Evolution and learning:** Plasticity and life-time learning. Lamarckian learning, How learning can guide evolution. The Baldwin effect.
11. **Symbiosis as a source of evolutionary innovation.** Macro-mutations, Major transitions in evolution, symbiosis and symbiogenesis. How symbiosis can guide evolution.
12. **Evolutionary algorithms as models:** Modeling sexual selection, modeling ecosystems, artificial life.
13. **Evolutionary robotics and evolutionary hardware:** Evolving control. Evolving morphology. Body-brain co-evolution. Evolution in simulation and in reality. The case for and against simulation.
14. **Modularity and regularity in evolution.** The scaling problem and the curse of dimensionality. Evolvability. Module acquisition. Developmental models. Compositional and hierarchical approaches.
15. **Swarm intelligence,** particle swarm optimization
16. **Estimation exploration** approaches for model inference

The topics above will include also examples for a variety of domains, such as robotics, scheduling, structural and architectural design, neural networks, electronics, software and games.

Textbooks and references

1. Melanie Mitchell, (1996) [An introduction to genetic algorithms](#), MIT Press, ISBN 9780262631853

Preparation

To make best use of your time in class, make sure you are comfortable programming in some language. In particular, you will need to be able to plot graphics, both 2D charts (x-y plots) and 3D (like drawing a 3D cube).

Grading and requirements

Grading will be based on

40% Two homework assignments (20% each, individual)

30% Individual/pair term project

30% Final exam (online, closed materials, 2 hours in a 24-hour period, honor system).

In the project, students will be asked to apply evolutionary computation to the design of a soft robot.

Late homework and personal/medical situations:

Students have up to 96 grace hours for late submission which they may use to delay homework submission for any reason -- no permission required. On the submission cover page, state how many grace hours have been used up and how many remain.

Students submitting homework early may accumulate hours. Students submitting in a group may pool their remaining grace hours, but must use up one hour per person for every hour after the deadline. If all grace hours have been used up, a penalty of 5% per day will be assessed, up to a maximum of 50%. All assignments, regardless of grace hours, must be completed by final exam date.

If you have a grave situation (medical, personal) that is preventing you from completing coursework in a timely manner, and is beyond what can be addressed by grace hours, do not send medical/personal information to the instructor, TA, or grader (they are prohibited from seeing this info due to privacy). Instead, reach out to the Office of Disability Services (<https://health.columbia.edu/content/disability-services>) and have them assess your situation (even if it is temporary). Once your situation is assessed, all faculty and course staff will be notified of accommodations to be made. This will help you throughout the remainder of the course, since delays often have a ripple effect. ODS is the only office allowed to make academic accommodations.

Academic Integrity

Students may NOT copy any part of someone else's source code, or written text (including from other students, external sources, previous years, the Internet, etc.) All text and source code must be created from scratch by the student(s) submitting the work. Copying is considered a violation of academic integrity.

Some assignments may be done in pairs, as described in the assignment briefing.

It is permitted to use external publicly available libraries such as 3D graphics, plotting and charting. It is NOT permitted to use external libraries for evolutionary algorithms, optimization, or physics simulation. Any library used must be cited. If in doubt, please consult instructor.

The following constitutes cheating:

- Copying code (in full or in part) from others.
- Completing individual assignments in a group not explicitly granted by instructor.
- Consulting assignments from previous years (unless explicitly shared by the instructor).
- Consulting exams from previous years that were not made available by instructor.
- Completing individual assignments in a group, when permission not explicitly granted by instructor.
- Plagiarizing the work of others without proper citation (quotes and reference).

Cheating may lead to the following consequences:

- Student receives a failing grade for a specific assignment.
- Student receives a failing grade for an entire course.
- Student may be expelled from the university.
- This course adheres to Columbia's policies on academic integrity, see <http://www.college.columbia.edu/academics/integrity>.

Abide by the Columbia Honor Code

- Honor code: <https://www.cc-seas.columbia.edu/integrity>
- Also review the guidelines posted here: <http://www.columbia.edu/cu/studentconduct/documents/StandardsandDiscipline.pdf>
- All coursework is to be done by the student working alone, except when permitted by instructor. For homework assignments, you may consult other students for general guidelines or to review and discuss material covered in class, but homework assignments must be completed individually, except when permitted by instructor.
- No external aids or electronic devices are allowed in exams, except when permitted by instructor.
- Do not look up homework solution sets posted from previous years or posted elsewhere.
- Consult the instructor if you require clarifications regarding the honor code

Notice of copyright

All lecture notes and slides made available to students in this course are copyrighted by the instructor and third parties and are not to be freely distributed/posted online without the written consent of the instructor and those third parties. The instructor explicitly denies consent to the posting of the lecture slides, exams, assignments and answers to any assignment or exam on any website outside of Columbia University's Courseworks. Providing and posting such content is in violation of the Digital Millennium Copyright Act.

Tentative Schedule

MECS 6616 - ROBOT LEARNING

Prof. Matei Ciocarlie

This course provides an applied introduction to machine learning and reinforcement learning from the perspective of applications in robotics. It is intended primarily for students interested in robotics but with limited prior exposure to machine learning.

We will cover the following topics:

- Supervised and unsupervised learning: dimensionality reduction, classification and regression. Note that this section will be brief, intended to serve mainly as a review of the basic topics learned in other courses.
- Learning in Computer Vision: "traditional" (i.e. before Deep Learning) methods for learning on images
- Deep Learning fundamentals: MLPs, backpropagation. This section will be brief, intended to serve mainly as a review of the basic topics learned in other courses.
- Transformers and applications for robot control
- Learning in Computer Vision: the Deep Learning revolution.
- Learning and using forward (dynamic) models. Application: Model Predictive Control with learned dynamics.
- Imitation learning and Behavioral Cloning: Action-Chunking Transformer, Diffusion Policies
- Reinforcement Learning (RL) and Deep Reinforcement Learning (DRL). We will cover DRL from scratch, without assuming any prior knowledge.
- Large Vision-Language-Action (VLA) models

Format

- 70%: standard lectures, where the instructor will present the topics above.
- 30%: instructor will discuss recent and seminal papers in the field (interspersed throughout the semester).

Grading will be based on programming assignments and a final exam.

- Assignments will require use of the Python language and many of its libraries. **We expect college-level programming abilities in a high-level language.**
- We are planning to use the [Google Colaboratory](#) framework for assignments
- There will be 5 assignments, equally weighted
- Typical assignment completion time will be 2 weeks
- Useful textbooks (note that none of these are formally required):
- Muller and Guido, Introduction to Machine Learning with Python
- Hastie et al., The Elements of Statistical Learning
- Goodfellow, Bengio and Courville, Deep Learning
- Sutton and Barto, Reinforcement Learning: An Introduction

Research Papers we will cover in class

This list is tentative and subject to change.

- General
 - Sutton, *The Bitter Lesson*, [\[link\]](#)
- Supervised and Unsupervised Learning
 - "[An SVM Learning Approach to Robotic Grasping](#)" by Raphael Pelosof, Andrew Miller, Peter Allen, Tony Jebara
 - "[The Columbia Grasp Database](#)" by Corey Goldfeder, Matei Ciocarlie, Hao Dang and Peter K. Allen
 - "80 Million Tiny Images: A Large Data Set for Nonparametric Object and Scene Recognition" by Antonio Torralba, Rob Fergus, and William T. Freeman
 - "Robotic Grasping of Novel Objects using Vision" by Ashutosh Saxena, Justin Driemeyer, Andrew Y. Ng
- Learning on Computer Vision
 - [PoseCNN](#)

- [DOPE](#)
- DL for Robotics and Architectures
 - Karpathy, *The Unreasonable Effectiveness of Recurrent Neural Networks*, [\[link\]](#)
 - Lenz et al., *Deep Learning for Detecting Robotic Grasps*, [\[link\]](#)
 - Pinto and Gupta, *Supersizing Self-supervision: Learning to Grasp from 50K Tries and 700 Robot Hours*, [\[link\]](#)
 - Levine et al., *Learning Hand-Eye Coordination for Robotic Grasping with Deep Learning and Large-Scale Data Collection*, [\[link\]](#)
 - Zeng et al., *TossingBot: Learning to Throw Arbitrary Objects with Residual Physics*, [\[link\]](#)
 - Wang et al., *On-Robot Learning With Equivariant Models* [\[link\]](#)
- MPC
 - Tassa et al., *Synthesis and stabilization of complex behaviors through online trajectory optimization*, [\[link\]](#), [\[video\]](#)
 - Hannigan et al., *Automatic Snake Gait Generation Using Model Predictive Control*, [\[arXiv\]](#), [\[video\]](#)
 - Carlo et al., *Dynamic Locomotion in the MIT Cheetah 3 Through Convex Model-Predictive Control* [\[link\]](#), [\[video\]](#)
 - Rosolia and Borrelli, *Learning How to Autonomously Race a Car: a Predictive Control Approach*, [\[arXiv\]](#), [\[talk\]](#), [\[example\]](#)
- Imitation Learning
 - Zhao et al., *Learning Fine-Grained Bimanual Manipulation with Low-Cost Hardware*, [\[link\]](#)
 - ALOHA 2 Team, *ALOHA 2: An Enhanced Low-Cost Hardware for Bimanual Teleoperation*, [\[link\]](#)
 - Chi et al., *Diffusion Policy: Visuomotor Policy Learning via Action Diffusion*, [\[link\]](#)
 - Chi et al., *Universal Manipulation Interface: In-The-Wild Robot Teaching Without In-The-Wild Robots*, [\[link\]](#)
 - Zhao et al., *ALOHA Unleashed: A Simple Recipe for Robot Dexterity*, [\[link\]](#)
- RL
 - OpenAI et al., *Learning Dexterous In-Hand Manipulation* [\[link\]](#)
 - Qi et al., *In-Hand Object Rotation via Rapid Motor Adaptation* [\[link\]](#)
 - Khandate et al., *Sampling-based Exploration for Reinforcement Learning of Dexterous Manipulation* [\[link\]](#)
 - Zhu et al., *The Ingredients of Real-World Robotics Reinforcement Learning* [\[link\]](#)
 - Bauza et al., *DemoStart: Demonstration-led auto-curriculum applied to sim-to-real with multi-fingered robots* [\[link\]](#)
- Large models
 - Ahn et al., *Do As I Can, Not As I Say: Grounding Language in Robotic Affordances* [\[link\]](#)
 - Driess et al., *PaLM-E: An Embodied Multimodal Language Model* [\[link\]](#)
 - Brohan et al., *RT-1: Robotics Transformer for Real-World Control at Scale* [\[link\]](#)
 - Open X-Embodiment Collaboration, *Open X-Embodiment: Robotic Learning Datasets and RT-X Models* [\[link\]](#)
 - Black et al., *Pi0: A Vision-Language-Action Flow Model for General Robot Control*, [\[link\]](#)
 - Google Robotics Team, *Gemini Robotics: Bringing AI into the Physical World* [\[link\]](#)

Example syllabus (note that lecture schedule is tentative and subject to change):

1	1/22	Wed	Introduction: what is Robot Learning?
2	1/27	Mon	Unsupervised learning: clustering and dimensionality reduction Assignment 1 released

3	1/29	Wed	Supervised learning I: regression
4	2/3	Mon	Supervised learning II: classification Paper discussions
5	2/5	Wed	Learning for Computer Vision: "traditional" methods
6	2/10	Mon	Deep Learning: fundamentals, Part I
7	2/12	Wed	Deep Learning: fundamentals, Part II
8	2/17	Mon	Deep Learning architectures: CNNs Paper discussions
9	2/19	Wed	Paper discussions: CNNs for object pose detection Assignment 2 released
10	2/24	Mon	Deep Learning architectures: AEs, RNNs, Representation Learning
11	2/26	Wed	Case study: supervised learning for a robotic hand orthosis
12	3/3	Mon	Deep Learning architectures: Transformers
13	3/5	Wed	Learning dynamics (forward) models
14	3/10	Mon	Model Predictive Control (MPC)

			Assignment 3 released
15	3/12	Wed	Paper discussions: MPC in robotics
			Spring break
16	3/24	Mon	Behavioral Cloning via Generative Models
17	3/26	Wed	Diffusion Models (guest instructor Zhanpeng He)
18	3/31	Mon	Diffusion Policies (guest instructor Zhanpeng He) Assignment 4 released
19	4/2	Wed	Paper discussions
20	4/7	Mon	Reinforcement Learning I: fundamentals, Q-Learning
21	4/9	Wed	Reinforcement Learning II: non-determinism, policy iteration Assignment 4 walk-through (Zoom lecture)
22	4/14	Mon	Reinforcement Learning III: Deep Q-Networks
23	4/16	Wed	Reinforcement Learning IV: Policy Gradient and Actor Critic
24	4/21	Mon	Domain Randomization and Policies with Memory, open-source RL Assignment 5 released

25	4/23	Wed	Paper discussions: RL in robotics
26	4/28	Mon	Large VLA models
27	4/30	Wed	Large VLA models
28	5/5	Mon	Final Exam

MEEE E4600 Continuous Control Systems

Course Number: MEEE E4600
Course Title: Continuous Control Systems
Lecture Hours: 2.5
Credits: 3
Instructor: Homayoon Beigi <hb87@columbia.edu>
Prerequisites: Linear Algebra, Ordinary Differential Equations

Textbooks:

Required:

Farid Golnaraghi and Benjamin C. Kuo, "Automatic Control Systems," 10th Edition, McGraw Hill, New York, 2017.

Reference:

Homayoon Beigi, "Fundamentals of Speaker Recognition", Springer, New York, 2011.

Thomas E. Fortman and Konard L. Hitz, "An Introduction to Linear Control Systems," Control and Systems Theory Vol. 5, Marcel Dekker, Inc, New York, 1977.

Grading:

Homework (30%):

Problem solving and coding assignments.

Midterm Exam – In-Class (30%)

Final Exam – In-Class (40%)

Course Description:

Introduction to continuous systems with the treatment of classical and state-space formulations. Mathematical concepts, complex variables, integral transforms and their inverses, differential equations, and relevant linear algebra. Classical feedback control, time/frequency domain design, stability analysis, Laplace transform formulation and solutions, block diagram simplification and manipulation, signal flow graphs, modeling physical systems and linearization. state-space formulation and modeling, in parallel with classical single-input single-output formulation, connections between the two formulations. Transient and steady state analysis, methods of stability analysis, such as root locus methods, Nyquist stability criterion, Routh Hurwitz criterion, pole/zero placement, Bode plot analysis, Nichols chart analysis, phase lead and lag compensators, controllability, observability, realization of canonical forms, state estimation in multivariable systems, time-variant systems. Introduction to advanced stability analysis such as Lyapunov stability and simple optimal control formulation. May not take for credit if already received credit for EEME E3601.

Note:

More advanced Lyapunov and optimal treatment and solutions are left to more advanced courses: see MEEE 6610 Nonlinear and Adaptive Control. A full treatment of discrete control systems will be covered in a subsequent course: see EEME E4601 Discrete Control Systems. Matlab will be used for simulations and coding assignments.

Lectures:

Week 1

Introduction to Control Theory

Terminology

Types of Control Systems

Sample Plants and Suitable Associated Control Systems

Nonlinear Systems, Linear Time-Variant and Time Invariant Systems

General Mathematical Forms

Block Diagrams

Sensor Data Collection Examples

Week 2

Control Problem Components

Review of Linear Algebra Concepts

Week 3

Review of Complex Variable Theory

Continuity and Analyticity

Power Series Representation – Taylor and Laurent

Review of Function Relations

Week 4

Laplace Transform and Laplace Inversion

Partial Fraction Expansion

Week 5

Review of Linear Differential Equations
Dynamic and Electrical System Plant Formulation
Simple Block Diagrams
Proportional Control
Integral Control and steady state response

Week 6

Derivative Control and transient response
PI, PD, PID Control
State-Space Representation
Controllability Canonical Form
Series Solutions for Scalar First Order ODEs
Series Solutions for Matrix First Order ODEs and the Matrix Exponential

Week 7

Block Diagram Manipulation and Signal Flow Graphs
Routh-Hurwitz Criteria for Stability
Bode Diagrams
Laplace and Fourier Transform Visualization

Week 8

Midterm (First half of class)
Root Locus Plot – Rules and Examples

Week 9

Root Locus Plot – Rules and Examples (continued)
Nyquist Stability Criterion
Nichols Chart

Week 10

Phase Lead/Lag Compensator
Eigenvalue-Eigenvector Formulation
Generalized Eigenvalue problem formulation and solution
Transformations – ie, Similarity Transform
Jordan Block Form
Eigenvector Solution to the General Controllable Canonical Equations

Week 11

Controllability, Observability, and Realizability
Second Order System Examples
Formulating External Disturbances
Formulating State Observer and State Feedback
Luenberger Observer

Week 12

Time-Variant Systems
Nonlinear Systems
Linearization
Lyapunov Stability Analysis

Week 13

Kalman Filtering
Optimal Control Set-up
Final Exam

MEEE E6610: Nonlinear and Adaptive Control

Course Number: MEEE E6610

Course Title: Nonlinear and Adaptive Control

Lecture Hours: 2.5

Credits: 3

Instructor: Homayoon Beigi <hb87@columbia.edu>

Prerequisites: Continuous Control Systems and Discrete Control Systems or Instructor's Permission

Recommended Supplemental Courses: Discrete Control Systems; Mathematics of Machine Learning, Signals, and Control

Textbooks:

Required:

C.M. Kellett and P. Braun, Introduction to Nonlinear Control, Princeton University Press, 2023

Reference:

Homayoon Beigi, "Fundamentals of Speaker Recognition", Springer, New York, 2011.

Grading:

Homework – 30%

Small Problems and/or Coding Assignments

Midterm – 20%

Problems and/or Coding Assignments

Project Proposal – 10%

2-page proposal, including state of the art and proposed methodology – 5-10%

Up to 5% class participation

Class Participation – 5%

Final Project – 35%

10% – Code

25% – 6-page IEEE Style Report of the methodology and result + 3 minute Video Presentation

1Up to 5% for class participation may be based on average participation in class. If most of the class is present, an attendance may not be taken, in which case the whole 10% will be counted toward the project proposal, otherwise, random attendance may be taken to assess class participation.

Course Description:

Nonlinear dynamics: Euler-Lagrange equations, Hamilton's principle, variational calculus; nonlinear systems: fundamentals, examples, stability Notions, linear systems and linearization, frequency domain analysis, discrete time systems, absolute stability, input-to-state stability, control design: control Lyapunov functions, sliding mode control, control barrier functions; adaptive control: self-tuning regular, model reference adaptive control, feedback linearization, extremum seeking control, model predictive control, observer design: extended, unscented, and mixture model Kalman filters, moving horizon estimation, high-gain observers; repetitive processes: iterative learning control, learning-adaptive control, repetitive control; optimal control: continuous setting, discrete time setting, constrained optimal control, linear matrix inequality (LMI) constraints, dynamic programming and backward recursion

Lectures:

Week 1

Nonlinear Dynamics

Euler-Lagrange Equations

Hamilton's Principle

Variational Calculus

Week 2

Nonlinear Systems

Fundamentals

Examples

Stability Notions

Week 3

Linear Systems

Linearization

Frequency Domain Analysis

Week 4

- Discrete Time Systems
- Absolute Stability
- Input-to-State Stability

Week 5

- Control Design
- Control Lyapunov Functions
- Sliding Mode Control
- Control Barrier Functions

Week 6

- Adaptive Control
- Self-tuning regular
- Model Reference Adaptive Control

Week 7

- Adaptive Control (continued)
- Feedback Linearization
- Extremum Seeking Control
- Model Predictive Control

Week 8

- Midterm (First half of class)
- Observer Design
- Luenberger Observers
- Kalman Filter

Week 9

- Observer Design (continued)
- Extended Kalman Filters
- Unscented Kalman Filters
- Mixture Model (GMM) Kalman Filters

Week 10

- Observer Design (continued)
- Moving Horizon Estimation
- High-Gain Observers

Week 11

- Repetitive Processes
- Iterative Learning Control
- Learning-Adaptive Control
- Repetitive Control

Week 12

- Optimal Control
- Continuous Setting
- Discrete Time Setting
- Constrained Optimal Control

Week 13

- Optimal Control (continued)
- Linear Matrix Inequality (LMI) Constraints
- Dynamic Programming and Backward Recursion

MEEC E6600: Mathematics of Machine Learning, Signals, and Control

Course Number: MEEC E6600
Course Title: Mathematics of Machine Learning, Signals, and Control
Lecture Hours: 2.5
Credits: 3
Instructor: Prof. Homayoon Beigi (hb87@columbia.edu)
Prerequisites: Linear Algebra and Ordinary Differential Equations

Textbooks:

Required:

H. Beigi, "Mathematics of Machine Learning, Signals, and Control," Springer-Verlag, New York, 2025.
H. Beigi, "Fundamentals of Speaker Recognition," Springer-Verlag, New York, 2011.

Reference Books:

K.P. Murphy, "Machine Learning, A Probabilistic Perspective," The MIT Press, Cambridge, MA, 2012.
M. Loève, "Probability Theory," Springer, New York, 4th Edition, 1977.
P.R. Halmos, "Measure Theory," Springer, New York, 1974.
I.T. Jolliffe, "Principal Component Analysis," Springer, New York, 2nd Edition, 2002.
R. Courant and D. Hilbert, "Methods of Mathematical Physics," John Wiley & Sons, New York, 1989.
C. F. Gerald and P. O. Wheatley, "Applied Numerical Analysis," Pearson College Div., 7th Edition, New York, 2003.
G.J. McLachlen and T. Krishnan, "The EM Algorithm and Extensions," John Wiley & Sons, 2nd Edition, New York, 2008.
W.E. Boyce and R.C. DiPrima, "Elementary Differential Equations and Boundary Value Problems," John Wiley & Sons, 11th Edition, New York, 2017.
P.W. Berg and J.L. McGregor, "Elementary Partial Differential Equations," Holden Day, San Francisco, 1966.
R. Fletcher, "Practical Methods of Optimization," John Wiley & Sons, 2nd Edition, New York, 2000.

Grading:

Homework (20%): - Problems and coding assignments.
Midterm (20%): - Coding assignment and Problems.
Project Proposal (10%): - 2-page proposal, including state of the art and proposed methodology.
Participation & Attendance (5%): Since there is no final exam, some level of class participation and attendance are mandatory.
Final Project (45%):
30% - Report of the methodology and results.
15% - Code.

Course Description:

Advanced Linear Algebra, Complex Variable Theory, Integral Transforms, Measure Theory and Probability Theory, Advanced Information Theory, Differential and Difference Equations, Calculus of Variations, Nonlinear Optimization, State-Space Modeling, Advanced Signal Processing and Recognition: non-Stationary Signal Recognition, Spectral and Cepstral Analysis, Supervised and Unsupervised Clustering, Decision Theory, Math of modern NN architectures.

Lectures:

Week 1

- Linear Algebra and Numerical Methods
 - Vectors & Operations
 - Matrices – Types & Extended Operations
 - Norms & Vector-Induced Norms
 - Moore-Penrose Generalized Inverse
 - Gram-Schmidt Orthogonalization (Normal and Modified)
 - Sherman-Morrison Inversion Formula
 - Vector Representation under a Set of Normal Conjugate Direction
 - Stochastic Matrix
 - Linear and Affine Transformations

Week 2

- Complex Variable Theory
 - Definitions, Representations, and Properties
 - Limits
 - Continuity (Types and Degree) and Boundedness
 - Convexity and Concavity of Functions

Odd, Even and Periodic Functions
Complex Differentiation and Laplace's Equation
Analyticity, and Cauchy Riemann Theorems
Application of Cauchy Riemann Theorem in Fluid Mechanics and Electrostatics
Complex Integration and Riemann Integral

Week 3

- Complex Variable Theory (Continued)
Law of Mean (Mean Value Theorem)
Contour Integration, Cauchy Integral Theorem, and Cauchy Integral Formula
Power Series Expansion of Functions (Taylor and Laurent Series plus)
Power Series Operations
Residues & Cauchy Residue Theorem
Relations Between Functions
 Convolution
 Correlation
 Orthogonality of Functions
 Bessel's Inequality, Completeness Relation & Hilbert Space
 Least Square Estimation

Week 4

- Measure and Probability Theory
Set Theory
 Equivalence and Partitions
 σ -Rough Sets (Rough Sets)
 Fuzzy Sets
Measure Theory
 Measure, Fields and Spaces – eg, Borel, Lebesgue, Dirac
 Multiple Dimensional Spaces
 Topology vs Measure Theory, Metric Spaces
 Banach Space (Normed Vector Space)
 Inner Product Space (Dot Product Space)
 Infinite Dimensional Spaces (Pre-Hilbert and Hilbert)
 Probability Measure
Probability Theory – Conditional, Total
Bayes Theorem, Statistical Independence, Cartesian Product Space
Integration Revisited
Functions Revisited

Week 5

Probability Theory – Continued

Radon-Nikodým Theorem, Continuity of Measures
Density Functions (eg, General, Probability, Marginal Probability, Joint Probability)
Independence, Correlation, Convolution
Function Spaces – Riemann vs Lebesgue Integration
Inequalities – Holder, Schwarz, Minkowski
Statistical Moments

- Neural Network Learning
 Perceptron
 Feedforward Networks
 Convolutional Neural Networks (CNN) and ResNets
 Adversarial Networks

Week 6

Neural Networks (Continued)

Time-Delay Neural Networks (TDNN, TDNNf, Wavenet)
Recurrent Neural Networks (RNN)
Long-Short Term Memory Networks (LSTM)
End-to-End Sequence (Encoder/Decoder) Neural Networks

Embeddings and Transfer Learning
Transformers (eg, ELMO, BERT, GPT)

Week 7

Neural Networks (Continued)
Conformers
- Neural Network Learning and Nonlinear Optimization Theory
Data Selection
Sequence Discriminative Criteria (eg, MMI, MPE, sMBR, Boosted MMI, Lattice-Free MMI)
Gradient-Based Optimization
The Steepest Descent Technique
Newton's Minimization Technique
Quasi-Newton or Large Step Gradient Techniques
Conjugate Gradient Methods
Gradient-Free Optimization
Search Methods
Gradient-Free Conjugate Direction Methods
The Line Search Sub-Problem
Practical Considerations
Large-Scale Optimization
Numerical Stability
Nonsmooth Optimization
Constrained Optimization
The Lagrangian and Lagrange Multipliers
Duality
Global Convergence

Week 8

- Review of Linear Differential Equations (Ordinary and Separable Partial)

State-Space Representation of Forced Differential Equations
Discrete State-Space Representation
State-Space Model NN Models and Subset State-Space Model Architectures
Mamba

Generalized Eigenvalue Problem
Similarity Transform

Week 9

Neural Networks (Continued)

Kolmogorov-Arnold Networks (KANs)
Physics Informed Neural Networks (PINN)
Differential Transformers

- Integral Transforms

Integral Equations

Kernel Functions

Hilbert's Expansion Theorem plus Schmidt extension and Mercer's Theorem
Eigenvalues and Eigenfunctions of the Kernel

The Laplace Transform

Some Useful Transforms

Solutions to State-Space Representation of Control Problems

Inversion and Partial Fraction Relation to Residue Theorem

Examples

- Probability Theory (Continued)

Transformations

Statistical Moments and Jensen's Inequality

Discrete Random Variables

Combinations of Random Variables

Convergence of a Sequence

Sufficient Statistics
Moment Estimation
 Estimating the Mean
 Law of Large Numbers (LLN) – Weak and Strong
 Different Types of Mean
 Estimating the Variance
Multi-Variate Normal Density, erf, tanh approximation

Week 10

Signals – general, time-dependent, stationary, non-stationary
Definitions

Complex Fourier Transform (Fourier Integral Transform)

 Translation
 Scaling
 Symmetry Table
 Time and Complex Scaling and Shifting
 Convolution
 Correlation
 Parseval's Theorem
 Power Spectral Density
 One-Sided Power Spectral Density
 PSD-per-unit-time
 Wiener-Khintchine Theorem

Week 11

Discrete Fourier Transform (DFT)

 Sampling and WKS (aka Shannon) Sampling Theorem and its extensions
 Inverse Discrete Fourier Transform (IDFT)
 Periodicity
 Plancherel and Parseval's Theorem
 Power Spectral Density (PSD) Estimation
 Fast Fourier Transform (FFT)

Discrete-Time Fourier Transform (DTFT)

 Power Spectral Density (PSD) Estimation
 Complex Short-Time Fourier Transform (STFT)
 Discrete-Time Short-Time Fourier Transform DTSTFT
 Discrete Short-Time Fourier Transform DSTFT
 Windowing and filtering

Discrete Cosine Transform (DCT)

 Efficient DCT Computation
Cepstrum and Homomorphic Deconvolution
Mel-Frequency Cepstral Coefficient Formulation and Computation

Week 12

- Calculus of Variations

 Euler-Lagrange Equations
 Hamilton's Principle
 Constrained Lagrange's Equations
 Examples

- Transformation

 Principal Component Analysis (PCA)
 Linear Discriminant Analysis (LDA)
 Factor Analysis (FA)
 Probabilistic Linear Discriminant Analysis (PLDA)

According to need and students' background,
some of the following subjects will be covered:

Week 13:

- Information Theory & Decision Theory
- Hidden Markov Modeling (HMM)
 - Memoryless Models
 - Discrete Markov Chains
 - Markov Models
 - Hidden Markov Models
 - Model Design and States
 - Training and Decoding
 - Gaussian Mixture Models (GMM)
- Practical Issues
- Sources
 - The Relation between Uncertainty and Choice
 - Discrete Sources
 - Entropy or Uncertainty
 - Generalized Entropy
 - Information
 - The Relation between Information and Entropy
 - Discrete Channels
 - Continuous Sources
 - Differential Entropy (Continuous Entropy)
 - Relative Entropy
 - Mutual Information
 - Fisher Information
- Metrics and Divergences
 - Distance (Metric)
 - Distance Between Sequences
 - Distance Between Vectors and Sets of Vectors
 - Hellinger Distance
 - Divergences and Directed Divergences
 - Kullback-Leibler's Directed Divergence
 - Jeffreys' Divergence
 - Bhattacharyya Divergence
 - Matsushita Divergence
 - F-Divergence
 - δ -Divergence
 - $\chi \alpha$ Directed Divergence
- Difference Equations and The z-Transform
 - Difference Equations
 - z-Transform – Definition
 - Translation
 - Scaling
 - Shifting – Time Lag
 - Shifting – Time Lead
 - Complex Translation
 - Initial Value Theorem
 - Final Value Theorem
 - Real Convolution Theorem
 - Inversion
- Cepstrum
- Decision Theory
 - Hypothesis Testing
 - Bayesian Decision Theory
 - Bayesian Classifier
 - Decision Trees
- Unsupervised Clustering and Learning

Vector Quantization (VQ)
Basic Clustering Techniques
Estimation using Incomplete Data

- Parameter Estimation
 - Maximum Likelihood Estimation (MLE, MLLR, fMLLR)
 - Maximum A-Posteriori (MAP) Estimation
 - Maximum Entropy Estimation
 - Minimum Relative Entropy Estimation
 - Maximum Mutual Information Estimation (MMIE)
 - Model Selection (AIC and BIC)

MEIE E4810 Intro to Human Space Flight

Course Description:

Introduction to human spaceflight from a systems engineering perspective. Historical and current space programs and spacecraft. Motivation, cost and rationale for human space exploration. Overview of space environment needed to sustain human life and health, including physiological and psychological concerns in space habitat. Astronaut selection and training processes, spacewalking, robotics, mission operations, and future program directions. Systems integration for successful operation of a spacecraft. Highlights from current events and space research, Space Shuttle, Hubble Space Telescope, and International Space Station (ISS). Includes a design project.

Prerequisites:

Junior standing and permission of instructor

Text:

- Harrison, A., “*Spacefaring - The Human Dimension*”, University of California Press, Los Angeles, CA, 2001. (available online at Columbia University Libraries)

Reference Material:

- Massimino, “*Spaceman – An Astronauts Unlikely Journey to Unlock the Secrets of the Universe*”, Crown, New York, 2016.
- United Space Alliance, LLC., *Shuttle Crew Operations Manual*, OI-33, NASA, Document Number USA007587. Available for free on-line: http://www.nasa.gov/centers/johnson/pdf/390651main_shuttle_crew_operations_manual.pdf
- International Space Station Flight Controller Console Handbooks. Available for free online at: <https://isslive.com/handbooks/>
- Mission Operations Directorate Space Flight Training Division NASA Johnson Space Center, *International Space Station Familiarization*. Available for free online at: <http://www.spaceref.com/iss/ops/iss.familiarization.pdf>

Course Objectives:

- Understand how astronauts, engineers, and scientists approach the human exploration of space.
- Understand how various spacecraft systems work together for successful space missions.
- Understand how the unique characteristics of the space environment affects astronauts and space systems requirements.
- Complete a class design project.

Grades:

- Homework: 40%
- Project: 50%
- Peer Review, Class Participation, Attitude: 10%

Homework & Reading Assignments:

Homework and reading assignments will be assigned on most of the weeks during the semester. The homework will be done by each student individually. The objective of the homework will be to re-enforce material covered in class and in the reading assignments.

Project:

Students will work in teams of four or five. Design project topic will be the chosen and developed by each group. It can be based on any of the topics covered throughout the semester or it can be a topic not covered in class that the group is interested in pursuing. The project will have graded milestones throughout the semester with the appropriate product, final report, and group presentation due at the end of the semester.

MEEM E6432 Small Scale Mechanical Behavior

Course: MEEM E6432: Small Scale Mechanical Behavior
Instructor: Professor Jeffrey W. Kysar
Office: 244 Mudd Building
Email: jwkysar@columbia.edu
Telephone: 212-854-7432
Office Hours: Fridays, 9:00 am – 10:00 am, or by appointment

Format: Weekly 150-minute lecture distributed via Columbia Video Network.

Textbook: No required textbook, but a detailed reading list will be distributed.

Homework: Homework sets will be assigned approximately weekly.

Grading: Several Homework Sets, 75%
Final Project, 25%

Description: Introduction to the mechanical behavior of small-scale components, structures and devices. It is common that the governing equations for such small systems are non-linear, either due to a non-linear relationship between displacement and strain or a non-linear relationship between strain and stress, or both. The Calculus of Variations is used as a means to derive the governing equations of beam and plate theory that account for the non-linearities. This will lead to detailed discussions of the deformation and vibration of beams and plates, to the stress, deformation, and substrate curvature in thin films, as well as fracture, delamination, bulging, buckling and of thin films. The thermodynamics of solids will be reviewed, which will provide the basis for a detailed discussion of non-linear elastic behavior as well as the study of the equilibrium and stability of surfaces.

Expectations: Students may freely discuss their work with others, but any work submitted for grading must be that of the student and must be representative of the level of understanding of the student. Under no circumstances will the copying of analysis or text from any source be tolerated.

Syllabus

1. Overview of governing equations to solve problems of mechanical deformation
 - (a) No previous experience with Elasticity will be required for this course
2. Overview of variational calculus with applications to
 - (a) Nonlinear beam theory
 - (b) Nonlinear plate theory
3. Stresses in thin films
 - (a) Measurement of stresses in thin films
 - (b) Wafer curvature and Stoney equation
 - (c) Stresses due to different deposition processes
4. Overview of fracture mechanics
 - (a) Classification of different types of crack and fracture behaviors
 - (b) Singular stress state at crack tip
 - (c) Energy release rate upon crack advance and fracture criterion
5. Delamination and fracture in thin films
 - (a) Morphologies of fracture
 - (b) Energy release rates and fracture criterion
6. Thermodynamics of deformed solids
 - (a) Free energies
 - (b) Thermodynamic definition of elastic properties
 - (c) Elastic properties under isothermal and adiabatic conditions
 - (d) Calculation of elastic properties from atomic potentials
 - (e) Linear and non-linear elastic properties
7. Mechanics of two-dimensional materials
 - (a) Linear and non-linear elastic properties
 - (b) Mechanical characterization

