Winter 2015

AERO 552 [Atkins] (Aerospace Information Systems)

AERO 575 [Kolmanovsky](Flight and Trajectory Optimization)

AERO 584 [Pangou] Navigation and Guidance of Aerospace Vehicles

AERO 740 [Girard and Kolmanovsky] Advanced Nonlinear Control

EECS 419 [Hofmann]

EECS 460 [Meerkov]

EECS 461 [Cook]

EECS 498 [Mathieu] (Grid Integration of Alternative Energy)

EECS 502 [Teneketzis]

EECS 560 (AERO 550, ME 564) [Ozay]

EECS 562 (AERO 551) [Revzen]

EECS 565 (AERO 580) [Bernstein & Freudenberg] (In W15, there will be 2 sections of the course. See below for further information)

EECS 598-01 [Lafortune] Control of Discrete Event Systems

ME 453 [Remy]

ME 458 [Karnik, Ford Motor Company]

ME 461 [Gillespie]

ME 542 [Orsoz] Vehicle Dynamics

ME 567 (EECS 567) [Tilbury]

Other ME courses unknown at this time.

Notes: Grizzle is teaching EECS 216.

ME 458 Automotive Engineering presents a systems approach to vehicle modeling for longitudinal, lateral and ride dynamics. Individual vehicle sub-systems are introduced and analyzed, and then incorporated into vehicle-level models for simulation and analysis using Matlab, Simulink and Stateflow. Topics covered include:

- Reciprocating internal combustion engines, air cycle thermodynamics of Otto and Diesel cycles, engine parameters and engine mapping, engine emissions
- Transmissions and driveline, analysis of epicyclical gear sets, gear ratio selection for economy and performance
- Tires and tire models, slip and cornering stiffness
- Brake systems, brake proportioning, anti-lock brakes and braking performance analysis
- Vehicle system modeling for longitudinal acceleration
- Ackermann steering mechanism, low speed turning, high speed turning, understeer, neutral steer and oversteer, cornering performance metrics and instability
- Bicycle model for vehicle lateral acceleration, transient vehicle cornering dynamics
- Suspension types and components, suspension effects on cornering dynamics, roll center and roll axis analysis, lateral load transfer during cornering, castor, camber and roll steer effects.
- Vehicle ride characteristics, noise, vibration and harshness (NVH), human response to vibration, 1- and 2-DOF quarter car ride models, frequency response and parametric analysis for vertical acceleration, 2-DOF model for vehicle pitch and bounce
- Random vibration, power spectral density modeling of road input
- Brief introduction to electric and hybrid-electric vehicles

EECS 565 (Aero 580) In W15, two sections of will be offered. The section that will meet Tu/Th 10:30-12:00 in 1500 EECS will be taught by Prof. Freudenberg of EECS. The section that will meet Wed/Fr 8:30-10:00 in 1024 FXB will be taught by Prof. Bernstein of AERO.

<u>Prof. Bernstein:</u> Standard problem framework for feedback and feedforward control. Basic servo loop with process and sensor noise. Deterministic and stochastic H2 performance metric. Fixed-structure derivation of LQR and LQG controllers. Controller synthesis based on the internal model principle. Analysis of the algebraic Riccati equation. Application to rigid body motion and structural vibration with non-minimum-phase zeros. Extensive use of Simulink to evaluate closed-loop performance.

<u>Prof. Freudenberg:</u> Control design concepts for linear multivariable systems. Review of single variable systems and extensions to multivariable systems. Purpose of feedback. Sensitivity, robustness, and design tradeoffs. Design formulations using both frequency domain and state space descriptions. Pole placement/observer design. Linear quadratic Gaussian based design methods. Design problems unique to multivariable systems.

EECS 598-01 (Winter 2015): Control of Discrete Event Systems

Advanced topics on control of discrete event systems, with focus on the following topics: distributed and decentralized control architectures; synthesis methodologies for controllers under safety and liveness properties; comparison of synthesis techniques for specifications described by automata and by temporal logics; joint control and diagnosis problems for fault-tolerant control; discussion of relevant case studies. Other topics may be explored, based on students' interests.

The course will combine lectures on the above topics with discussion of representative papers in the literature led by the students. In addition, the students will choose a topic for a term paper to be presented and discussed in class. Grading will be based on class participation and on the term paper.

Recommended prerequisites are EECS 566 or the Special Topics class EECS 598-05 taught by Prof. Ozay in Fall 2013. Students without these pre-requisites may still enroll but should contact the instructor first.

Please contact Prof. Lafortune for additional information.
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ME 458: Automotive Engineering

Winter 2015 – Mondays, 5-8PM – In Class or Online

Why EE and CE students should take this course	• You liked EECS 461 and/or EECS 460. • EEs in the automotive sector make $10K higher median salary than MEs. • You're interested in the control software and electronics for high technology automobiles (e.g., autonomous, electric, connected) and want to know more about how automobiles work in general.

Instructor: Dr. Amey Karnik, Technical Expert in Engine Air and Fuel Control Strategy, Ford Motor Company

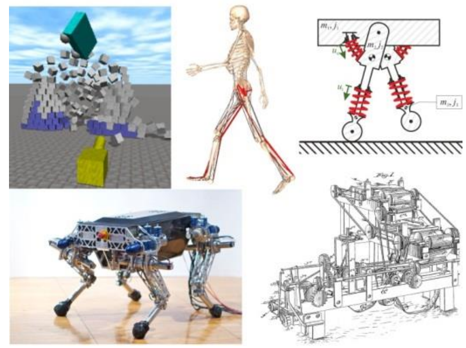
Prerequisites: EECS216 should provide sufficient background. EECS 460 and/or 461 are also desirable.

Course Overview: ME458 presents a systems approach to vehicle modeling for longitudinal, lateral and ride dynamics. Individual vehicle sub-systems are introduced and analyzed, and then incorporated into vehicle-level models for simulation and analysis using Matlab, Simulink and Stateflow. **Counts toward Flexible Technical Electives (FTE) for CE and EE undergrads.**

Topics covered include:
- Reciprocating internal combustion engines, air cycle thermodynamics of Otto and Diesel cycles, engine parameters and engine mapping, engine emissions
- Transmissions and driveline, analysis of epicyclical gear sets, gear ratio selection for economy and performance
- Tires and tire models, slip and cornering stiffness
- Brake systems, brake proportioning, anti-lock brakes and braking performance
- Vehicle system modeling for longitudinal acceleration
- Bicycle model for vehicle lateral acceleration, transient vehicle cornering dynamics
- Suspension types and components, suspension effects on cornering dynamics, roll center and roll axis analysis, lateral load transfer during cornering
- Vehicle ride characteristics, noise, vibration and harshness (NVH), human response to vibration, 1- and 2-DOF quarter car ride models.
- Random vibration, power spectral density modeling of road input
- Brief introduction to electric and hybrid-electric vehicles

ME 543 Analytical and Computational Dynamics I Winter 2015

Course Description:



ME 543 deals with the dynamics of multibody systems. That is, of systems of rigid bodies that are connected through joints and other constraints. A large number of mechanical systems can be modeled this way and multibody dynamics are thus found virtually everywhere: In trucks and cars they govern the behavior of steering, suspension, or powertrains; in robotics, they are used to accurately plan and control highly dynamic motions; and in movies and computer games, they create the realistic behavior of virtual worlds. In a biomechanical analysis, even our own human body can be regarded as a multibody system.
ME 543 provides a solid theoretical background to describe such systems in a precise mathematical way. It develops tools and methods to create the governing differential equations analytically and it looks at algorithms that do so in a numerically efficient way. The course also covers advanced computational techniques and more sophisticated problems, including unilateral contacts and collisions. Over the course of the semester you will write your own dynamics engine in object-oriented MATLAB. You will be able to use all this knowledge to build better controllers for robots, to debug your solutions more intuitively, and to understand what is going on when you use off-the-shelf software for design or analysis.

Content:

From course catalogue: Modern analytical rigid body dynamics equation formulation and computational solution techniques applied to mechanical multibody systems. Kinematics of motion generalized coordinates and speeds, *analytical and computational determination of inertia properties*, generalized forces, *Gibb's function, Routhian,* Kanes's equations, *Hamilton's principle,* Lagrange's equations holonomic and nonholonomic constraints, constraint processing, computational simulation.
Deviations from this: Topics in grey are likely not covered, but instead the following: Recursive algorithms, Collisions, Screw theory, Applications in control, Matrix based methods.
Relation to other courses: There is some overlap with ME 540 (kinematics, motion of a single body, holonomic constraints) and ME 567 (kinematic chains, joint models, Jacobians).

Prerequisites*:*

An intermediate course in dynamics and vibrations that covered Newton/Euler and Lagrangian formulations for three-dimensional motion of particles and rigid bodies (for example, ME440), a good grasp of linear algebra, and some prior experience with MATLAB.

Instructor:

Prof. C. David Remy
Department of Mechanical Engineering
2028 GGB
(734) 7648797
cdremy@umich.edu

Lectures:
MWF 2:30 – 3:30, 104 EWRE

Office Hours:
MW 3:30 – 5:00; in my office; and by appointment

Course Website:
Materials and announcements will be posted on ctools. https://ctools.umich.edu/

Reading Material:
There is no official course book, but I will upload parts of the following books and other material onto the course website:

- Amirouche, F.: Computational Methods in Multibody Dynamics
- Pfeiffer, F. & Glocker, C.: Multibody Dynamics with Unilateral Contacts
- Shabana, A.: Dynamics of Multibody Systems
- Wittenburg, J.: Dynamics of Systems of Rigid Bodies

Additional Reading:

- Huston, R.: Multibody Dynamics
- Featherstone, R.: Rigid Body Dynamics Algorithms
- Murray, R., Li, Z., and Sastry S.: A Mathematical Introduction to Robotic Manipulation
- Moon, F.: Applied Dynamics with Applications to Multibody and Mechatronic Systems

Homework:
Homework will be assigned regularly (about 9 sets) and posted on ctools. It is always due at the start of class. Due dates will be posted with each set of homework. You get a total of **three** late days which each grant you a 24h extension. You are encouraged to **discuss and work on homework in teams** but the final documents and programs must represent your own understanding of the material.

Please hand in your homework electronically as a **single PDF file called 'HWXY_uniquename.pdf'** (e.g., 'HW01_cdremy.pdf). This file can contain scans of handwritten notes and must include all required figures and supporting material. Always cite your sources clearly. On the first page, **state explicitly with whom you collaborated**. Matlab code should be submitted in separate files. Only submit code files that you created or changed. **Do not ZIP or otherwise archive your files**.

Project:
A small project will test your implementation skills at the end of the semester. It is similar in format to the homework sets but must be completed by yourself. Please see http://ram-lab.engin.umich.edu/me543_-_analytical_and_computational_dynamics.html for a video of the final project.

Exams

Midterm:	Wednesday, February 25 (TBC)	Time/Room: TBD
Final:	Thursday, April 30	10:30 am - 12:30 pm, Room: TBD

Grading Policy

Homework: 30%

Project: 15%

Midterm Exam: 20%

Final Exam: 35%

The Engineering Honor Code:

No member of the community shall take unfair advantage of any other member of the community. http://www.engin.umich.edu/students/honorcode/

Course Outline

(The bullet points below do not correspond to individual lectures and are not in the final order. Please refer to the course schedule on ctools for up-to-date information and reading assignments)

- *Introduction:* Applications of multi-body dynamics in robotics, biomechanics, and control; problems of inverse kinematics; inverse dynamics; forward dynamics
- *Tools:* MATLAB/Simulink and the SimMechanics Toolbox
- *Repetition:* Scalars, vectors, tensors, and coordinate systems
- Moving coordinate systems; differentiation in moving coordinate systems; kinematics of a rigid body
- *Tools:* The MATLAB Symbolic Math Toolbox
- *Tools:* Object Oriented Programming in Matlab
- *Repetition:* Fundamental laws of dynamics, applications to particles
- *Repetition:* Dynamics of a single body
- Constraints and minimal/generalized coordinates, speeds, and forces
- Nonholonomic and rehonomic constraints
- Jacobians; duality of forces and velocities; motion subspaces; constraint spaces
- Recursive Methods
- *Tools:* Advanced object oriented concepts: Inheritance, polymorphism
- Modeling multi-body systems; connectivity; trees and loops
- Principles of d'Alambert, Jourdain, Gauss
- Projected Newton – Euler –Equations
- Ithe canonical form of the equations of motion for a multi-body system
  $\mathbf{M}(\mathbf{q},t)\ddot{\mathbf{q}} = \mathbf{g}(\mathbf{q},t) + \mathbf{f}(\mathbf{q},\dot{\mathbf{q}},t) + \mathbf{J}(\mathbf{q},t)\boldsymbol{\lambda} + \mathbf{S}\boldsymbol{\tau}$
- Unilateral constraints; soft and hard contact models
- Collisions
- *Application:* Control examples using virtual constraints and virtual models
- Kinematics: Algorithms and implementations
- Inverse dynamics: Algorithms and implementations
- Forward dynamics: Algorithms and implementations

Lecture	Date	Topics	Reading	HW Given	HW Topic	HW DUE
Start Of Year	Mon 1/5 14:30	**NO CLASS**				
1	Wed 1/7 14:30	Intro				
2	Fri 1/9 14:30	Introduction of Names and Concepts; the EOM; Simple Oscillator Example	Simmechanics Documentation (SimMechanics > Getting Started > Modeling, Simulating, and Visualizing Simple Machines)	HW 01	SimMechanics	
3	Mon 1/12 14:30	Complex Simechanics Example; Scalar Values				
4	Wed 1/14 14:30	Physical and Numerical Vectors				
5	Fri 1/16 14:30	Coordinate systems	PfeifferGlocker_Chapt_02 (pages 19- 17)	HW 02	Transformations and Derivatives	HW 01
MLK Day	Mon 1/19 14:30	**NO CLASS**				
6	Wed 1/21 14:30	Derivative of Vectors				
7	Fri 1/23 14:30	Moving Coordinate Systems; MATLAB Symbolic Math Toolbox				
8	Mon 1/26 14:30	Transformation of Matrices; Object Oriented Prgramming	Weisfeld_Chapter_1 (pages 5-22)			
9	Wed 1/28 14:30	Ridgid Body Kinematics		HW 03	Rigid Body Kinematics	HW 02
10	Fri 1/30 14:30	Integrating Kinematics (Review of HW 02) & Dynamics of Particles				
11	Mon 2/2 14:30	Angular Momentum	Ginsberg_EngineeringDynamics_Chapter_5			
12	Wed 2/4 14:30	The Inertia Matrix				
13	Fri 2/6 14:30	Rigid Body Dynamics		HW 04	Rigid Body Dynamics/ Inertia	HW 03
14	Mon 2/9 14:30	Energy; Inertia Computation; Parallel Axis Theorem, Rigid Body Dynamics in Matrix Form				
15	Wed 2/11 14:30	Explicit and Implicit Constraints	Amirouche_FundamentalsOfMultibody_Chapter_3			
16	Fri 2/13 14:30	Constraint Classification: Implicit-Explicit / Equality- Inequality/ Scleronomic-Rheonomic/ Holonomic-non holonomic				
17	Mon 2/16 14:30	Kinematic Chaincs and Trees, Linked Lists		HW 05	Constraints/ Pre Test	HW 04
18	Wed 2/18 14:30	Concept of recursion, Outward and Inward Pass Algorithms				
19	Fri 2/20 14:30	Recursive computation of Joint Displacement				
20	Mon 2/23 14:30	Planar Joint Types	Weisfeld_Chapter_1 (pages 22-29)	HW 06	Recursive Algorithms	HW 05
Midterm-Exam	Wed 2/25 14:30	**Midterm 8:00-10:00am in DOW-1014**				
21	Fri 2/27 14:30	Concept of Inheritance, Implementation of Recursive Kinematics Trees using OO-Programming.	Matlab Documentation (User's Guide -> Object-Oriented Programming -> MATLAB Classes Overview / -> Building on Other Classes)			
Spring Break	Mon 3/2 14:30	**NO CLASS**				
Spring Break	Wed 3/4 14:30	**NO CLASS**				
Spring Break	Fri 3/6 14:30	**NO CLASS**				
22	Mon 3/9 14:30	Polymorphism in Kinematic Trees				
23	Wed 3/11 14:30	Velocties and Accelerations, Computation of the Constraint Jacobian	PfeifferGlocker_Chapt_02 (pages 18 - 20)	HW 07	Recursive Positions, Velocitities, and Accelerations	HW 06
24	Fri 3/13 14:30	Duality of Forces and Velocities, Jacobi-Transposed mapping				
25	Mon 3/16 14:30	Virtual Power and the Principle of Jourdain	Shabana_DynamicsMultibody_Chapter_3 (Pages 102-115)			
26	Wed 3/18 14:30	Projected Newton-Euler Equations for systems of particles				
27	Fri 3/20 14:30	Projected Newton-Euler Equations for systems of rigid bodies	PfeifferGlocker_Chapt_03 (pages 21 -25)	HW 08	Multi-Body Dynamics for Particles and Rigid Bodies	HW 07
28	Mon 3/23 14:30	Implicit Constraints, Closing Loops Dynamically				
29	Wed 3/25 14:30	Implicit Constraints, Issues and Implementations				
30	Fri 3/27 14:30	Unilateral Constraints				
31	Mon 3/30 14:30	Collisions		HW 09	Collisions	HW 08
32	Wed 4/1 14:30	Collisions Example I				
33	Fri 4/3 14:30	Collisions Example II; HW08 Revisited				
34	Mon 4/6 14:30	HW08 Revisited				
35	Wed 4/8 14:30	The Canonical Form of the EOMs and its Components Revisited				HW 09
36	Fri 4/10 14:30	Virtual Model Control		Project	Final Project	
37	Mon 4/13 14:30	Algorithmic Implementations: Computational complexity and Inverse Dynamics				
38	Wed 4/15 14:30	Algorithmic Implementations: Inverse Dynamics & Forward Dynamics				
39	Fri 4/17 14:30	Algorithmic Implementations: Order-N Forward Dynamics				
40	Mon 4/20 14:30	Recap				Project
Final Exam	Tue 4/30 10:30	**Final 10:30-12:30 in TBD**				