ME 451
Kinematics and Dynamics of Machine Systems
Fall 2014

Time: 09:30AM – 10:45AM Tuesday and Thursday
Room: 1153 ME

Instructor: Dan Negrut
Office: 4150ME
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E-Mail: negrut@engr.wisc.edu
Graders: Luning Fang (for pen and paper assignments)
WoongJo Choi (for MATLAB and ADAMS components)
Office Hours: Monday, 10:00 – 11:00 AM
Wednesday, 10:00 – 11:00 AM
Other times by appointment (please call or email to arrange)

Course Page: https://learnuw.wisc.edu (grades) and www.sbel.wisc.edu/Courses/ME451/2014/index.htm

Text: The books below have been placed on reserve at Wendt library in conjunction with this course. The first book will be the one that comes closest to the material covered in the class. The author provided a pdf of the entire book and gave me permission to distribute it for free.

1. Computer-Aided Kinematics and Dynamics of Mechanical Systems, Volume I: Basic Methods, by Edward J. Haug, Allyn and Bacon, 1989
2. Dynamics of Multibody Systems, by Ahmed A. Shabana, 3rd ed., 2007

Prerequisites: ME 240 or equivalent, MATLAB programming

Recommended Supplemental Text: *MATLAB & Simulink Student Version Release R2013a*
Available for purchase at bookstore and at www.mathworks.com/academia/student_version/index.html
MATLAB (R2012b) is available through CAE.

Course Objectives: This course reviews and reinforces the student's understanding of Kinematics and the Dynamics of multibody systems with immediate application to the study of mechanisms and machines. All aspects of multi-body kinematics and dynamics are covered making the course good as a senior elective course or as a graduate level review for the PhD qualifying exam. This course assumes knowledge of elementary vector algebra and the concepts of time and partial derivatives. An elementary Physics course covering Newton's laws or course(s) on Statics and Dynamics will prove very helpful in understanding the material covered in ME451. More precisely, the course reviews these topics and then applies them to more complex problems. The course will place equal emphasis on gaining both an analytical understanding and insight/intuition on the subject. The material presented in the class will emphasize the analytical component of the subject, while the homework, particularly through the MATLAB coding and ADAMS modeling assignments, will encourage you to see beyond equations and abstract constructs. It is also anticipated that this course will significantly improve your MATLAB programming skills and help you learn how to model/simulate/analyze mechanical systems in ADAMS, the most widely used mechanical system simulation software package. Note that this course requires a good deal of MATLAB programming. The course covers materials that is routinely part of the Kinematics & Dynamics PhD qualifying exam.

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Course Grading

Grades will be based on your performance on written homework, two midterm exams, and one final exam. All homework and exam scores will be maintained on the Learn@UW course website. This will allow you to monitor your performance and also see aggregate scores for the rest of the class, which should give you a continuous idea of your performance. Should you have questions about your score, please contact the instructor. Specific score-related questions about homework and exams must be raised prior to the next class period after receiving the score. If homework that is turned in does not appear to be graded (missing) on the Learn@UW course website please point that out to me within one week after the return of the corresponding set of graded homework.

Percentage participation to the final grade shall be distributed in the following manner:

Homework	**40 %**
Project I	**7.5 %**
Project II	**7.5 %**
Final Project	**10 %**
Exam I	**7.5 %**
Exam II	**7.5 %**
Final Exam	**20 %**
Total	**100 %**

The PowerPoint notes used in class, handwritten notes, and examples covered in class will be made available on the course web-site at www.sbel.wisc.edu/Courses/ME451/2014/index.htm. Solutions to homework problems will be posted at https://learnuw.wisc.edu.

Homework & Projects: Problems will be assigned regularly during the semester. All assigned homework will be collected at the beginning of class on the date due. No late homework will be accepted. Homework solutions should be *neat and well organized*. All necessary diagrams and calculations must be clearly shown. Homework solutions will be made available. The homework with the lowest score will be dropped when computing the final homework average. There will be two Intermediate Projects, involving the MATLAB simulation code that you will be developing throughout the course of the semester. There will be one Final Project, which can be an ADAMS project or a MATLAB simulation engine. You will get to choose the topic of the final project that you work on after the topic is approved by the instructor.

Exams: Exams will include short-answer questions and problems, and may include both take-home and in-class portions. In-class portions will be given during the lecture sessions shown on the schedule. The best way to prepare for exams is to participate in class, learn the fundamental concepts, and redo homework and example problems. The first exam will be given on October 28. The second exam will be given on December 4. Reviews will be held for each of these two exams, one or two days before the exam. The ME451 final exam will be a comprehensive exam, scheduled for Tuesday, December 16 between 2:45-4:45 PM (room TBA).

Disability requests: I must hear from anyone who has a disability that may require some modification of seating, testing or other class requirements so that appropriate arrangements may be made. Please see me after class or during my office hours.

Complaints: If you have a complaint regarding the course and if you are unsatisfied with the response of the instructor, then you should contact the Chair of the Department of Mechanical Engineering. The Chair's office is in 3107 Mechanical Engineering Building, and an appointment to see the Chair can be made by contacting the Department Office at (608) 265-2155.

Letter Grades: Final letter grades will be based on the total score accumulated on homework and exams throughout the semester using the following scale:

Score	Grade
≥ 94	A
87-93	AB
80-86	B
73-79	BC
66-72	C
55-65	D
Below 55	F

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Schedule Fall 2014 [DRAFT]

(SUBJECT TO CHANGE; CHECK CLASS WEBISTE FOR UP-TO-DATE VERSION)

Date	Topic	Learning objectives	Assignments
09/02	Scope of Kinematics and Dynamics Analysis Overview of Existing Methodologies	Understanding the scope of the course. Understanding the goals of the course.	
09/04	Geometric and Algebraic Vectors. Matrix Algebra.	Concept of geometric vector. Concept of algebraic vector and reference frame. Matrices and matrix-vector operations.	HW 1: 2.2.5, 2.2.8, 2.2.10
09/09	Vector Calculus	Review of concepts of calculus. Vector and matrix differentiation. Partial derivatives.	
09/11	Vector Calculus	Chain rule of differentiation. Velocity and acceleration in moving frames. Absolute vs. Relative Generalized Coordinates.	HW 2: Problem assigned in class and 2.4.4, 2.5.2, 2.5.7
09/16	MATLAB Tutorial (1153ME)	Brief overview of MATLAB. Discuss JSON format.	
09/18	Basic Concepts of Planar Kinematics	Kinematic constraints. Degrees of Freedom. Jacobian. Absolute Kinematic Constraints.	HW 3: 2.5.11, 2.5.12, 2.6.1, 3.1.1, 3.1.2 MATLAB 1
09/23	Absolute Kinematic Constraints	Kinematic constraints involving one body: position and angular constraints.	
09/25	Basic Relative Kinematic Constraints	Kinematic constraints involving pairs of bodies.	HW 4: 3.1.3, 3.3.2 MATLAB 2
09/30	Relative Kinematic Constraints. Composite Joints.	Kinematic constraints between pairs of bodies: distance constraint, revolute and translational joints. Constraints replacing massless links (couplers).	
10/02	Cam-Follower Constraints Point-Curve Constraints	Geometry of cam-followers and point-followers.	HW 5: 3.3.4, 3.3.5 MATLAB 3
10/07	ADAMS Tutorial (1153ME)	Brief overview of ADAMS. (lecture given by Dr. Justin Madsen)	
10/09	Problem solving session	(lecture given by Dr. Arman Pazouki)	HW 6: 3.5.1, 3.5.4, 3.5.5, 3.5.6 ADAMS 1
10/14	Driving Constraints	Completing the set of constraints for kinematic analysis (absolute and relative drivers).	
10/16	Position, Velocity, and Acceleration Analysis	Formulating and solving the kinematic problem: Wrecker Boom Example.	MATLAB 4
10/21	Elements of the Solution of Kinematic Analysis of Mechanisms	Implicit Function Theorem. Newton-Raphson method.	
10/23	MATLAB Considerations, Kinematic Analysis. Singular configurations	Characterize and identify lock-up and bifurcation configurations.	MATLAB 5 ADAMS 2

10/28	Wrecker-Boom Example. Discussion of Project 1. Discussion of simEngine2D		PROJECT 1[1]
10/30	Dynamics of Planar Systems; Principle of Virtual Work	Variational approach to deriving the equations of motion (EOM) for one planar body.	
11/04	MIDTERM EXAM I[2]		
11/06	Equations of Motion for a Single Rigid Body	Equations of Motion for a body with centroidal reference frame.	HW 7: 6.1.1, 6.1.2, 6.1.3, 6.1.4 MATLAB 6 ADAMS 3
11/11	Virtual Work and Generalized Forces	Definition of Virtual Work and Generalized Force. Computing generalized forces for translational and rotational force elements.	
11/13	Equations of Motion for Systems of Coupled Rigid Bodies	Understand how to generate the set of constrained equations of motion that govern the time evolution of a mechanical system.	HW 8: 6.2.1 MATLAB 7 ADAMS 4
11/18	Initial Conditions for Dynamics Analysis Computation of Reaction Forces	Discuss Initial Value Problems. Introduce the concept Constraint Force.	Final Project Proposal Due
11/20	Computation of Reaction Forces. Numerical Integration.	Learn how to recover constraint reaction forces from the Lagrange multipliers. Discuss numerical integration methods. Introduce the Forward Euler formula.	HW 9: 6.3.3, 6.4.2 MATLAB 8 ADAMS 5
11/25	Numerical Integration Methods for First Order IVP	Understand how to solve an Initial Value. Stiff differential equations: implicit integration methods.	PROJECT 2[3]
		THANKSGIVING RECESS	
12/02	Numerical Integration Methods for second order IVPs and DAEs	Learn about Newmark's method for handling second order differential equations. Learn how to solve the index 3 Differential Algebraic Equations (DAEs) of multibody dynamics.	MATLAB 9 ADAMS 6
12/04	MIDTERM EXAM II[4]		
12/09	Inverse Dynamics Analysis	Learn how to compute the set of forces/torques that are required to obtain a prescribed motion of the mechanical system.	
12/11	Equilibrium Analysis. Wrap up. Open problems in Computational Multibody Dynamics	Understand the numerical formulation of the equilibrium problem.	

Final Exam: Tuesday, December 16, 2:45 PM. Room: TBA

Final Project Due Date: Tuesday, December 15, 11:59 PM. Room: TBA

[1] Due on 11/11, at 11:59 PM
[2] Review session will be held on Monday, 11/03/2014 at 7:15 PM, in room 1153ME.
[3] Due on 12/08 at 11:59 PM
[4] Review session will be held on Wednesday, 12/03/2014 at 7:15 PM, in room 1163ME.