ME 751
Computational Multibody Dynamics
Fall 2016

Time: 9:30 – 10:45 Mo & Wd & Fr
Location: 1164ME
Instructor: Dan Negrut
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Course Page: http://sbel.wisc.edu/Courses/ME751/2016/index.htm and http://learnuw.wisc.edu
Office Hours: Tu & Th, 12 – 1 PM.

Text: The first book below will be the one that comes closest to the material covered in the class. Author provided a pdf of the entire book with permission to distribute it freely[1]. The other textbooks are provided as supplemental material.

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, 4th ed., 2013
3. Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations, by U. Ascher and L. Petzold, SIAM, 1998
4. Solving Ordinary Differential Equations I: Nonstiff Problems, by E. Hairer, S. Norsett, G. Wanner, 1993
5. Solving Ordinary Differential Equations II: Stiff and differential-algebraic Problems (Second Revised Edition) by E. Hairer and G. Wanner, 2002

Prerequisites: ME451 or equivalent, C programming, MATLAB Elementary Linear Algebra and Calculus

Course Objectives: This course reviews and reinforces the student's understanding of Kinematics and Dynamics of multibody systems with immediate application to the dynamics of systems of rigid and deformable bodies. This course assumes knowledge of elementary vector algebra and the concepts of time and partial derivatives. The course ME451 or an elementary Physics course covering Newton's laws or course(s) on Statics and Dynamics will prove helpful in understanding the material covered. 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 coding and Chrono modeling assignments, will encourage you to see beyond equations and abstract constructs. It is also anticipated that this course will improve your MATLAB programming skills and help you learn how to model/simulate/analyze mechanical systems in Chrono. Chrono is an open source simulation program available online at http://www.projectchrono.org/.

[1] Available at http://sbel.wisc.edu/Courses/ME751/2010/bookHaugPointers.htm

ME 751
Kinematics and Dynamics of Machine Systems
Course Grading

Grades will be based on your homework, a midterm examination, and a final project. All homework and exam scores will be maintained on the Learn@UW course website. This will allow you to monitor your performance and 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 issues about homework and exam must be brought up within one week after receiving the score. If homework that is turned in does not appear to be graded (missing) on the Learn@UW course website please bring that to the attention of the instructor within one week after the return of the corresponding graded homework.

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

Homework	=	**30%**
Midterm Exam	=	**20%**
Final Project	=	**45%**
Class Participation	=	**5%**

The PowerPoint notes used in class, handwritten notes, and examples covered in class will be made available on the course web-site at http://sbel.wisc.edu/Courses/ME751/2016/index.htm.

Homework: 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.

Exams: The midterm exam will include problems as well as short-answer questions, and may include both take-home and in-class portions. In-class portions will be given during the lecture session shown on the schedule. Take-home problems, if any, will be more involved and may require the use of computational tools and/or software packages (MATLAB or Chrono). The best way to prepare for exams is to participate in class, learn the fundamental concepts, and redo homework and example problems.

Final Project: There will be no final exam. Instead, each student will choose a Final Project that he/she will be working on. Teams of two students are ok. A 30 minute final presentation will be made in front of the instructor and any other class student who chooses to attend the presentation. The Final Project presentation will be organized as follows: a 20 minute PPT document will be used to describe the final project and explain your contributions/innovations/achievements. The rest of the time will be dedicated to a Q&A session. Each student/team will choose after consultation with the instructor a time slot for this presentation during the last week of class or finals' week.

The proposal for the Final Project is due on 10/19/2016. You are encouraged to think of your interests and propose topics for the project that best fit them. You should try hard to leverage your ongoing research even though it might be slightly away from the core topics covered in the class. As long as the proposed project topic has to do with rigid body dynamics, numerical integration methods that solve the time evolution of a dynamic system, or draws on high performance computing, chances are that the final project proposal will be acceptable.

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 608 263-5372.

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

ME 751[2]: Advanced Computational Multibody Dynamics
Fall 2016

Date	Topic	Details regarding learning objectives	HW
09/07	Review	Course Overview. Basic Matrix Algebra, Lagrange Multiplier Theorem	
09/09	Review	Calculus, Implicit Function Theorem, Newton's Method	HW01
09/12	Kinematics Analysis (1)	Generalized coordinates. Kinematics of a rigid body. Rotation of a rigid body in space	
09/14	Kinematics Analysis (2)	Rotation of a rigid body in space: Euler Angles, Euler Parameters, Rodriguez Angles	
09/16	Kinematics Analysis (3)	Kinematic Constraints: spherical, revolute, translational, cylindrical, etc.	HW02
09/19	Kinematics Analysis (4)	Position, Velocity, and Acceleration Analysis	
09/21	Overview of Chrono	Modules, Parallelization, Chrono::Vehicle, Examples	
09/23	Dynamics Analysis (1)	Equations of Motion for one rigid body in Cartesian coordinates	HW03
09/26	Dynamics Analysis (2)	Applied forces; Generalized forces	
09/28	Dynamics Analysis (3)	Equations of motion for constrained systems in Cartesian coordinates; Computation of Reaction Forces	
09/30	Dynamics Analysis (4)	Deriving the equations of motion using Lagrangian or other non-Cartesian generalized coordinates	HW04
10/03	Equilibrium Analysis and Inverse Dynamics	Problem setup, applications	
10/05	Numerical Integration Methods (1)	Explicit vs. Implicit Methods Stability, Convergence, Order of an Integration formula	
10/07	Numerical Integration Methods (2)	Multi-step Methods; Runge-Kutta Methods	HW05
10/10	Numerical Integration Methods (3)	Methods for the numerical solution of index 3 DAEs. Coordinate Partitioning Method	
10/12	Numerical Integration Methods (4)	Direct methods: BDF, Newmark, Generalized Alpha	
10/14	FMBD (1): Intro to Flex. Body Dynamics	Introduction to Flexible MBD, Continuum Mechanics, Methods of FMBD, Small Deformation, Corotational formulation	HW06
10/17	FMBD (2): Kinematics of the Floating Frame of Reference (FFR)	FFR kinematics, Angular Momentum of Flexible Bodies, FFR Reference Conditions, Eigenvalue Analysis	
10/19	FMBD (3): Equations of the FFR	FFR Mass Matrix, Quadratic Inertia Terms, Applied Forces, Inertia Shape Integrals, Model Order Reduction	
10/21	FMBD (4): Finite Element FFR	FFR Intermediate Coordinate System, Kinematics, Equations, Moving Loads in FFR. Application Examples	HW07
10/24	FMBD (5): Large Deformation Formulations	Geometrically Exact Theory, Isoparametric Finite Elements, Absolute Nodal Coordinate Formulation	
10/26	FMBD (6): ANCF beam element	ANCF Beam Kinematics, Strains, Inertia Forces, ANCF Beam Element in Chrono, Examples	
10/28	FMBD (7): ANCF shell element I	ANCF Bilinear Shell Element Kinematics, Covariant strains, Inertia Forces, Generalized Forces	HW08

[2] Tentative schedule; changes might occur during the semester. Document will be updated to reflect these changes.

10/31	FMBD (8): ANCF shell element II	Locking Issues, Alleviation of Locking, Enhanced Assumed Strain, Assumed Natural Strain, Examples	
11/02	FMBD (9): Implementation Details	HHT Numerical Integrator, Jacobian of Internal Forces, EAS Loop, Timing, Reference Configuration, Implementation in Chrono	
11/04	Frictional Contact Problems	Introduction Penalty Methods	HW09
11/07	Frictional Contact Problems	Introduction. Penalty Methods	
11/09	Frictional Contact Problems	DVI-Based approaches LCP problems Anitescu-Tasora Approach	
11/11		Midterm Exam	HW10

Date of Final Exam: 12/20/2016, 07:45 – 09:45AM
(no final exam, only Final Project presentation)