

EE 521

Kinematics and Dynamics of Machines

Fall 2021

COURSE INFORMATION

Time: Tuesday 10:40am – 11:30am and Wednesday 2:40pm – 4:30pm
Location: Tuesday at FENS L030, Wednesday at FENS L067 and online
Credit: 3 credit hours

INSTRUCTOR

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Office Hours: Open door policy. You can drop by anytime.

RESOURCES

Web Site: Available through SUCourse+. Please check regularly for announcements and updates.
Recommended Reading: Kane and Levinson, *Dynamics Online: Theory and Implementation with Autolev*, www.autolev.com, 2000.
Reference Books: Kane and Levinson, *Dynamics: Theory and Applications*, https://ecommons.cornell.edu/bitstream/1813/638/10/Dynamics-Theory_opt.pdf, 1985.

PREREQUISITES

Students are expected to have a working knowledge of differential equations, linear systems, statics, kinematics and dynamics. Familiarity with programming, especially with Matlab is recommended.

PURPOSE

This course is designed to equip students with fundamental theories and computational methodologies that are used in (computer aided) analysis of multi-body systems. Students will learn how to analytically formulate dynamics equations for multi-body systems as well as how to utilize numerical algorithms to simulate such systems. Computational mechanics is of high value for the purposes of performance evaluation, sensitivity studies, control system design, model based monitoring and so on.

Students will be introduced to generalized coordinates and speeds, analytical and computational determination of inertia properties, generalized forces, Kane's method, Lagrange's equations, holonomic and non-holonomic constraints. Computerized symbolic manipulation and time integration methods for dynamic analysis will be exercised.

Of the available techniques for formulating equations of motion for multi-body systems, symbolic formulation and Kane's method will be emphasized. Being a vector based approach and making optimal use of generalized coordinates and speeds, Kane's method is preferred for its relative ease of computerization and its computational efficiency. Efficiency may be interpreted here both as producing equations efficiently (with the fewest symbolic operations) and producing efficient equations (which require the fewest numerical operations for their solution). Also, Kane's method produces equations in ordinary differential form (ODEs) even for non-holonomically constrained systems, which can be accommodated using (stabilized) standard solvers.

The emphasis in this course is not on the excessive mathematical abstraction but rather on an integrated understanding of modeling, equation derivation and numerical solution. A solid understanding of the principles of dynamics in the context of modern analytical and computational methods is aimed.

COURSE OBJECTIVES

The goal of this course is to equip each student with an integrated understanding of modeling, equation derivation and numerical solution of multi-body systems. By the end of the course, each student should be able to do the following:

1. Identify relevant points, bodies, and bases; choose generalized coordinates to represent a system.
2. Relate several frames through rigid body rotations.
3. Form the required position vectors.
4. Differentiate relevant vectors to form required velocities and accelerations.
5. Select generalized speeds and formulate kinematical differential equations.
6. Formulate equations of motion for unconstrained systems.
7. Form constraint equations and solve for independent variables.
8. Formulate equations of motion for systems with constraints.
9. Numerically integrate resulting equations of motion even for systems with changing kinematic constraints.
10. Check validity of numerical integration of equations of motion.
11. Linearize equations of motion.
12. Form work functions, calculate kinetic and potential energy of the system.
13. Formulate the Lagrangian and express the equations of motion in a DAE form.
14. Numerically solve for the DAEs using stabilized integration methods.

HOMEWORKS

Homework will be assigned regularly and posted on the course web site. Hard copies will generally not be made available in class, so you will have to produce your own printout.

EXAMS

There will be one mid-term and one (possibly take-home) final exam. Since the course continually builds upon previous material, all exams will be comprehensive. In class exams are closed book, with one page of formulas supplied by the instructor.

LECTURE

The lecture format will be loose. There may be a short break during the two hour lecture period. Extra lectures and problem solving sessions may be scheduled if necessary. Class participation and cooperation among students are highly encouraged. Student feedback will be collected throughout the semester and adaptation will be undertaken accordingly.

PROJECT/TAKE-HOME EXAM

Students will be given the freedom to choose a project topic of their interest subject to instructor's approval. A list of possible project topics will also be recommended by the instructor. A candidate project topic should address a real life (possibly related to research) problem and should involve enough to let students demonstrate their proficiency at a technical level. The projects will involve a progress report. All reports should be written in academic paper format. The projects will be evaluated as a take-home exam.

TENTATIVE GRADING POLICY

Your course grade is determined from the total points you receive from homeworks, midterm and final exams, and the project. Borderline grades are determined by class participation.

Homeworks and project must be submitted to my office by the end of the date due (midnight). No late problem sets are accepted. (Extensions may be granted for special circumstances and only when requested in advance.)

You are responsible for all information given in class verbally and/or in writing. Any information about the course on the web may be replaced by the information given in class.

Cooperative efforts at understanding the material and the assignments of the course are encouraged. However, you may only submit work that you have completed individually. For example, you may communicate verbally about methods for solving assigned problems, but sharing of written work is not permitted. Submitting any work that is not the result of a student's own effort is considered cheating.

Homework:	30%
Midterm Exam:	20%
Take-Home Exam:	30%
Final Exam:	20%
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	100%

OTHER NOTES

Any student with a disability requiring accommodation in this course is encouraged to contact the instructor during the first two weeks of the semester.

ADDITIONAL READING

- Moon, *Applied Dynamics with Applications to Multibody and Mechatronic Systems*, Wiley, 1998.
- Shabana, *Computational Dynamics*, Wiley-Interscience, 1994.
- Nikravesh, *Computer-Aided Analysis of Mechanical Systems*, Prentice Hall, 1987.
- Kane, *Spacecraft Dynamics*, Mcgraw-Hill College, 1981.
- Kane and Levinson, *Dynamics: Theory and Applications*, Mcgraw Hill, 1985.
- Greenwood, *Principles of Dynamics*, Second Edition, Prentice Hall, 1987.
- Seabra Pereira (ed.) and Ambrosio (ed.), *Computational Dynamics in Multibody Systems*, Springer, 2006.
- Nayfeh and Balachandran, *Applied Nonlinear Dynamics: Analytical, Computational, and Experimental Methods*, Wiley-Interscience, January 1995.
- Paul Mitiguy, *Advanced Dynamics & Motion Simulation for Professional Engineers and Scientists*, Prodigy Press, Inc, 2011.

TENTATIVE SCHEDULE AND TOPICS

Definitions

Week 1 and 2

- Vectors, Bases, Frames
- Vector Operations
- Simple Rotations
- Vector Functions
- Differentiation of Vector Functions

Kinematics

Weeks 3 – 5

- Rotations in Space
- Angular Velocity
- Differentiation in Two Reference Frames
- Auxiliary Reference Frames and Auxiliary Variables
- Angular Acceleration
- Velocity and Acceleration
- State Variables
- Kinematical Differential Equations
- Partial Angular Velocities, Partial Velocities
- Constraint Equations and Independent Variables

Mass Distribution

Week 7 and 8

- Mass Center
- Inertia Dyadics, Inertia Vectors, Inertia Scalars, Inertia Matrices
- Principle Axes, Principle Planes, Principle Moment of Inertia

Forces

Weeks 8 and 9

- Moment About a Point, Bound Vectors, Resultant
- Couples, Torque
- Equivalence, Replacement
- Generalized Active Forces
- Contributing and Noncontributing Forces
- Interaction Forces
- Terrestrial Gravitational Forces
- Bringing Noncontributing Forces into Evidence

Equations of Motion

Weeks 10 – 12

- Dynamical Equations
- Auxiliary Dynamical Equations
- Numerical Solution of Differential Equations of Motion
- Linearization of Equations of Motion
- Numerical Simulation of Systems with Changing Kinematic Constraints

Energy and Momentum Considerations

Weeks 13 and 14

- Work Functions
- Kinetic and Potential Energy
- Lagrangian and DAEs
- Checking Numerical Integration of Equations of Motion
- Linear and Angular Momentum