Course description

Course objectives and student outcomes

This course covers elementary particle and rigid body dynamics — the study of how particles and rigid bodies respond to applied forces and/or torques. Although you should have some background in this subject from an earlier course in physics, this course provides a framework for the application of the principles of dynamics to much more complex systems than those you encounter in typical entry-level physics courses. Despite providing a framework for approaching more complex problems, this course is still limited in scope because we will deal almost entirely with greatly simplified systems using idealized elements and we will restrict ourselves to systems for which the resulting differential equations can be easily solved.

By the end of this course, you will be able to:

1. draw the Free Body Diagrams (FBD) of particles acting under the influence of applied forces;
2. recognize a non-rotating or rotating frame of reference in which the path of a particle is simple to describe;
3. select a coordinate system in which the position, velocity, acceleration, and jerk of a particle are easy to express;
4. recognize constraints on the motion of a particle;
5. combine the equations of motion and constraints into a set of equations sufficient to solve for all of the unknown quantities;
6. apply the separation-of-variables method to solve simple differential equations involving the motion of single particles;
7. predict the motion that results from a particular set of forces applied to a particle;
8. determine the forces required to cause a particle to follow a specified path;
9. extend items 1-8 above to systems of particles;
10. determine the position, velocity, and acceleration of one location on a rigid body in terms of another location on the same or another rigid body, the angular velocity of the body, and the angular acceleration of the body; and
11. extend items 1-8 above to one or more rigid bodies.

Caveat emptor

Numbers are not the focus of this course and you will be disappointed if you want or expect a course that simply shows you how to shove numbers into an equation. Rather, this course is intended to acquaint you with the tools you need to understand elementary dynamics and use that knowledge to analyze and design basic mechanical systems. Many students consider the study of dynamics to be one of the most challenging subjects in the entire engineering curriculum because it combines so many topics that are typically studied in isolation into a single arena in which all of those topics are important. Think of all the math you have studied over the past 14 years—elementary arithmetic, basic geometry, simple algebra, vector arithmetic, linear algebra, differential calculus, integral calculus, setting up and solving differential equations, etc. Now add physical objects—with real shapes, sizes, and mass properties—moving through the space-time continuum. Every single math tool you have ever learned will be used in this course to determine what causes an object to move (or constrains the movement), how to best describe the potentially complicated one-, two-, and three-dimensional paths that characterize the motion, how to predict the future behavior of the object, how design choices affect dynamics, and how dynamics affects design choices. Entire branches of mathematics have been developed specifically to talk about the field of dynamics.

In order to fit the discussion into 15 weeks, we will make many, many simplifying assumptions; e.g., only ideal entities such as particles and rigid bodies will be considered; gravity will usually either be ignored or considered constant; friction will often be ignored entirely; we will primarily concentrate on simple 1- and 2-dimensional motion; only certain types of forces will be considered; etc.

Although some of the material one needs to for this course was developed thousands of years ago, the foundation for the field of dynamics was laid by Isaac Newton (1643-1727) in his seminal work, *Philosophiæ Naturalis Principia Mathematica* (often referred to simply as *The Principia*) and this entire course is predicated upon Newton's observation that the force applied to a particle is proportional to the change in the linear momentum of the particle. Simple mathematical operations (like vector arithmetic), basic geometry, some algebra, and straight-forward applications of differential and integral calculus lead directly to everything else covered in the course. Not coincidentally, Newton is also responsible (along with Gottfried Wilhelm von Leibniz) for the branch of mathematics known as calculus.

For other major contributions, you can attribute geometry to Archimedes (287-211 BC) and his colleagues in Ancient Greece; algebra to Muhammad ibn-Musa al-Khwarizmi (780-850 AD); most modern mathematical notation, calculus texts, and the extension of Newton's work to rigid bodies to Leonhard Euler (1707-1783); the principle of dimensional homogeneity and the importance of the equal sign to Joseph Fourier (1768-1830); and vector analysis to Josiah Willard Gibbs (1839-1903).

Although the following quote comes from a text in a completely different field, it is worth including here because it addresses a truth that is applicable to all branches of engineering.

> It is difficult, if not impossible, for anyone to learn a subject purely by reading about it, without applying the information to specific problems and thereby being encouraged to think about what has been read. Furthermore, we all learn best the things that we have discovered for ourselves. Therefore the exercises form a major part of this work; a definite attempt has been made to keep them as informative as possible and to select problems that are enjoyable as well as instructive.[1].

Applying the sentiment expressed by the quote to the field of dynamics—you must repeatedly apply the theoretical concepts to practical problems. Assuming your goal is to really learn about the field of dynamics as opposed to simply clearing another hurdle on your way to graduation, there isn't a choice between following the theoretical development or doing exercises—you must do both. Following the development through either lectures and/or the text is essential to understanding the theory, the limits beyond which it does not apply, and the conditions under which specific equations do apply. Exercises then help you to apply that theory to solve real-world problems. As you encounter (the hopefully enjoyable, informative, and instructive) problems in the text, you will see that many may be solved multiple ways. While you should endeavor to apply the concepts from the sections that immediately precede the problems so you practice and learn new ways to solve problems, you are encouraged to think about other ways such problems may be solved and see if the solutions agree.

[1]Donald C. Knuth, *The Art of Computer Programming*, Volume 4A, Fascicle 5, Addison-Wesley, 2019, ISBN 978-0-13-467179-6, in Notes on the Exercises

Course details

Text: *Engineering Mechanics: Dynamics, 9th Edition* (9^{th} Edition); James L. Meriam, L. Glenn Kraige, and Jeffrey N. Bolton; John Wiley & Sons; 2018; ISBN: 9781119390985 (enhanced epub); 9781119390985 (ePub); $69/term (available from WileyPLUS via single sign-on through Blackboard. If you want a hardcopy for your bookshelf, the 9th edition is not that much different than the 8th edition which is not that much different than the 7th edition and so on. The 1st hit on a recent simple search for "meriam engineering mechanics dynamics" was a Google Docs version for the 7th edition found here (https://docs.google.com/file/d/0Bw8MfqmgWLS4V0NFR2dVUWpuYzg/edit?pli=1). If you don't have a Google account, your search will also return innumerable hits for pdf versions of various previous editions. The biggest difference between editions lies in the end-of-section problems so you will need access to WileyPLUS to complete the problem assignments.

Grading policies: *Homework*

- There will be weekly problem assignments delivered through WileyPLUS, the online content and learning platform associated with the text.
- The number of problems and associated points may vary from week-to-week, but all assignments will be equally weighted.
- You are encouraged to work together (which is admittedly difficult in the current environment) and teach one another. Piazza has been enabled for this course so you may discuss problems and share ideas asynchronously.
- Helping one another does not extend to copying someone else's work, allowing someone else to copy your work, doing assigned work for someone else, or allowing someone else to do the assigned work for you.
- Late homework loses 50% of the original value per day that it is late which means homework submitted after but within 24 hours of the due date/time can receive no more than 50% of the maximum score and homework submitted more than 24 hours late earns a score of 0.

Exams

- There will be four equally weighted exams given at roughly equal intervals. The last exam will be given on the day scheduled for the final exam. The first two exams will focus on particles and the last two exams will focus on rigid bodies.
- Since the timing of the exams depends on how quickly we can move through the material, it is impossible to provide exact dates for any exam other than the final exam which will be given in the day and time listed in the Schedule of Classes. You may expect exams at roughly monthly intervals and each exam will be preceded by an announcement of the exact day at least one week in advance of the exam.
- Many of you have similar schedules and your other courses will have their own exams. We will try to coordinate with the most common courses to avoid multiple exams on a single day.
- As the semester progresses, announcements will be posted on Blackboard anywhere between 7-14 days in advance of an exam to provide the exact date/time for each exam.

Final grade calculation

- Your homework average will provide 20% of your grade.
- Your exam average will provide 80% of your grade.

What do grades mean?

Unlike some classes, the average weighted score is not set to some specific letter grade with your letter grade assigned depending on how far your score falls from the mean. Instead, final course grades are determined based on your demonstrated mastery of the content and your ability to apply the theories and the ideas presented in lectures and readings to real-world problems. Accordingly, the following aspirational rubric is used to guide the assignment of course grades:

- A Performs to the highest standards; demonstrates a mastery of all course material and an ability to apply all aspects of the course content, theories and the ideas presented in lectures and readings to real-world problems; actively engages in class by paying attention and/or participation. Assignments are complete and on-time; grades on all assignments, exams, and discussion activities are consistently excellent.
- B Performs to high standards; demonstrates mastery of most course material and a frequent ability to apply aspects of the course content, theories and the ideas presented in lectures and readings to real-world problems; usually engaged in class. Assignments rarely incomplete and/or late; grades on assignments, exams, and discussion activities are normally good, but not excellent.
- C Performs to moderate standards; demonstrates incomplete mastery of most course material and a limited ability to apply aspects of the course content, theories and the ideas presented in lectures and readings to real-world problems; sometimes engaged in class. Assignments may occasionally be incomplete and/or late; grades on assignments, exams, and discussion activities are typically only fair.
- D Performs to low standards; demonstrates mastery of only a small fraction of the course material and an ability to apply only a few aspects of the course content, theories and the ideas presented in lectures and readings to real-world problems; rarely engaged in class. Assignments may often be incomplete and/or late; grades on assignments, exams, and discussion activities are often poor.
- F Performs to very low standards; fails to demonstrate mastery of any course material and shows almost no ability to apply aspects of the course content, theories and the ideas presented in lectures and readings to real-world problems; almost never engaged in class. Assignments frequently incomplete and/or late; grades on assignments, exams, and discussion activities are routinely poor.

With such a rubric, there is no reason that you—along with everyone else—can't receive an A in the course. Obviously, there is another side to this coin as well. The outcome is in your hands.

Course schedule

While not fixed in stone, the schedule in the table below roughly illustrates what we'll be discussing each week and the work you'll be expected to complete. We may not follow the exact sequence of topics in the text — depending on class progress, we might jump ahead at some points during the term or return to earlier material at other points — but this is the outline we will try to follow. Please read the relevant material in the text before we discuss it in class.

We will start with single particles and examine their kinematics, their motion as described by Newton's Laws, and how Newton's Laws lead to relationships between impulse and momentum and between work and energy. We will then introduce multiple particles and see how multiple particles affect Newton's Laws, the relationships between impulse and momentum, and the relationships between work and energy. Finally, we'll introduce the concept of a rigid body and see what happens to those same Newton's Laws, impulse/momentum relationships, and work/energy relationships when rigid bodies are involved.

Week-by-week schedule

The columns in the following table show the week of the term, the reading material for the week, the topics that will be discussed in class that week; the problem assignment for the week.

Week	Reading assignment	Lecture topics	Problem set
1	Text: Ch. 1 Bb: Vector review handout Bb: Separation of Variables handout	Nomenclature; ideal systems; problems solvable by SoV [$\ddot{s} = \ddot{s}(t)$, $\ddot{s}(s)$, or $\ddot{s}(\dot{s})$]; rectilinear motion	Set #1 [Review] (ungraded)
2	Text: Ch. 2 (§2.1-7) Bb: Coordinate systems handout	Curvilinear motion; Cartesian, intrinsic, cylindric, and spherical coordinate systems	Set #2
3	Text: Ch. 2 (§2.8-9)	Relative and constrained motion	Set #3
4	Text: Ch. 3 (§3.1-5) Bb: Systems of particles handout (§1-2)	$\mathbf{F} = \dot{\mathbf{L}}$ for single particles	Set #4
5	Text: Ch. 3 (§3.8-9, 11-12) Bb: Particle collision handout	Linear impulse/momentum; particle impacts	Set #5
6	Text: Ch. 3 (§3.10, 13)	Angular impulse/momentum; central force motion	Set #6
7	Text: Ch. 3 (§3.6-7) Bb: Conservative forces handout	Work/energy; power; conservative forces; potential energy	Set #7
8	Text: Ch. 4 (§4.1-7) Bb: Systems of particles handout (§3)	Closed systems of particles; force, energy, and momentum	Set #8
9	Text: Ch. 5 (§5.1-5)	Rigid body planar kinematics; abs. and rel. vel./acc.; Joints/contact conditions	Set #9
10	Text: Ch. 5 (§5.6-7)	Rotating frames	Set #10
11	Text: Ch. 6 (§6.1-4) Bb: Rigid body motion handout (§1-3)	$\mathbf{F} = \dot{\mathbf{L}}$ and $\mathbf{M}_O = \dot{\mathbf{H}}_O$ for rigid bodies in planar motion;	Set #11
12	Text: Ch. 6 (§6.5)) Bb: Rigid body motion handout (§1-3)	$\mathbf{F} = \dot{\mathbf{L}}$ and $\mathbf{M}_O = \dot{\mathbf{H}}_O$ 2-D constrained motion	Set #12
13	Text: Ch. 6 (§6.8) Bb: Rigid body motion handout (§4)	Impulse/Momentum for rigid bodies in planar motion; Rigid body impact	Set #13
14	Text: Ch. 6 (§6.6-7) Bb: Rigid body work/energy handout	Work/Energy for rigid bodies in planar motion	Set #14
15		Catch up, review, etc.	
—	Study and final exam period		