Engineering Mechanics 112H:
Mechanics of Motion
Course Information
Spring 2001

Professor Dr. Gary L. Gray
Associate Professor
Engineering Science & Mechanics

409C Earth-Engineering Sciences Bldg.
phone: 863-1778
email: gray@engr.psu.edu

Time/Place MWF 11:15–12:05, 118 (120?) Earth-Engineering Sciences Bldg.

Office Hours *Professor Gray:*
MW 10:00–11:00 a.m. or by appointment. To make an appointment, please see me at class time or contact me via email.

Textbook J. L. Meriam and L. G. Kraige (1997) *Engineering Mechanics: Dynamics*, 4th Edition, John Wiley & Sons, New York.

Objectives The primary objective in any introductory mechanics course is to develop in the engineering student the ability to analyze any problem in a simple and logical manner and to apply to its solution a few, well-understood, basic principles. This objective will be obtained by developing good problem solving skills (think before beginning the solution, ask what principles apply and critically judge your results), visualization skills (good free-body diagrams), and emphasizing basic principles (dynamics is not a sequence of independent methods for solving problems, but is a coherent class of techniques all based on Newton's laws). You will learn to develop and (sometimes) solve mathematical models describing the motion and forces of machines and structures that are of interest to engineers. In the formulation and solution of dynamics problems, you will learn which physical and mathematical assumptions are appropriate and those that are not. Finally, you will begin to develop the analytical capability necessary for tackling a wide variety of engineering problems as well as a way of thinking about the world that will allow you to model and predict its behavior.

Expectations In line with Penn State University's educational mission, both professors and students should be committed to nothing less than *academic excellence*. Therefore, just as the professor is responsible for attending every class period, so are you, the student, also responsible for doing so. Therefore, you are responsible for everything covered or announced in *every* class period. There are no exceptions.

In addition, each student is expected to have a working knowledge of the material covered in *all* prerequisite courses. That means you should know:

- Geometry and trigonometry, including the laws of sines and cosines, direction cosines, and the like.
- Statics. That is, how to draw correct free-body diagrams, find force and moment equilibrium, write friction laws, find support reactions, and find moments of inertia.

- Differential and integral calculus. That is, how to differentiate and integrate most simple functions, simple sequences and series.

You are also expected to devote sufficient time to master the course material. It is unreasonable to expect that good performance can be achieved without study and that is especially true for this course. The general "rule of thumb" stating that the student should devote **at least** two hours outside of class for every hour in class certainly applies to EMch 112H, though you will probably find this course to be more difficult than most.

Grading

Your grade will be determined by your performance. The latter will be evaluated without reference to that of your classmates. In other words, your performance will be evaluated using *objective* standards rather than standards based on a notion of average class performance (*i.e.*, **I do not grade on a curve**). Your grade will be based on a scale of 100 points. The following chart provides letter grade equivalents of your numerical grade:

A	A–	B+	B	B–	C+	C	D	F
93–100	90–93	87–90	82–87	79–82	76–79	68–76	60–68	< 60

Given this information, it should be apparent that you will always have all the information required to compute your current grade.

Grade Determination

The final exam in EMch 112H is **optional**. That is, during the last week of the semester you must choose one of the following two options regarding your final grade:

1. **Take the final exam.** Then your grade will be determined according to:

Category	*Percent of Grade*
Midterm Exams (3)	18% per exam
Homework	14%
Mini-Projects	14%
Final Exam	18%

2. **Do not take the final exam.** Then your grade will be determined according to:

Category	*Percent of Grade*
Midterm Exams (3)	24% per exam
Homework	14%
Mini-Projects	14%

   This second option is equivalent to saying that your grade on the final is the average of your grades on the three midterms without taking the final.

Therefore, if you are satisfied with your grade after the third midterm, then you can take that grade and not take the final. If not, then you can take the final to try and improve your grade. On the other hand, keep in mind that you can also hurt your grade by taking the final. A form will be handed out during the last week of class on which you will state your decision regarding the final.

Mini-Projects

Finally, we will be doing 2–3 mini-projects this semester. The projects will be done in teams, will involve some of the engineering tools used in the "real world", will cover the dynamics used in modeling and design, and will allow us to integrate some other areas of engineering and mathematics.

Exams

The midterms will be given in the evening on the dates shown on the Syllabus. In the event you are unable to attend one of the scheduled exams, please make every effort to notify me (by phone or email) before the exam. Generally, exams are missed because of a direct conflict, in which case you will take the same exam as everyone else on the same day as the exam. If you miss an exam for a legitimate reason and can't take it on the same day as the exam, I will administer an *oral makeup exam*.

An equation sheet will be handed out the first day of class. You will be allowed to use it for each exam and for the final exam. Please let me know if there is anything you would like to see added to the equation sheet—I will grant all reasonable requests.

Homework

You will receive your homework assignments by email every Friday. At the *beginning* of every Friday class, one of you will roll a die to randomly determine which problem you will turn in that week to be graded.

General Info

- **Bring your textbook to every class**. I will work many example problems out of the text and you will not be able to keep up if you don't know what problem I am working. In addition, I can work more examples if I don't have to draw every figure on the board.
- I cannot emphasize enough how important it is for you to attempt all the homework and keep pace with the class. If you do not keep pace with the class, attempt the homework, and regularly attend class you will have a very difficult time. I would like to see every student do the following:
  1. Read the section that is to be covered in class *before* the class. Also take a look at the assigned homework problems before attending class.
  2. Attend class and see what I have to say about the current topic. Doing Step 1 will help you understand the examples I work in class.
  3. Read the section one more time after class and then try the homework problems. See me if there are problems you can't get after an honest effort.

EMch 112H: Mechanics of Motion

Course Syllabus Spring 2001

Exam	*Date*	*Location*
Exam 1	Tuesday, February 13, 6:30–7:45 p.m.	262 & 362 Willard
Exam 2	Tuesday, March 27, 6:30–7:45 p.m.	101 & 112 Chambers
Exam 3	Monday, April 23, 6:30–7:45 p.m.	111 Forum
Final Exam	Time and date will be announced.	TBD

Reading (Ch./Sect.)	**Topic**
1	Course Introduction, Review, Preliminaries
	Dynamics of Particles
2/1–2/4	Kinematics: Rectilinear Motion, Plane Curvilinear Motion, Rectangular Coordinates
2/5	Kinematics: Normal-Tangential or Path Coordinates
2/6	Kinematics: Radial-Transverse or Polar Coordinates
2/8	Motion Relative to Translating Axes
2/9–2/10	Constrained Motion of Connected Particles ("Pulley Problems") and Review
3/1–3/4	Kinetics: Newton's 2nd Law, Equations of Motion, Rectilinear Motion
3/5	Kinetics: Curvilinear Motion in the Plane
3/6	Kinetics: Work, Kinetic Energy, and the Work-Energy Principle
3/7	Kinetics: Potential Energy and Conservation of Mechanical Energy
3/8–3/9	Kinetics: Linear Impulse and Momentum and the Impulse-Momentum Principle
3/10	Kinetics: Angular Impulse and Momentum and Conservation of Angular Momentum
3/11–3/12	Special Topic: Particle Impact
4/1–4/5	Kinetics of Systems of Particles
	Dynamics of Rigid Bodies
5/1–5/2	Rotation
5/3	Differentiating Constraint Equations: Absolute Motion
5/4, 5/6	Relative Velocity and Relative Acceleration
6/1–6/5	Equations of Motion for Rigid Bodies
6/6	Work-Energy Principle for Rigid Bodies
6/8	Impulse-Momentum Principle for Rigid Bodies
	Special Topics (Time Permitting)
4/6–4/7	Steady Mass Flow and Variable Mass Systems
5/7	Motion Relative to Rotating Axes
8/1–8/4	Introduction to Vibrations of Particles and Rigid Bodies

Equation Sheet for EMch 112H
Mechanics of Motion

Miscellaneous

If $ax^2 + bx + c = 0$, then $x = \left(-b \pm \sqrt{b^2 - 4ac}\right) \Big/ 2a$.

Rectilinear (1-D) Motion

Position: $s(t)$; Velocity: $v = \dot{s} = ds/dt$; Acceleration: $a = \ddot{s} = dv/dt = d^2s/dt^2 = v dv/ds$. For *constant acceleration* a_c:

$$v^2 = v_0^2 + 2a_c(s - s_0) \qquad v = v_0 + a_c t \qquad s = s_0 + v_0 t + \tfrac{1}{2} a_c t^2$$

There are corresponding equations for constant angular acceleration α.

2D Motions—Cartesian Coordinates

Position: $\vec{r} = x\,\hat{\imath} + y\,\hat{\jmath}$; Velocity: $\vec{v} = d\vec{r}/dt = \dot{x}\,\hat{\imath} + \dot{y}\,\hat{\jmath}$; Acceleration: $\vec{a} = d\vec{v}/dt = d^2\vec{r}/dt^2 = \ddot{x}\,\hat{\imath} + \ddot{y}\,\hat{\jmath}$

2D Motions—Normal-Tangential (Path) Coordinates

$$\vec{v} = v\,\hat{e}_t = \rho\dot{\beta}\,\hat{e}_t \qquad \vec{a} = \dot{v}\,\hat{e}_t + (v^2/\rho)\,\hat{e}_n,$$

2D Motions—Polar Coordinates

$$\vec{r} = r\,\hat{e}_r \qquad \vec{v} = \dot{r}\,\hat{e}_r + r\dot{\theta}\,\hat{e}_\theta \qquad \vec{a} = (\ddot{r} - r\dot{\theta}^2)\,\hat{e}_r + (r\ddot{\theta} + 2\dot{r}\dot{\theta})\,\hat{e}_\theta$$

Relative Motion

$$\vec{r}_B = \vec{r}_A + \vec{r}_{B/A} \qquad \vec{v}_B = \vec{v}_A + \vec{v}_{B/A} \qquad \vec{a}_B = \vec{a}_A + \vec{a}_{B/A}$$

Newton's Second Law

$$\vec{F} = m\vec{a}; \quad F_x = ma_x; \quad F_y = ma_y; \quad F_n = ma_n; \quad F_t = ma_t; \quad F_r = ma_r; \quad F_\theta = ma_\theta$$

Work-Energy Principle

$$U_{1-2} = \int_{\text{path}} \vec{F} \cdot d\vec{r} \qquad T = \tfrac{1}{2}mv^2 \qquad T_1 + U_{1-2} = T_2$$

$$V_g = mgh \qquad V_e = \tfrac{1}{2}k\delta^2 \qquad T_1 + V_{g1} + V_{e1} + U'_{1-2} = T_2 + V_{g2} + V_{e2}$$

Linear Impulse-Momentum Principle

$$\vec{G} = m\vec{v} \qquad \vec{F} = \dot{\vec{G}} \qquad m\vec{v}_1 + \int_{t_1}^{t_2} \vec{F}\,dt = m\vec{v}_2$$

Angular Impulse-Momentum Principle

$$\vec{H}_O = \vec{r}_{P/O} \times m\vec{v}_P \qquad \vec{M}_O = \dot{\vec{H}}_O \qquad \vec{H}_{O_1} + \int_{t_1}^{t_2} \vec{M}_O\,dt = \vec{H}_{O_2}$$

Impact of Smooth Particles

$$m_1(v_1)_n + m_2(v_2)_n = m_1(v_1')_n + m_2(v_2')_n; \quad (v_1)_t = (v_1')_t; \quad (v_2)_t = (v_2')_t; \quad e = \frac{(v_2')_n - (v_1')_n}{(v_1)_n - (v_2)_n}$$

Systems of Particles

$$\sum \vec{F} = m\vec{a}_G \qquad T_1 + V_{g1} + V_{e1} + U'_{1\text{–}2} = T_2 + V_{g2} + V_{e2}$$

$$T = \tfrac{1}{2}mv_G^2 + \sum \tfrac{1}{2}m_i|\dot{\vec{\rho}}|^2 \qquad \vec{G} = m\vec{v}_G$$

$$\sum \vec{M}_O = \dot{\vec{H}}_O \qquad \sum \vec{M}_G = \dot{\vec{H}}_G$$

$$\sum \vec{M}_P = \dot{\vec{H}}_G + \vec{r}_{G/P} \times m\vec{a}_G \qquad \sum \vec{M}_P = (\dot{\vec{H}}_P)_{\text{rel}} + \vec{r}_{G/P} \times m\vec{a}_P$$

Rigid Body Kinematics

$$\vec{v}_B = \vec{v}_A + \vec{v}_{B/A} \qquad \vec{a}_B = \vec{a}_A + \vec{a}_{B/A}$$

$$\vec{v}_B = \vec{v}_A + \vec{\omega} \times \vec{r}_{B/A} \qquad \vec{a}_B = \vec{a}_A + \vec{\alpha} \times \vec{r}_{B/A} + \vec{\omega} \times (\vec{\omega} \times \vec{r}_{B/A})$$

$$\vec{a}_B = \vec{a}_A + \vec{\alpha} \times \vec{r}_{B/A} - \omega^2 \vec{r}_{B/A}$$

Moments of Inertia

$$(I_G)_{\text{disk}} = \tfrac{1}{2}mr^2 \qquad (I_G)_{\text{rod}} = \tfrac{1}{12}ml^2 \qquad (I_G)_{\text{plate}} = \tfrac{1}{12}m(a^2 + b^2) \qquad (I_G)_{\text{sphere}} = \tfrac{2}{5}mr^2$$

Parallel Axis Theorem: $I_A = I_G + md^2$; Radius of Gyration: $I_A = mk_A^2$

Angular Momentum and Equations of Motion for a Rigid Body

Angular Momentum

$$\vec{H}_G = I_G\vec{\omega} \qquad \vec{H}_O = I_G\vec{\omega} + \vec{r}_{G/O} \times m\vec{v}_G$$

Equations of Motion

The *translational equations* are given by

$$\sum \vec{F} = m\vec{a}_G$$

The *rotational equation*. For the mass center G: $\sum M_G = I_G\alpha$ and for a fixed point O: $\sum M_O = I_O\alpha$. For an arbitrary point A:

$$\sum \vec{M}_P = I_G\vec{\alpha} + \vec{r}_{G/P} \times m\vec{a}_G \qquad \sum \vec{M}_P = I_P\vec{\alpha} + \vec{r}_{G/P} \times m\vec{a}_P \qquad \left(\vec{M}_A\right)_{\text{FBD}} = \left(\vec{M}_A\right)_{\text{KD}}$$

Work-Energy for a Rigid Body

The work-energy principle is the same as that for particles. The kinetic energy of a rigid body is:

$$T = \tfrac{1}{2}I_O\omega^2 \qquad T = \tfrac{1}{2}mv_G^2 + \tfrac{1}{2}I_G\omega^2$$