Lecture 1 – Introductory Material

Administrative Information

Reading for Next Class: Chapter 1, Chapter 2/1 and 2/2
Homework 1: Download from WEBCT, Due Monday August 29, 2005
Diagnostic Test for Accreditation (30 min today)

A. Introduction, Class Organization, and Grading

1. Background on Me!

If you care about my background and interests you can visit my website at www.coe.uncc.edu/~madavies. However, I have a secret counter to see how many of you visit, so that I can feel sorry that you don't have anything more interesting to do! There is however a stunning picture of me in a nice pink tie (from a bad tie contest at a conference a few years back). I still have the tie if anyone wants to borrow it.

2. Teaching Style and Philosophy

Well, I have taught Dynamics I enough times now that I suspect that you know more about how I teach, my homework assignments and my exams than I do. But just in case…I think my teaching style can be characterized as fair – I am not aiming to give lots of "D" and "F" grades, but I do want you to learn something, and I will reward effort. I am probably not an easy professor, but probably not the hardest you've ever had either. DYNAMICS IS HOWEVER A HARD SUBJECT AND IT TAKES A LOT OF PRACTICE! I like to encourage you to talk to me whenever you have difficulties and to give me input about how the class is going because that is the only way I can improve. Dynamics is my favorite engineering subject, and hopefully I can help make it one of your favorites as well. However, you will have to think a lot and practice a lot if you really want to understand it.

3. Dynamics & Statics – what is the difference and why should you care?

If I try to put it in simple language, *Statics* is the study of things that don't move …when something doesn't move the forces on it are balanced…and a Statics course teaches you the techniques for calculating the relationship between forces on objects that don't move. When something doesn't move we say it is in *Static Equilibrium*. The name Statics is a little deceiving though, because things that don't accelerate but do move at constant velocity are also in "static" equilibrium! In *Statics*, you should have become very familiar with the concept of static equilibrium, free-body diagrams, and the balance of forces. You should remember that forces have both *magnitude* and *direction*, and remember that things that have magnitude and direction re called *vectors*. You should already be very familiar with vectors, but in case you are not completely comfortable, I am going to have an optional vector review class in a couple weeks. A good understanding of *Statics* allows you to calculate the forces in many situations that are very important in engineering. When you know what forces are required, you can decide how "strong" to make the things that provide these forces – this is design. In fact, you try to make the things that provide the forces strong enough, but not overly strong, otherwise you end up over-engineering and probably spending too much money on a project. Of course, your judgment comes in when you decide just how close to cut your designs making them as inexpensive and elegant as possible without making them likely to fail in response to small unexpected additional disturbances forces.

In equally simple language, *Dynamics* is the study of things that do move in such a manner that the motion cannot be ignored. When the forces on an object are not balanced, the object will accelerate. The magnitude and direction of the accelerations that occur and the relation of these accelerations to the position and velocity of engineering objects is what this course is about. Because the ability to determine the acceleration of an object first involves the ability to determine just how "out of balance" the forces that act on it are, you will find that your understanding of *Statics* is critical for and closely related to your understanding of *Dynamics*. As it says in the first chapter of your textbook, engineering originally focused to a very great extent on *Statics*. In fact, the comment on the top of page 4 in your book states that the first real engineering device that utilized dynamic analysis to a great extent was the pendulum clock invented by Huygen's in 1657! Of course the application that drove the development of the understanding of *Dynamics* as a scientific discipline was probably the understanding of how the planets move around the sun…or even realizing that the planets do move around the sun and not around the Earth as was first thought.

The practical engineering importance of *Dynamics* has increased rapidly in recent years, particularly with the use of computers in control systems, since these allow for very complicated motions of equipment with high velocities and high accelerations. In addition, efficient use of materials is important in designing air, land and sea vehicles is critical as people look for the most efficient solutions to problems…for example race cars or aircraft that can move as fast as possible for as long as possible without refueling or failing. The critical thing to remember here is that when something accelerates the forces it experiences are substantially higher than the forces it would experience in *Static* equilibrium. Therefore, if you can't determine those forces, you can't design your structure or device to handle them, and you either over-engineer the system or your system fails. A common example that you may be familiar with is the force on your leg when you run versus stand still.

Example: Estimate the force on the leg of a 75 kg person who is (1) standing; (2) running.
<u>Case 1: Static</u> The static force on a person standing is ½ of their weight on each foot.

$$
\begin{aligned}
F_{static} &= W/2 \\
F_{static} &= mg/2 \\
F_{static} &= 75kg \cdot 9.81 m/s^2 / 2 \\
F_{static} &\cong 370N
\end{aligned}
$$

<u>Case 2: Dynamic</u> The dynamic force on a person running is a little harder to estimate and it requires you to make some reasonable approximations and to think about what is happening – as well as remembering some of your Phys 2101.

The dynamic force on a person's foot as they land is their whole static weight (assuming they land on the forward foot) plus the acceleration multiplied by their mass (Newton's second law F=ma).

$$F_{total} = F_{static} + F_{dynamic}$$
$$F_{total} = W + ma$$

Now what is the acceleration of someone if they land on a running shoe. Well the acceleration is the change the speed divided by the change in time (rate of change of speed). Suppose a person's center of mass goes up and down by a distance d=0.2m as they run. Then the speed as their foot hits the ground can be found by conservation of energy (change in kinetic=change in potential).

$$v_{impact} = \sqrt{2gh}$$
$$v_{impact} = \sqrt{2 \cdot 9.81 m/s^2 \cdot 0.2 m}$$
$$v_{impact} = 1.98 m/s$$

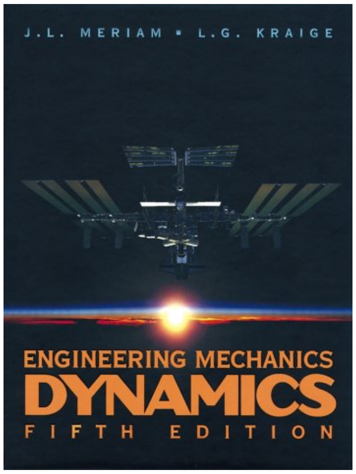
The acceleration is estimated by dividing the impact speed by the approximate time to go from the impact speed to zero speed. This is probably about a twentieth of a second or so; this is how you make reasonable guesses, something you should become more and more familiar with as you go on in your career.

$$a = v_{impact} / \Delta t$$
$$a = 1.98\ m/s / 0.05s$$
$$a = 39.6 m/s^2$$

So the final estimated force of impact is as follows.

$$F_{total} = 740N + 75kg \cdot 39.6 m/s^2$$
$$F_{total} = 3710N$$

So the dynamic force during running is ten times the static force in standing! If you are a runner, you have probably heard this before. It is true and as you can see, if you are a shoe designer, a static analysis is clearly not enough. *Dynamics* is important!



4. The Textbook

The textbook for the course is Merriam and Kraige, Edition 5 (see picture). We get a lot of complaints about the textbook in this course and I think some are justified while others are probably inevitable no matter which textbook we use. The book is well organized and has very good problems.

5. Grading

The grading is divided as follows.

- 3 exams – 20% each
- 1 comprehensive final – 30 %
- homework – 10%
- other (quizzes, MATLAB etc) – 5%

The homework will receive numerical grades. The homework is important and is due approximately every two lectures. The lectures will alternate between descriptions of theory and lectures dedicated to example problems and demonstrations where possible. The homework problems will be assigned the day I describe a new aspect of the theory, but you will get a problem lecture before that homework is due, so hopefully the problem lecture will come when you are thinking about the homework problems for the next lecture and the examples will be similar to some of the homework problems.

6. Computer Use

There are two main uses of the computer in this class.

1. WEB CT
2. MATLAB

You are responsible for using WEB CT to do the following:

a. Obtain Class Announcements and Information, HW Assignment Downloads, Class Notes,
b. Online Help Sessions,
c. Check class emails.

Some announcements may only be made on WEB CT so you are responsible for checking it frequently.

7. Class Improvement Committee

The Class Improvement Committee (CIC) is a voluntary group of three of four students with the following responsibilities.

1. Meet with each other once a week for 15 minutes,
2. Meet with me up to once every two weeks and report about the class – make suggestions about how to improve the class,
3. Conduct class surveys as necessary to provide feedback on the class quality.

When you meet with me I will buy coffee and snacks for the committee.

Let me know if you would like to volunteer for the CIC.

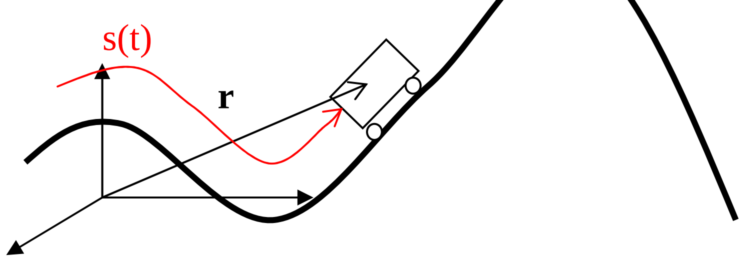
B. Basic Definitions & Coordinate Systems

(Supplemental – read but not covered in class)

Dynamics is the study of particles or bodies in motion. These objects move in 3 dimensional space which we describe by a set of coordinates – e.g Cartesian (rectangular), polar or spherical – and these coordinates change with the passage of time.

So consider some examples…
(1) A roller coaster car – constrained motion in three dimensions best described by a vector represented in a Cartesian coordinate system with three time dependent coordinates x(t), y(t) and z(t). Because the car is constrained to move on the track, it only has one degree-of-freedom (think of these as variables that can change independently and arbitrarily), the distance it travels along the track s(t) and so the problem can be simplified by looking at that coordinate only.

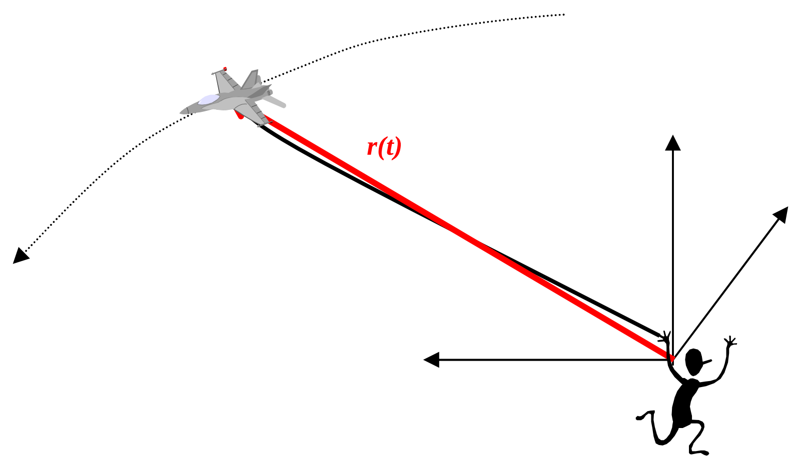
$$\mathbf{r} = x(t)\mathbf{e}_x + y(t)\mathbf{e}_y + z(t)\mathbf{e}_z$$



Unit vectors in the *x*, *y* and *z* directions. You may be used to **i**, **j**, and **k**. In my notes, I use **e** with a subscript to represent unit vectors so that all of the coordinate systems that we use will be consistent.

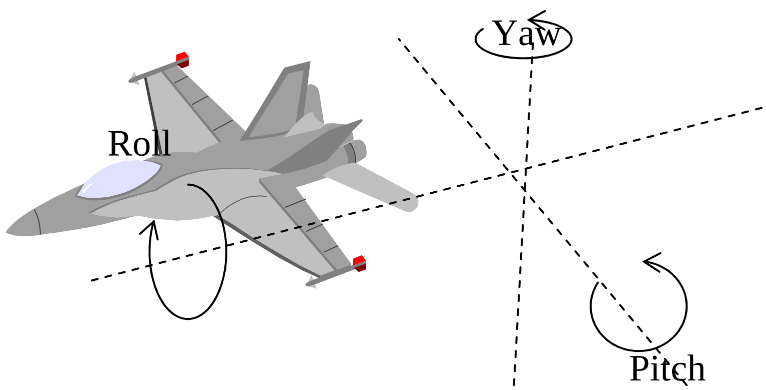
$$\mathbf{i} \Leftrightarrow \mathbf{e}_x$$
$$\mathbf{j} \Leftrightarrow \mathbf{e}_y$$
$$\mathbf{k} \Leftrightarrow \mathbf{e}_z$$

(2) The motion of a toy plane on a string – best described by a vector represented in polar coordinates, r(t), θ(t), z(t) that points to the plane's center of mass.

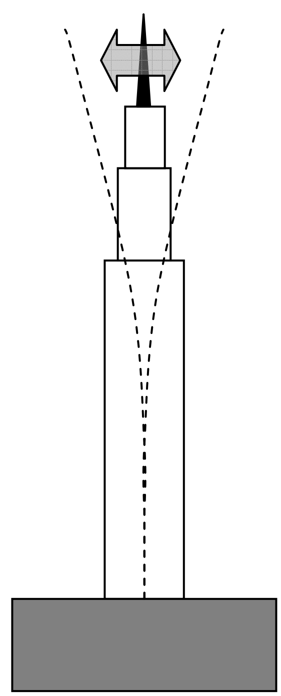


In this case, the plane is treated as a particle with two independent degrees of freedom because it must move on a sphere of fixed radius R. Alternately the vector might be represented in spherical coordinates – $r(t)$=R, $\theta(t)$, $\phi(t)$ where the angles θ(t) and ϕ(t) represent its degrees of freedom.

(3) Suppose we wanted to look at the motions of the flight of the plane in detail. Then, we have to treat the plane as a rigid body with three coordinates that describe the location of its center of mass (x(t), y(t), z(t)) and three additional angles that describe its orientation with three additional angles. If you proceed to more advanced dynamics classes you might also describe this orientation with so-called *Euler angles*. They can be defined in a number of other ways. The familiar definitions sometimes used are roll, pitch and yaw. If the plane is assumed to be a rigid body, these three additional angles or degrees-of-freedom are all that is necessary to fully describe its motions. If the plane is moving on a string then its coordinates must be consistent with the plane moving on a sphere. If it is not constrained by the string, the plane can be considered as a rigid body that six degrees of freedom, three positions and three angles.



(4) Another problem might be the vibrations of a large skyscraper under wind loading. In theory, this actually has an infinite number of degrees of freedom because the body cannot be treated as rigid and therefore every particle has the ability to move independently, and there is a VERY, VERY LARGE NUMBER OF these particles. However, in practice the building has a limited number of modes and can therefore be treated as having limited degrees-of-freedom. For example, consider the motion a string suspended between two points – if you use your imagination, you might convince yourself that this could be a crude model for a bridge span. When we pluck it we see that the first mode dominates. That first mode looks like (and is) one hump of a sinusoid.



C. Newton's Laws of Motion

The motions these examples are caused by the action of forces. What governs the actions and results of these forces is Newton's three laws of motion.

Law 1: A body at rest remains at rest or continues to move in a straight line with a constant velocity if there is no unbalanced force acting upon it.

Law 2: The acceleration of a body is proportional to the resulting force acting on it and is in the direction of this force.

Law 3: The forces of action and reaction between interacting bodies are equal in magnitude, opposite in direction and collinear.

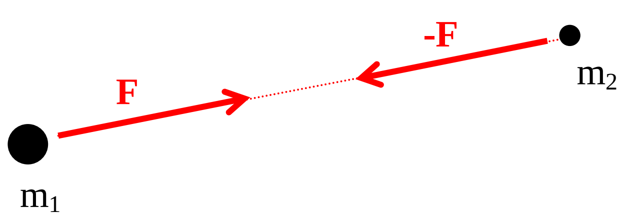
These laws **come from experimental observations** and are valid for velocities whose magnitude does not approach the speed of light ($2.998\text{x}10^8$ m/sec). The first is a consequence of the second which can be written in the following way.

$$\mathbf{F} = m\mathbf{a} \tag{1}$$

Here **F** is the vector sum of all of the forces acting on the body, **a** is the resultant acceleration vector, and *m* is the mass of the particle. If *m* is the mass in kg, and **a** is measured in m/s^2, then the force is in Newtons ($kg\text{-}m/s^2$). This is the most important law of engineering mechanics – although sometimes you won't believe it, everything we do in this class and in any future dynamics or vibrations classes is a consequence of these laws.

D. An Example of Forces – the Gravitational Force Law

Now one of the most fundamental and important forces for engineers and physicists is the force of gravity exerted by one body on another. Consider two bodies, one of mass m_1 and the other of mass m_2. The force of gravity between them acts along the line connecting them (collinear), is equal in magnitude and opposite in direction.



The magnitude of the force is given by an inverse square law which has also been empirically verified.

$$F = \frac{Gm_1 m_2}{r^2} \tag{2}$$

where G is the universal gravitational constant (see book) and r is the distance between the particles. Recall from your physics classes that this is the same form of law that governs the electrostatic force between two charged particles.

$$\left(F = \frac{kq_1q_2}{r^2} \right)$$

E. Writing Equations and Checking Your Units?

I know you have been told this before, but it really is critical to check your units when you are working with equations. This becomes more and more important in topics such as dynamics because the equations become more complex and there is more room to make mistakes. The famous physicist Richard Feynman said that it was possible to derive many of the basic laws of physics from units alone.

Why should I use Equations? I would rather just plug in the numbers as soon as possible and drop the units altogether!

In my experience, it is also tough to convince you to drop this belief, but you should. When you keep your variables in your expressions as long as possible there are a number of important benefits.

1. *You can check the physics of the equation* and see whether you have made mistakes. For example if you are working on the expression for the drag on an ball you KNOW without taking any classes, that if the AREA goes up, the DRAG FORCE should also go up. If the equation you are working on does not agree, then you made a mistake in deriving the equation. *A very powerful way to think about this is to imagine that quantities get very big and see what happens to the equation.* For example ask what if the area gets really big, does the drag get really big too. Once you get used to it, these are very easy questions to answer and they keep you from carrying your mistakes and wasting time.
2. You eliminate the risk of writing down numbers wrong…particularly if you are like me and you accidentally change the order of numbers or put the decimal in the wrong place.
3. *Equations are very powerful for design.* You can ask how the things you can change in you design affect the things you care about.
4. *Equations often can save you from having to do expensive simulations or prototype experiments* until you are already pretty sure about what will happen.

Checking Units

Checking Units is the fastest and easiest way to check your answer. The Units that are used most frequently in Dynamics are given in the table below. The SI and English units are given even though I prefer SI units because they are easier to deal with.

Unit Type	SI	English
Mass	Kilogram (kg)	Slug (sl)
Length	Meter (m)	Foot (ft)
Time	Second (s)	Second (s)
Force	Newton (N) (1N=1kg-m/s^2)	Pound (lb) (1 lb=1 sl-ft/s^2)

Not only is unit checking good on exams, but you can use it to impress your friends. Suppose you are at a high-class sorority party at Duke University and some overconfident Medical Student is claiming that those new body-swimsuits for the Olympics are good because they keep the heat in the muscles so they don't cramp up. However, you know that the real reason is that they decrease the drag on the swimmer. But your friends don't believe you. You know that if you could just rattle off some mathematical formula for the drag to back you up, you would win the argument and shut up the Med Student, but since you haven't taken Fluid Mechanics and you are a careful Charlotte student (not an overconfident Dukie). You don't know what to do.

Then you remember how Dr. D. told you about units and while you are drinking your Koolaid™, you think to yourself … the drag force should depend on the density of the water, the speed of the swimmer, the overall area of the swimmer, and the fluid effects like viscosity/friction. You know that if any of these things go up, the drag should go up and then you also remember from a motorsports talk that there is some unitless quantity that can be measured called a drag coefficient that takes into account the fluid friction effects and the general shape of the object. You quickly put this together in your head (with the help of the Koolaid you are drinking) and get the following.

$$Drag = C_D A \rho v$$

C_D is the unitless drag coefficient you heard about ρ is the density of the water, v is the swimmers speed, and A is the swimmer's surface area. You've done all this in a few seconds, and the Dukie is now saying that Doctors are smarter than engineers because they invented this swimsuit idea. You need to hurry before everyone is swept away by her apparent greatness…you want to check the units on your equation before you jump out with it. You just have to check the units on your equation and you are ready to drop your bombshell on the loudmouth Med Student.

$$Drag = C_D A \rho v$$
$$\text{Drag} = \text{Unitless} \cdot \text{Area} \cdot \text{Density} \cdot \text{Velocity}$$
$$\text{Drag} \Rightarrow m^2 \cdot \frac{kg}{m^3} \cdot \frac{m}{s} = \frac{kg}{s}$$

But…Dr. D. said that force was kg-m/s^2…so did Newton … F=ma … Man, what a stupid class! What good is dynamics anyway! …. But, wait a second … if the speed is squared … you "sort of" remember v^2 from the motorsports talk … then …

$$Drag = C_D A \rho v^2$$
$$\text{Drag} = \text{Unitless} \cdot \text{Area} \cdot \text{Density} \cdot \text{Velocity}^2$$
$$\text{Drag} \Rightarrow m^2 \cdot \frac{kg}{m^3} \cdot \frac{m^2}{s^2} = \frac{kg - m}{s^2} \Rightarrow N \text{ Force!}$$

You go public with your explanation[1]. Everyone is so impressed they spend the rest of the party being depressed about paying so much to go to Duke instead of Charlotte and wondering why they are Med Students instead of engineers. You just drink the rest of your Koolaid™, and tell them that at least they have really pretty buildings at Duke.

[1] You forgot a ½ in your equation but luckily no one (even you) noticed because it has no units!