FIRST LECTURE: Coordinates, Mass, Inertia, Gravity & ‘cg’

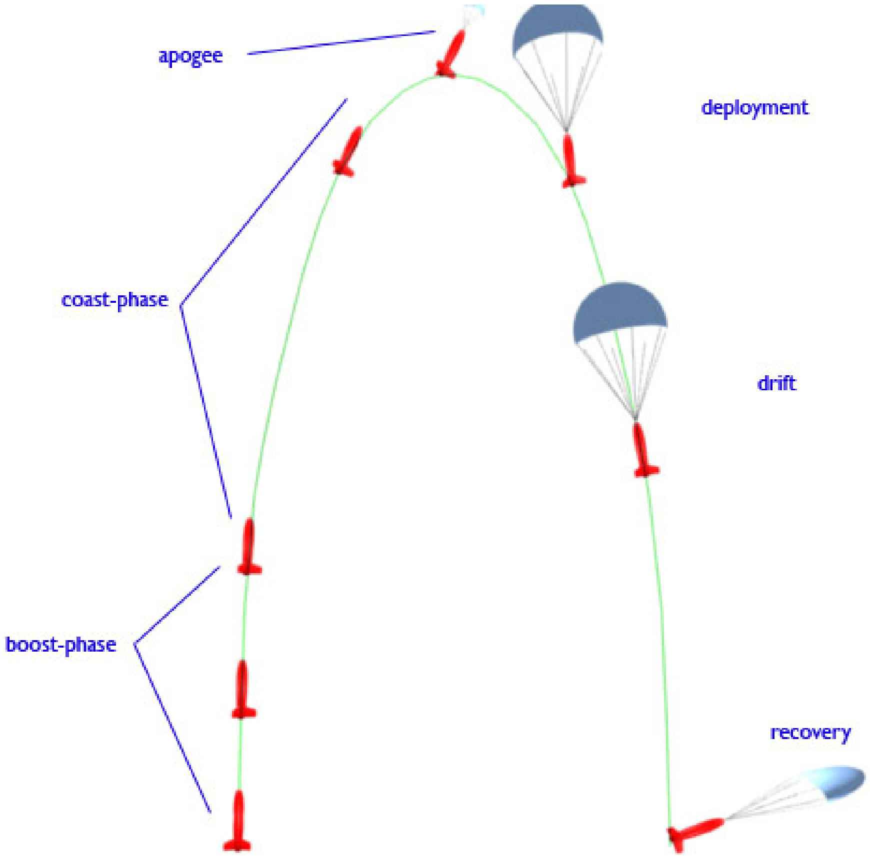
The motion of an object in response to an external force was first accurately described over 300 years ago by Sir Isaac Newton, using his three laws of motion. Engineers today use Newton's laws (among many scientific theories) to design and predict the flight of full scale rockets and today of course they have computers and calculators. The principles YOU WILL LEARN are the very foundation of these theories.

In the lessons that follow, we’re going to learn how to CALCULATE these forces, to PREDICT the flight of our own model rockets. Why do we need to do this? Why not just pop in the biggest engine we can find, and ‘light the fuse’?

This is an actual picture of a U.S. Navy Trident missile that went out of control just after a test launch from a submarine off the coast of Cape Canaveral several years ago. The missile exploded shortly after this photo was taken. There was no injury to the submarine or its crew, although family members of the crew who had been invited to watch the launch from a nearby ship (from which this photo was taken) were understandably quite upset. The submarine captain, watching the test through the sub's periscope, was reported to have been mesmerized for several hours.

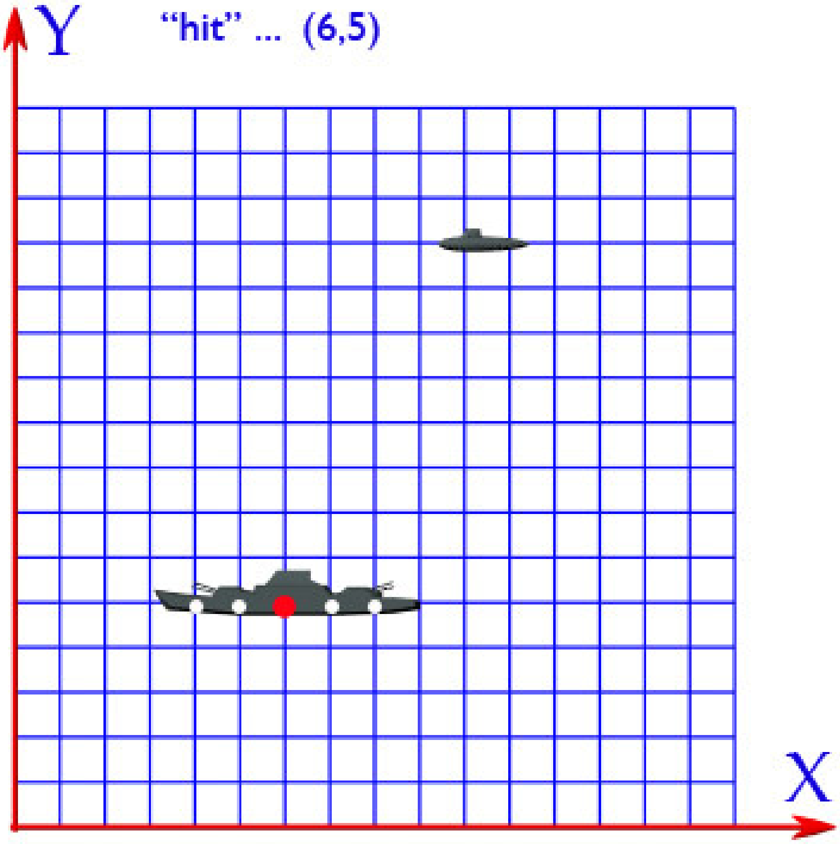
This is what was left of a normally very reliable Titan IV rocket that exploded on the morning of August 12, 1998, spectacularly lobbing a billion-dollar, top-secret "Mercury" spy satellite into the Atlantic just off the Cape Canaveral beach. The explosion occurred 40 seconds after launch at an altitude of about 20,000 feet and was loud enough to set off car alarms 20 miles away. Investigators suspected a failure of a part of the solid rocket booster. The salvage operations were the largest ever except for those for the Challenger disaster. For weeks afterward parts washed ashore on Space Coast beaches.

Here's a very simple picture below of what your rocket will do—if you build it properly—if you launch it during proper weather conditions—and if the engine and recovery systems perform "to spec." Can you see the shape of the path of the rocket—called its trajectory—in figure 1? This is a very beautiful geometric form first described by the ancient Greeks—called a parabola.



As it turns out, once we understand and we can begin to make good assumptions about the forces that govern our rocket's motion, we'll be able to see how rocket trajectories can be predicted. Building upon this foundation and continuing your studies, you will also be able to recognize other more complicated trajectories that NASA engineers use to determine how to make a rocket payload go into orbit, or to go from one planet to another.

But first, we need to understand a few basics. Let's begin with a fun example of a game that we've probably all played, called "Battleship." What's this got to do with our rockets? It will help us understand the concepts of COORDINATE SYSTEMS—one of the most basic ideas that we'll need.



You'll notice our battleship has been "hit" –at coordinates (6,5)–corresponding to the larger dot smack in the middle—a great shot! Now what I want you to do is COUNT from the bottom left-corner by ones' along the "X" axis, until you get to the big dot. "6" right? Do the same up the "Y" axis also until you get to the dot. Did you get "5"?

That's all there is to it. We WRITE the COORDINATES, little "x" first, a comma, and then little "y", and then we surround them with PARENTHESES, like THIS (6,5).

The only thing I haven't told you about this coordinate system, is, what is a "unit" worth? The answer is… anything you want to measure, in this case, you might want to set a unit equal to about 100 linear feet, since a (big) battleship is about 600 feet long!

OK, now just to be sure you have this coordinate thing down, I want you to look again at the figure and WRITE YOUR ANSWERS to the questions below:

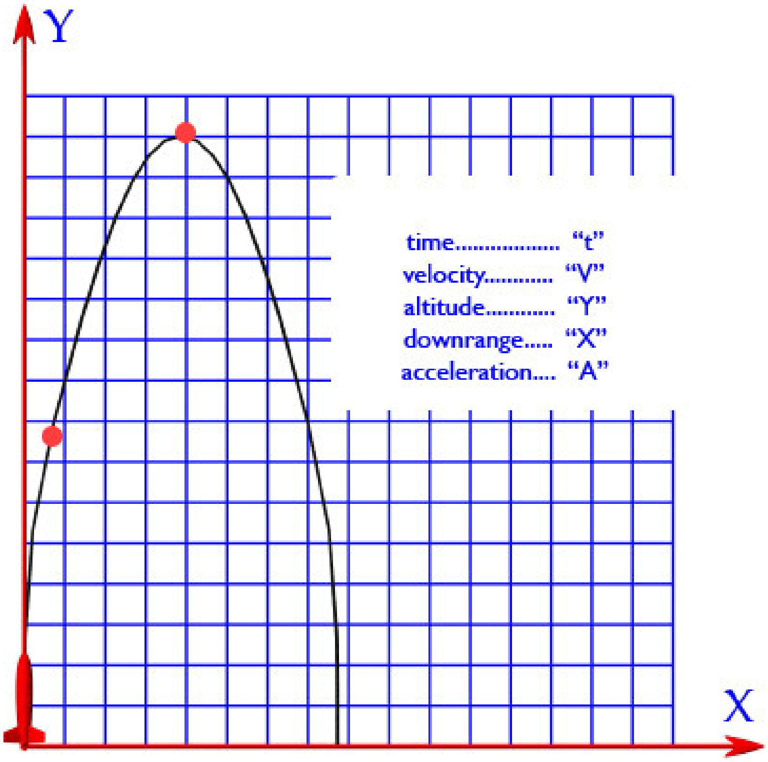
PROBLEM 1: What are the coordinates of the FOUR other "shots" we'll have to make to sink the battleship?

(,) (,) (,) (,)

PROBLEM 2: How many hits will you need to sink the smaller submarine?
what are the coordinates of those hits?

ANSWER ______ hits (,) (,) coordinates

Now here's a picture (below) of our coordinate system and as you can see I've set it up just behind the picture of our earlier rocket's trajectory. Do you notice how the coordinates of the ORIGIN ("0,0" or the left-bottom corner) have been placed directly at the launch position?



I’ve marked THREE POSITIONS that might be of interest: the LAUNCH position; the first ‘dot’ –the point of the trajectory at a time when the rocket engine has used up all of its propellant; and, the second dot or ‘apogee’ (highest altitude) our rocket will reach.

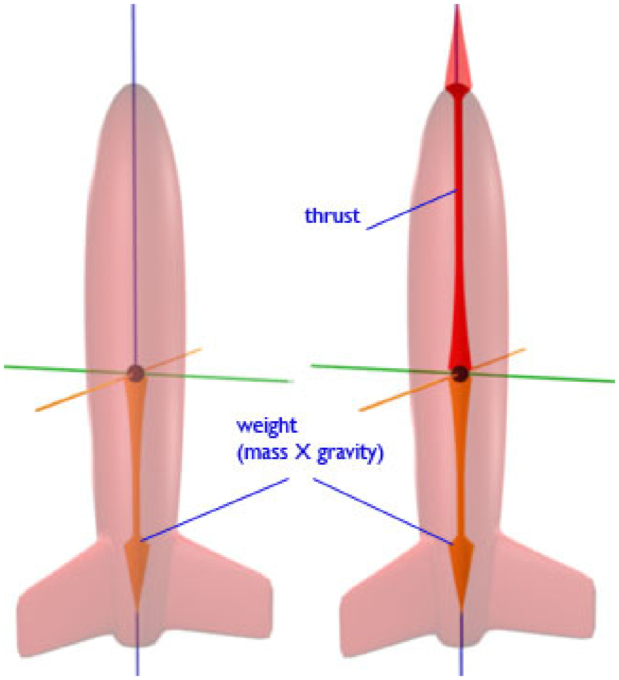
I’ve also LABELED several VARIABLES (rocket scientists call them “parameters”) as well. Remember the battleship? Well, when we want to find out how far our rocket is down-range, we simply count the number of X units—whether they might be in feet, meters or kilometers—it doesn’t matter, as long as we keep those units the same on both the X and the Y axis. How high does our rocket go? We measure the number of Y units.

Later, we’ll see how to calculate things like the elapsed time and the velocity and acceleration at ANY point on our coordinate system. We’ll do that by using FORMULAS that are derived from the study of the FORCES on our rocket.

Changes Of Motion Result From Changes Of Force

As you can see from the title above, I want to talk with you now about CHANGES, MOTION, and FORCE, so let’s dive right in. Below are two pictures, side-by-side of your rocket: Pretend for a moment that you have ‘X-ray’ vision, and that you can see right through the rocket to the very center.

On the left is the rocket sitting on the launch pad. The only force it experiences is its weight—which is the Earth’s gravitational attraction to the rocket’s mass. Now, we hit the launch button, and boom—in about one one-thousandth of a second, the rocket’s engine develops a force—we call it ‘THRUST’—and as you can see on the right side, the arrow points straight up, which is where we want the rocket to go!



I want you to notice TWO other things about the picture. Do you see how the arrow for 'thrust' is quite a bit longer than the one for weight? It turns out this is quite important. An arrow has both a DIRECTION and a MAGNITUDE (its length). In math and physics, we call these arrows VECTORS.

Now I'm going to talk a lot more about vectors in the next lecture, but for now I just want you to remember that arrows are a very handy way to describe FORCES. Just by looking at our picture for example, we can see that the thrust force is opposite the weight force (so we see the DIRECTION) and, thrust is quite a bit larger than weight, so we can probably assume our rocket will 'take off!'

I mentioned <u>two</u> things to notice. The second one is this: do you see the dark little spot where the back ends of the arrows meet? This is a fictional 'spot' within our rocket that we call its 'cg' or center-of-gravity.

What you need to know about 'cg' is that every rocket has one. In fact, all SOLID OBJECTS[1] have one—your body, a 747 aircraft, a door, the space station, a pillow—anything with MASS has one. In most cases, cg is NOT exactly at the longitudinal center of the rocket, but normally somewhat close to it. This is because objects are seldom perfectly symmetrical ('equally shaped' from all points of view from their centers) nor is their 'consistency' or makeup of solid objects that are constructed of a uniform material. There may be pockets of air, plastic (which is less 'dense') in some areas or heavier metal in other portions of attached or connected objects!

"VIC" --Very Important Concept

What's "mass" you ask? All matter has the property of mass—it is the QUANTITY of a solid body's ability to RESIST CHANGES of its motion. Another way to describe this condition is that a big MASS has a big INERTIA—or tendency to keep doing what it's doing—whether that is standing still or moving in a straight line. The STRAIGHT LINE part is important. It doesn't count if the object is moving in a curved fashion.

Now, a dump truck has much more mass than a tricycle, as your experience tells you it is much harder to make it move. But once its moving, a dump truck is also much more difficult to STOP or to TURN! What's important to realize about mass is that what it resists is CHANGE to its motion—it has INERTIA.

If you understand this concept you have a pretty fair idea of <u>Sir</u> Isaac Newton's FIRST LAW .

Another thing you need to know is that all of the forces on our rocket eventually "add up." THEY ACT THROUGH this imaginary point called the 'cg.' Let's look at a very familiar example below.

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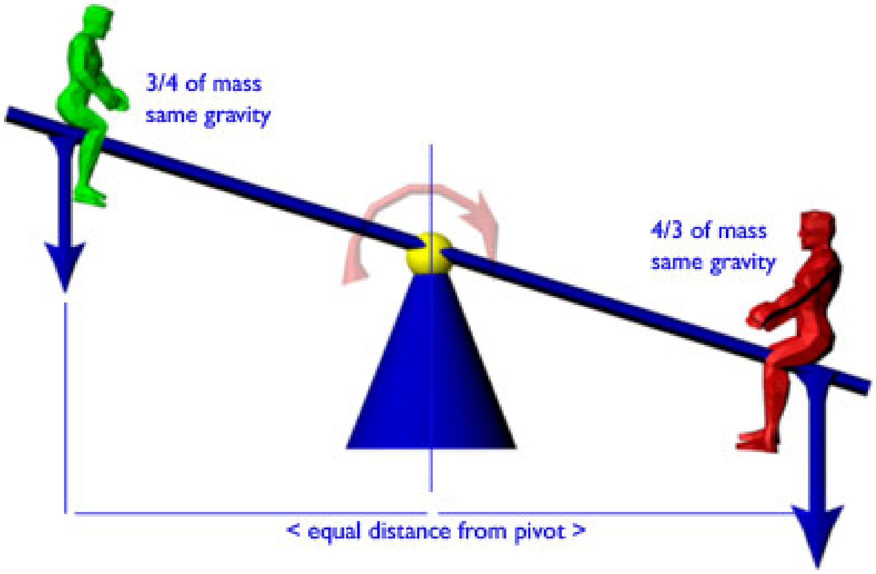
[1] If you want to split hairs, even CONFINED liquids or gases (a <u>cup</u> of water for instance).



Thinking about the see-saw, can you 'see' (sorry) that the weight-force on the heavier person (with 4/3 a mass of "1") ACTS through the pivot (the 'cg') as does the weight-force of our person with 3/4 a mass of "1"?

Both forces are equidistant from the cg. Both are acting through the cg, but one is greater. So the see-saw ROTATES about the cg! We call a rotation (the lighter arrow in the center) caused by unbalanced forces like these a TORQUE—it means a "turning force" and it is CAUSED BY a "MOMENT" –which is a weight-force which is CONNECTED at a particular direction and distance, and therefore able to act upon something.

So what if we want things to be balanced (in equilibrium) again? Just about every school child knows how to fix this situation. The heavier person just slides along closer to the pivot (or 'cg' in our case) until the lighter person comes down, right?

But what if you couldn't move the people—let's say they were glued to their seats as it were. What could you do? Take a moment and write down your answer. Use the back of the previous page to DRAW YOUR OWN PICTURE of the see-saw to try and figure things out.

PROBLEM 3: What will make the two players level again---
if they can't move themselves?

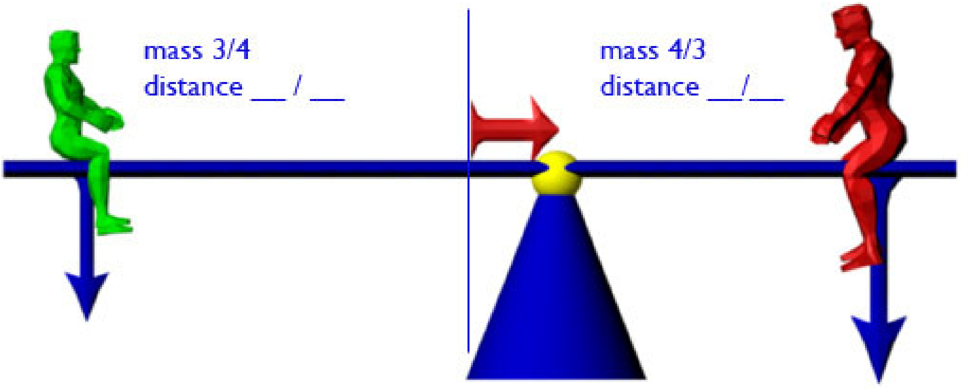
ANSWER:

HINT: I DON'T want you to put either one of the people on a crash-diet or weight-gain program!

(Please don't turn the page until I say to ☺)

All right. Here's the answer to our last question. What happens is WE MOVE THE cg if we can't move the mass of either one of the people—and by moving the cg TOWARDS the heavier person, it is as if that person moved closer to our original cg, and as if the lighter person moved further away—what some of you may recognize as a "lever" principle.

> [By the way, did you ever see someone remove the tire from a big 18-wheeler truck? Now you know why his 'jack' was so much longer than the one your mom or dad have in the car—it takes a lot more torque to get the bigger lug-nuts off the wheel!]



Take a closer look at the picture above. Notice the NEW distance between the heavier person and the cg, and the lighter person and the cg. Do you also notice something INTERESTING about each one's DISTANCE from the new cg?

LOOK at the RATIOS of the masses… and then I want you to consider what RATIO of DISTANCES might seem nifty… just from your sense of intuition.

PROBLEM 4: Write down what you THINK each person's distance RATIO is –their distance from cg (numerator), expressed as a 'fraction' vs. the other person (denominator).

ANSWER: lighter person's distance _____/_____ (remember, it's a ratio)

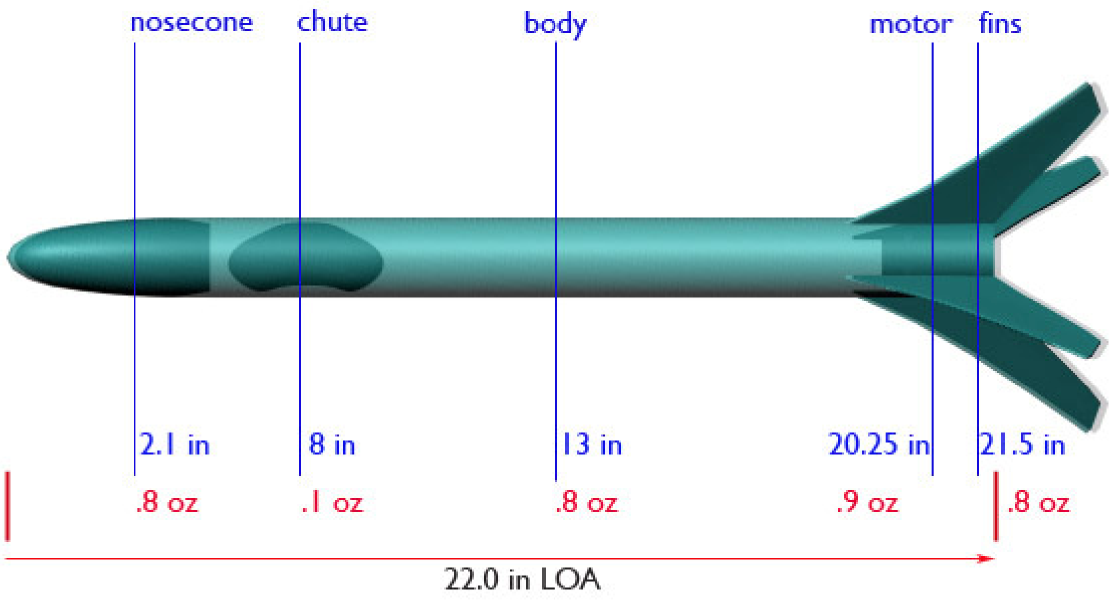
heavier person's distance _____/ _____

What's your reasoning? ____

Finding The cg Of Your Rocket—And By The Way, Most Objects

OK. Take a look at the picture below. I've tried to make (as close as reasonable) the shape of the actual rocket you will build (its called a 'Rhino' for some reason, I think because for the average model rocket its big). I've turned it over on its side to make our calculations look just like the exercise we just did with the see-saw.

So what we want to do is find the cg of the rocket. This will be very, very important, as you'll see in my next lecture.



Here is the process: First, notice that we'll measure in the "X" direction and that the rocket, from the tip of the nose cone to the end of the body tube, is exactly 22 inches.

Now, fill in the following table. Do this by MULTIPLYING the WEIGHT of each major part of the completed rocket times its distance, or DISPLACEMENT, from the ORIGIN of our measuring coordinate (0,0). Use your slide rule!

Nose cone	(.8 oz) X (2.1 in)	________
Parachute assbly	(.1 oz) X (8.0 in)	________
Body tube	(.8 oz) X (13.0 in)	________
Motor assbly	(.9 oz) X (20.25 in)	________
Fins	(.8 oz) X (21.5 in)	________

Now, sum the five “MOMENTS” ……………………… ________ (∑ of “oz-in”)

Then sum all of the WEIGHTS to find the Total ________ (∑ of “oz”)

DIVIDE ∑ Moments by the Total Weight ________ (in. , cg)

And you’re done!

By the way, you’ve probably guessed, but the Greek symbol
∑ (a capital sigma) means “sum of.”

Now what we would do is go back to our rocket, and place some sort of fancy marking on it, like I have below, to indicate our cg.

That’s the end of this lecture, except for the classroom exercise!

[You might want to write your notes from our discussion at the bottom of this page, so that you won’t forget.]