Names of group members: ______________________ ______________________

______________________ ______________________

Acceleration*

When the velocity of an object changes it is said to be accelerating. Acceleration is the rate of change of velocity with time.

In everyday English, the word acceleration is often used to describe a state of increasing speed. For many Americans, their only experience with acceleration comes from car ads. When a commercial shouts "zero to sixty in six point seven seconds" what they're saying here is that this particular car takes 6.7 s to reach a speed of 60 mph starting from a complete stop. This example illustrates acceleration as it is commonly understood, but acceleration in physics is much more than just increasing speed.

Any change in the velocity of an object results in an acceleration: increasing speed (what people usually mean when they say acceleration), decreasing speed (also called deceleration or retardation), or changing direction. Yes, that's right, a change in the direction of motion results in an acceleration even if the moving object neither sped up nor slowed down. That's because acceleration depends on the change in velocity and velocity is a vector quantity — one with both magnitude and direction. Thus, a falling apple accelerates, a car stopping at a traffic light accelerates, and an orbiting planet accelerates. Acceleration occurs anytime an object's speed increases or decreases, or it changes direction.

Much like velocity, there are two kinds of acceleration: average and instantaneous. Average acceleration is determined over a "long" time interval. The word long in this context means finite — something with a beginning and an end. The velocity at the beginning of this interval is called the initial velocity ($v_{initial}$) and the velocity at the end is called the final velocity (v_{final}). Average acceleration is a quantity calculated from measurements.

$$a=\frac{\Delta v}{\Delta t}=\frac{v_{final}-v_{initial}}{\Delta t}$$

In contrast, instantaneous acceleration is measured over a "short" time interval. The word short in this context means infinitely small or infinitesimal — having no duration or extent whatsoever. It's a mathematical ideal that can only be realized as a limit.

units

Calculating acceleration involves dividing velocity by time — or in terms of units, dividing meters per second [m/s] by second [s]. Dividing distance by time twice is the same as dividing distance by the square of time. Thus the SI unit of acceleration is the meter per second squared.

$$\left[\frac{\mathrm{m}}{\mathrm{s}^2}=\frac{\mathrm{m}/\mathrm{s}}{\mathrm{s}}=\frac{\mathrm{m}}{\mathrm{s}}\frac{1}{\mathrm{s}}\right]$$

Another frequently used unit is the acceleration due to gravity — g. Since we are all familiar with the effects of gravity on ourselves and the objects around us it makes for a convenient

* taken from The Physics Hypertextbook (http://physics.info/acceleration/)

standard for comparing accelerations. Everything feels normal at 1 g, twice as heavy at 2 g, and weightless at 0 g. This unit has a precisely defined value of 9.80665 m/s^2, but for everyday use 9.8 m/s^2 is sufficient, and 10 m/s^2 is convenient for quick estimates. Although the term "g force" is often used, the g is a measure of acceleration, not force. Of particular concern to humans are the physiological effects of acceleration. To put things in perspective, all values are stated in g.

In roller coaster design, speed is of the essence. Or, is it? If speed was all there was to designing a thrill ride, then the freeway would be pretty exciting. Most roller coasters rarely exceed 30 m/s (60 mph). Contrary to popular belief, it is the acceleration that makes the ride interesting. A well designed roller coaster will subject the rider to maximum accelerations of 3 to 4 g for brief periods. This is what gives the ride its dangerous feel.

Despite the immense power of its engines, the acceleration of the Space Shuttle is kept below 3 g. Anything greater would put unnecessary stress on the astronauts, the payload, and the ship itself. Once in orbit, the whole system enters into an extended period of free fall, which provides the sensation of weightlessness. Such a "zero g" environment can also be simulated inside a specially piloted aircraft or a free fall drop tower.

Fighter pilots can experience accelerations of up to 8 g for brief periods during tactical maneuvers. If sustained for more than a few seconds, 4 to 6 g is sufficient to induce blackout. To prevent "g-force loss of consciousness" (G-LOC), fighter pilots wear special pressure suits that squeeze the legs and abdomen, forcing blood to remain in the head. Pilots and astronauts may also train in human centrifuges capable of up to 15 g. Exposure to such intense accelerations is kept very brief for safety reasons. Humans are rarely subjected to anything higher than 8 g for longer than a few seconds.

Acceleration is related to injury. This is why the most common sensor in a crash test dummy is the accelerometer. Extreme acceleration can lead to death. The acceleration during the crash that killed Diana, Princess of Wales, in 1997 was estimated to have been on the order of 70 to 100 g, which was intense enough to tear the pulmonary artery from her heart — an injury that is nearly impossible to survive. Had she been wearing a seat belt, the acceleration would have been something more like 30 or 35 g — enough to break a rib or two, but not nearly enough to kill most people.

Video Analysis

Today you will calculate the acceleration experienced by your rocket by analyzing the launch video. As you might guess, the first step is to extract a table of distances and corresponding times from the video. Thus, two pieces of information must be extracted from each frame, the distance the rocket has travelled from the starting point and the corresponding elapsed time. In Quicktime, you can advance/rewind the movie frame by frame with the arrow keys while the “movie inspector” window (toggled on/off with control-I) lists the time of the current frame displayed. However, this time does not account for special slow motion effects performed by the camera. Quicktime will think that the video was shot at 15 frames per second but these videos were made were shot in extreme slow motion mode which means that 8 images were taken in the same time as a normal video frame (or 120 frames per second). To retain the most accuracy, for now just keep track of the frame number for each distance point. You can scale the frame number to account for the correct time later in the analysis.

How can you measure the distance traveled by the rocket? To be comparable to the values in the tables below, you must perform your analyses in SI units. This means estimating the distances in meters. Obviously, the screen images are smaller than reality. You don't need to be extremely accurate, but your results will be easier to interpret if you are as precise as possible (what is the difference between accuracy and precision?). For now, just measure the distance with a ruler in millimeters as precisely as you can. To scale the measurements at a later stage to meters, you need to estimate how many millimeters on the screen correspond to 1 meter. Include that conversion factor here:

1 meter = ________ mm

Frame #	Distance on screen (mm)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

Frame #	Distance on screen (mm)
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	

Once you have a table of distance vs. frame number, you are ready to switch to a spreadsheet program like Excel.

As described above, acceleration is the rate of change of velocity. Velocity in turn is the rate of change of distance. Since you have distances as a function of time in your table, once you have the raw data transferred into a spreadsheet, you can begin to convert it into accelerations. Here's a template table to give you an idea for how to organize your data. If you aren't familiar with Excel, we will review how to perform these calculations in a spreadsheet program in class.

Frame #	Distance (mm)	Time (sec)	Distance (m)	Velocity (Δdistance/ Δtime)	Acceleration (Δvelocity/ Δtime)	Accel (g)
1	0	0.0083	0.000	18.5	1108	113
2	2	0.0167	0.154	27.7	4431	452
3	5	0.0250	0.385	64.6	1108	113
4	12	0.0333	0.923	73.8	4431	452
5	20	0.0417	1.538	110.8	…	…
6	32	0.0500	2.462	…		
…	…	…	…			

Here are some sample accelerations to compare to your calculations.

a (m/s^2)	event
5×10^{-14}	smallest acceleration in a scientific experiment
2×10^{-10}	galactic acceleration at the sun
9×10^{-10}	anomalous acceleration of pioneer spacecraft
0.5	elevator, hydraulic
0.6	free fall acceleration on pluto
1	elevator, cable
1.6	free fall acceleration on the moon
8.8	International Space Station
3.7	free fall acceleration on mars
9.8	free fall acceleration on earth
10–40	manned rocket at launch
20	space shuttle, peak
24.8	free fall acceleration on jupiter
20–50	roller coaster
80	limit of sustained human tolerance
0–150	human training centrifuge
100–200	ejection seat
270	free fall acceleration on the sun
600	airbags automatically deploy
104–106	medical centrifuge
106	bullet in the barrel of a gun
106	free fall acceleration on a white dwarf star
1012	free fall acceleration on a neutron star

Automotive acceleration (g)

event	typical car	sports car	F-1 race car	large truck
starting	0.3–0.5	0.5–0.9	1.7	< 0.2
braking	0.8–1.0	1.0–1.3	2	~ 0.6
cornering	0.7–0.9	0.9–1.0	3	??

Acceleration of selected events (smallest to largest)

a (g)	event
2.9	sneeze
3.5	cough
3.6	crowd jostle
4.1	slap on back
8.1	hop off step
10.1	plop down in chair
60	chest acceleration during car crash at 48 km/h with airbag, design limit
70–100	crash that killed Diana, Princess of Wales, 1997
150–200	head acceleration limit during bicycle crash with helmet