

## G-Force

G-force is really just the force that you experience by being accelerated. Have you ever been riding in a really fast car and you almost feel “pushed” back into your seat because of how fast you start? Probably not, because most of us don’t ride in cars that fast. More likely you’ve been “thrown” forward when someone had to slam on the brakes, or you feel pushed to the side whenever someone takes a fast turn. Whenever you feel these “pushes” that means you are accelerating or changing speeds.

The higher the acceleration, the harder the “push” feels. The reason I use quotation marks to describe the push, is to describe the “push” you feel when you experience the G-force. This push you feel is actually just your own inertia wanting to maintain the motion (or rest) your body was already in. When you suddenly stop, your body wants to continue moving forward, but your sense of relative motion is set to the car as a stationary location. When you feel yourself wanting to continue going forward, and the car is stopping you think of yourself as being “pushed” or “pulled” when you are really just trying to keep your original motion.

The same happens when you are turning, even when you are moving a constant speed. I know it seems confusing, but we need remember that velocity is a vector, meaning that it takes into account speed *and* direction. When you are turning at a constant speed, you are changing direction, and that directional change means your velocity changes, so you have an acceleration.

The concept of the “push” or “pull” is the same as braking: your body wants to continue to move in a straight line. When the car is turning to the left your body wants to go straight, but in relative motion to the car you appear to be moving to the right of the car, so you feel “pulled” to the right.

How does this all relate to “G-Forces”? Well, like we learned before the acceleration due to gravity is  $9.8 \text{ m/s}^2$ , or  $32 \text{ ft/s}^2$ . And the g-force that you experience is just a multiple of this number. For example, if you experience an acceleration of  $19.6 \text{ m/s}^2$ , you would divide this by  $9.8 \text{ m/s}^2$  to get 2 g’s. If you experience an acceleration of  $48 \text{ ft/s}^2$ , you divide this by  $32 \text{ ft/s}^2$ , and you get 1.5 g’s. So it’s just how many multiples of gravity’s acceleration you experience.

How does acceleration relate to force? Through Newton’s second law:  $F = ma$ ! But there different kinds of forces (and thus acceleration): centripetal and centrifugal. How can you tell the difference?

Centripetal (translation = “center-seeking” ) is the force needed to keep an object following a curved path. Remember how objects will travel in a straight line unless they bump into something or have another force acting on it (gravity, drag force, etc.)? Well, to keep the bucket of water swinging in a curved arc, the centripetal force can be felt in the tension experienced by the handle (or your arm, in our case). Swinging an object around on a string will cause the rope to undergo tension (centripetal force), and if your rope isn’t strong enough, it will snap and break, sending the mass flying off in a tangent (straight) line until gravity and drag force pull the object to a stop. This force is proportional to the square of the speed - the faster you swing the object, the higher the force.

Centrifugal (translation = “center-fleeing”) force has two different definitions, which also causes confusion. The inertial centrifugal force is the most widely referred to, and is purely mathematical, having to do with calculating kinetic forces using reference frames, and is used with Newton’s laws of motion. It’s often referred to as the ‘fictitious force’.

Reactive centrifugal force happens when objects move in a curved path. This force is actually the same magnitude as centripetal force, but in the opposite direction, and you can think of it as the reaction force to the centripetal force. Think of how you stand on the Earth... your weight pushes down on the Earth, and a reaction force (called the “normal” force) pushes up in reaction to your weight, keeping you from falling to the center of the Earth. A centrifugal governor (spinning masses that regulate the speed of an engine) and a centrifugal clutch (spinning disk with two masses separated by a spring inside) are examples of this kind of force in action.

Imagine driving a car along a banked turn. The road exerts a centripetal force on the car, keeping the car moving in a curved path (the “banked” turn). If you neglected to buckle your seat belt and the seats have a fresh coat of Armor-All (making them slippery), then as the car turns along the banked curve, you get “shoved” toward the door. But who pushed you? No one – your body wanted to continue in a straight line but the car keeps moving in your path, turning your body in a curve. The push of your weight on the door is the reactive centrifugal force, and the car pushing on you is the centripetal force.

What about the fictitious (inertial) centrifugal force? Well, if you imagine being inside the car as it is banking with the windows blacked out, you suddenly feel a magical ‘push’ toward the door away from the center of the bend. This “push” is the fictitious force invoked because the car’s motion and acceleration is hidden from you (the observer) in the reference frame moving within the car.

## G-Force Activity

Let's make two acceleration-measuring instruments (called 'accelerometers') so you can jump, run, swing, and zoom around to find out how many g's you can pull. You're going to make a cork-accelerometer and a g-force ring, both of which are used by my students when I teach mechanical engineering dynamics.

Objective: To visually see the effect acceleration has on objects

Materials:

- bucket
- Water
- Outdoor area
- Clear tubing (12-18" long)
- Nylon or metal barbed union that fits inside the tubing
- Empty soda bottle
- Cork or Styrofoam that fits inside the soda bottle
- string

Procedure #1 (spinning bucket):

- 1) Fill the bucket about halfway with water
- 2) Grasp the handle and spin the bucket around in a circle vertically
- 3) Switch to spinning the bucket horizontally with your arm outstretched from your chest
- 4) Try slowing down to find the slowest you can spin while keeping the water in the bucket

Procedure #2 (cork accelerometer):

- 1) Fill the empty soda bottle with water
- 2) Tie the string around your cork or Styrofoam, tightly so it will not detach from the string
- 3) Glue the string to the cap of the bottle. Make sure the length of the string is such that the cork/Styrofoam is about halfway down the bottle.
- 4) Place the cork/Styrofoam in the water and feed in as much of the string as you can. Make sure to completely fill the water bottle so you will not get any air bubbles in the bottle when it is flipped over.
- 5) Place the cap on the bottle and close it tightly, being careful not to get the string caught in the threading of the cap.
- 6) Turn the bottle upside down and you have an accelerometer. If the bottle accelerates the cork will be flung against the side of the bottle, but if you move at the same speed, the cork will remain in the middle of the bottle.
- 7) Play with the accelerometer. Use skateboards and your driveway, take it in the car, see how often you are actually accelerating and just keeping the same speed.

## Procedure #3 (water accelerometer):

- 1) Take the clear plastic tubing and fill it about halfway with water.
- 2) Bend it around so it makes a complete circle. Close the tubing with the nylon or metal union to it makes a completely closed circle.
- 3) Make sure the water level in the circle is completely halfway full. It is important to half  $\frac{1}{2}$  water and  $\frac{1}{2}$  air mixture. Once the level is just right add a few drops of food coloring to the water, so you can easily see the water.
- 4) Hold the tubing so the union is directly at the top. Make a mark on one side of the tubing with a permanent marker at the water line. This is your 0 G mark.
- 5) Using a protractor, make a mark 45 up from the mark you just made (halfway between the first mark and the union). Label this as 1G.
- 6) Make another mark 22.5 up from the 1 G mark. This will be 2 G's
- 7) Make another mark 11.25 up from the 2 G mark. This will be 3 G's
- 8) Make another mark 5.625 up from the 3 G mark. See the pattern yet?
- 9) You can take this accelerometer and actually make measurements of how much G-force you are experiencing and as a result, how much you are accelerating. Just hold it upright, and the level of the water will indicate how many G's it experiences
- 10) As before, play with it. Take it outside, see which of your friends can accelerate the fastest, Find out which experiences more G's turning or braking in a car.

## Analysis:

- 1) Which accelerometer was better at giving a visual representation of accelerating?
- 2) Which one do you prefer? Why?
- 3) What activity did you do that created the most accelerating?
- 4) What does that tell you about acceleration?

### G-Force Problems

Again, to calculate the # of G's, just calculate the acceleration (linear or centripetal) and divided by the acceleration due to gravity. Linear has more options to calculate acceleration (remember kinematics) but here are the main 2 equations:

Linear:  $v_f = v_i + at$

Centripetal:  $v^2/r = a_c$

$v_f$  = final velocity (m/s)

$v$  = velocity (m/s)

$v_i$  = initial velocity (m/s)

$r$  = radius of the curve (m)

$a$  = acceleration ( $m/s^2$ )

$a_c$  = acceleration ( $m/s^2$ )

$t$  = time(s)

G-force =  $a/g$

$a$  = acceleration

$g = 9.8 m/s^2$

- 1) A car is driving along at 49 m/s, and suddenly has to slam on the brakes and stop in 2 seconds. How many G's does a passenger experience?

Given:	Equation(s):	Solve: 2.5 G
	Substitute:	
Unknown:		

- 2) You are riding your bicycle around a curve that has a radius of 10 m at 20 m/s. How many G's do you experience on your bicycle?

Given:	Equation(s):	Solve: 4.1 G
	Substitute:	
Unknown:		

- 3) You are in a plane that is taking off down the runway and you are thrown back in your seat. You experience a G-force of 1.85 G's and you decided to time the takeoff and realize it took 6.6 seconds. What was the plane's velocity when it took off?

Given:	Equation(s):	Solve: <i>119.66 m/s</i>
	Substitute:	
Unknown:		

- 4) A racecar travels around a curve at around 110 m/s. The radius of the curve is 274.38 m. What is the G-force experienced by the driver?

Given:	Equation(s):	Solve: <i>4.5 G</i>
	Substitute:	
Unknown:		

- 5) When a minivan drives around a corner, a dog standing in the back experiences a G-force of 2.25 G's. If the radius of the curve is 28.34 m, how fast is the minivan going around the curve?

Given:	Equation(s):	Solve: <i>25 m/s</i>
	Substitute:	
Unknown:		

Analysis:

- 1) Which accelerometer was better at giving a visual representation of accelerating?  
*The liquid in the tube*
- 2) Which one do you prefer? Why?  
*The liquid in the tube actually gives a numerical measurement*
- 3) What activity did you do that created the most accelerating?  
*Spinning around in a circle*
- 4) What does that tell you about acceleration?  
*Centripetal acceleration is much higher and easier to achieve than linear acceleration*

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