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Features



## Galloping gyroscopes

by Kona Macphee and Hugh Hunt



### Gyroscopic forces

If I told a cave man about the "centrifugal force" we experience as we go around a corner in a car, he wouldn't know what I was talking about because the fastest he's ever gone is running pace. It usually takes some personal experience to believe that something exists. We believe in centrifugal force because we have all experienced it. How about the gyroscopic effect?

Well, our daily experience doesn't include this one. If our bodies contained spinning parts we would notice. The closest we get is by feeling the strange tug on the hair dryer or the coffee grinder or the electric drill as we move it around quickly. Maybe we notice the clockwise weather patterns in England and the anti-clockwise patterns in Australia. What is going on?

### The Coriolis force

Imagine sitting at the North pole. You are not moving, but the Earth is – it completes a full rotation about its north–south axis every 24 hours. If you sit at the pole for a full 24 hours, you will "turn on the spot" one complete rotation with respect to the space surrounding the Earth.

In general, if you stand on the one spot for 24 hours anywhere on Earth, your body will actually trace out a circular path in space as the earth rotates. At either Pole, the radius of this circle will be zero, and hence you will "spin on the spot" with respect to space.

The further you get from either pole, however, the larger the radius of this circle will be (until you reach the equator, where the earth is widest about its north–south axis). Now, it takes the *same* amount of time to trace

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out each circular path (24 hours), and therefore on larger paths you must be moving faster than on smaller ones.

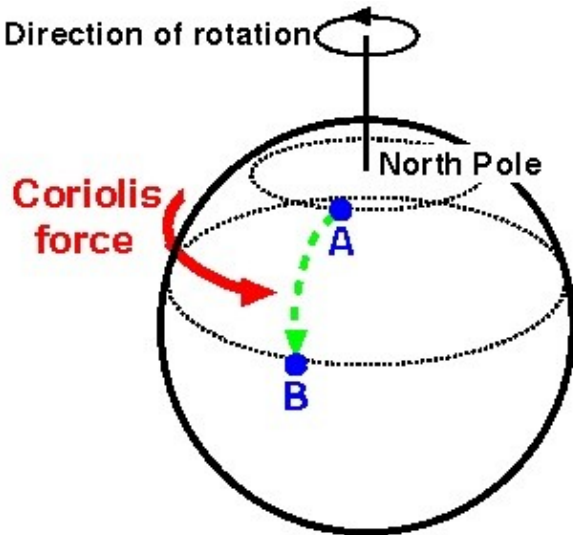


Figure 1: The Coriolis force.

Now imagine actually walking south away from the North pole. With every step, the radius of the circular component of your path produced by the rotation of the earth gets larger. Thus, the component of your velocity that relates to this circular path gets larger – you are accelerating.

Since you are accelerating, there must be a force acting on you to produce the acceleration. This force is known as the *Coriolis force*. Figure 1 shows the Coriolis force as you walk from point A (closer to the North Pole) to point B (further from the North Pole, but north of the equator). The Coriolis force moves weather patterns around in circles, and it is an example of a gyroscopic effect.

You can find some excellent animations of the Coriolis effect at the web site of the [Danish Wind Turbine Manufacturers' Association](#).

Like the earth, a gyroscope experiences interesting forces when it is spinning. Unlike the earth, however, a gyroscope is carefully made so that you can see all these effects happening quite easily!

## The traditional gyroscope



Figure 2: A spinning transparent disc.

The traditional gyroscope

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All that's needed to explore gyroscopic forces is a simple spinning disc, as shown in figure 2.

However, it's difficult to experience the gyroscopic effects produced by a spinning disc unless it's supported in some way, so you can pick it up and move it around.

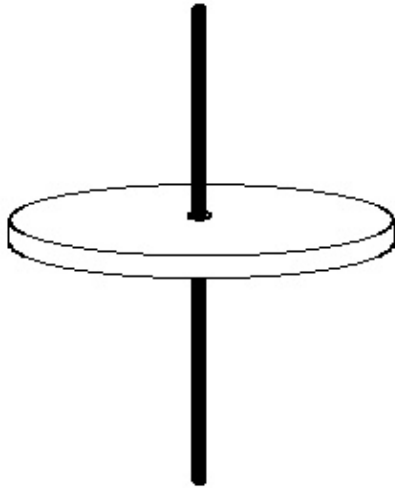


Figure 3: Basic gyroscope – spinning disc on a stick.

Figure 3 shows a very simple gyroscope – a disc that can spin around a fixed rod passing through its central bearing. Most gyroscopes that you'll come across are variations on this simple theme: a spinning disc supported in some way (such as in gimbals) so that it is free to rotate in all directions, but its centre will remain in the same place.

## Hit the power!

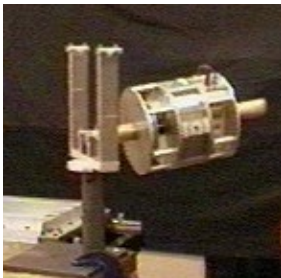


Figure 4: A motorised gyroscope, clamped in gimbals.

You can experiment with gyroscopes much more easily if they are motorised, and preferably battery-powered. In the Department of Engineering at Cambridge University we have a few hand-held battery-powered gyros, as shown in figure 4, and they do really strange things.

## Conservation of angular momentum

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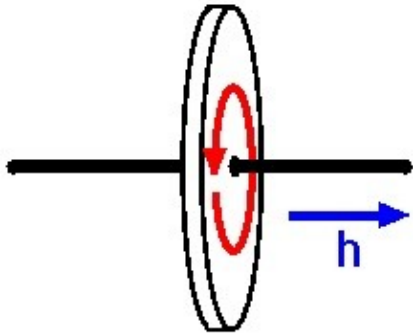


Figure 5: Angular momentum of a spinning disc.

Angular momentum is a measure of the momentum of an object that is spinning. The direction of the angular momentum vector  $\mathbf{h}$  of a spinning object is parallel to the axis of spin, as shown in figure 5.

For any independent collection of spinning objects, the total angular momentum must stay constant. This is known as the *conservation of angular momentum*.



Figure 6a: Holding the gyroscope horizontally.

Conservation of angular momentum can easily be observed if you sit on a swivelly chair while holding a spinning gyroscope. The chair is mounted on a pivot so that the chair can rotate about the vertical axis. If you hold the gyroscope so that its axis of rotation is horizontal (so that the spinning disc is in the vertical plane), the gyroscope's angular momentum is in the horizontal plane and there is none in the vertical plane (as in figure 5).

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Figure 6b: Move it to the vertical and you spin around.

If you now tilt the gyroscope to the vertical, so that its spinning disc is in the horizontal plane, you have transferred its angular momentum to the vertical plane. Since the net angular momentum in this plane must remain zero (to conserve angular momentum – it was zero in this plane when we started) you'll find that you and the chair start spinning to compensate! You will, of course, move in the opposite direction to the spinning disc.



Figure 6c: Do it the other way, spin the other way!

If you move the gyroscope back to the original position, your spin will again cease. Turn it vertically the *other* way, and you'll spin in the other direction. Enough to make anybody dizzy! This is a really fun experiment to do and it works really well if you're skinny – less than 8 stone and you'll spin really fast!

## Inducing precession

We saw in [this issue's article about boomerangs](#) that when a couple is applied to a rotating body perpendicular to the body's axis of rotation, the body begins to rotate about a third axis, mutually perpendicular to the other two. This induced rotation is known as precession.

Another explanation for precession is that Newton's law for rotational motion says  $\mathbf{Q} = d\mathbf{h}/dt$  where  $\mathbf{Q}$  is the applied couple and  $\mathbf{h}$  is the angular momentum vector. To cut a long story short, this means that the angular momentum vector is changed by a small amount in the direction of the applied couple  $\mathbf{Q}$ . So the axis of

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rotation (which is in the same direction as  $\mathbf{h}$ ) will move a little in the direction of  $\mathbf{Q}$ .

If a spinning gyroscope is mounted horizontally at one end, precession will occur. Let's look at the forces involved.

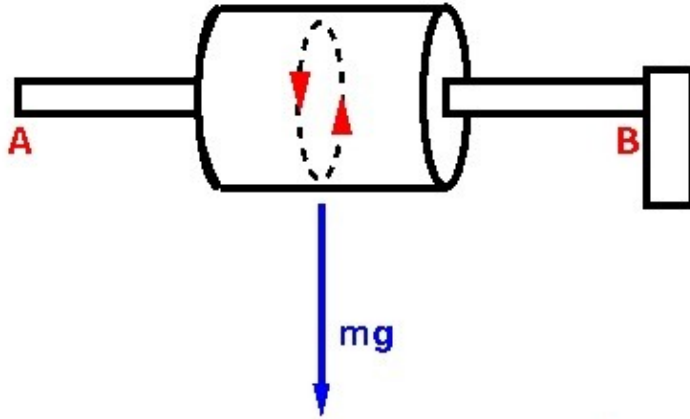


Figure 7: Gravitational force on an end-mounted gyroscope.

In figure 7, a spinning gyroscope has been mounted horizontally at one end (**B**). The centre of gravity of the gyroscope is midway between the free end **A** and the mounted end **B**, so the gravitational force  $mg$  (where  $m$  is the mass of the gyroscope) acts at a distance from the mounting point. There is therefore a couple  $\mathbf{Q}$  along the  $z$ -axis, pointing out of the page (see the [discussion about couples](#) in this issue's [boomerangs article](#)).

Since the gyroscope's disc is spinning about the horizontal ( $x$ -) axis, the couple is perpendicular to the gyroscope's axis of spin and the axis of rotation will move in the direction of the couple (because of Newton's law for rotational motion), so the axis will move out of the page. In other words, the gyroscope will rotate around its mounting at **B**, moving in a circle in the horizontal plane. This is precession.



Figure 8: A toy gyroscope, spinning while dangling on a string.

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If you have a toy gyroscope at home, you can easily observe this effect yourself. Spin up the gyroscope and dangle it from one end on a piece of string, as shown in figure 8. The gyroscope will rotate around the string due to precession under gravity.

### Harnessing precession

If you've ever tried to pick up a heavy pole while keeping it horizontal, you'll know that it's much easier to do this by picking it up in the middle (at its centre of mass) than by picking it up by one end.

The motorized gyroscopes are quite heavy – they typically weigh 10kg – and normally it would be very difficult to pick up a mass like this from the end with one hand while keeping it horizontal. (Note that it *wouldn't* be so difficult to hold it horizontally if you were allowed to pick it up under its middle.)

Now, if you set the gyroscope spinning, a curious thing happens. As long as you allow the gyroscope to precess as you're picking it up (i.e. you turn yourself in the direction it wants to go as you're holding it), you find that you suddenly *can* pick it up from one end, and in fact it feels about as heavy as it would if you picked it up from the middle. This allows you to perform what look like amazing feats of strength!



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Figure 9: Amazing feats of strength!

There was a famous Professor Laithwaite who used to demonstrate this effect and claim that gyroscopes were anti-gravity devices because you could pick them up more easily when they were spinning. (Sadly, he died before he could make his first space ship propelled by his anti-gravity gyroscopes!)

In fact, of course, there is no "anti-gravity effect" due to gyroscopes. Using your understanding of couples and gyroscopes, can you explain what's going on here?

### Try this at home!



Figure 10: Do-it-yourself bicycle wheel gyroscope!

Obviously, most people won't have a motorised gyroscope at home. However, all the same effects can be observed with a toy gyroscope like the one shown in figure 8. If you're interested in a more powerful physical experience of gyroscopic effects, you can build yourself a gyroscope using an ordinary bicycle wheel with a foot-peg or other rod attached to the axle as something to hold on to.

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*To find out more about gyroscopes, visit [Hugh Hunt's website](#).*

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*Plus* is part of the family of activities in the Millennium Mathematics Project, which also includes the NRICH and MOTIVATE sites.