

## FSI RESEARCH MODULE #7: THE CORIOLIS FORCE

### 1. MAIN GOALS AND OBJECTIVES

Physics can describe in rather striking detail some rather bizarre phenomenon in nature. For example, the fact that the Earth is a rotating sphere yields curvature effects in the winds that produce strange forces, such as the Coriolis Force. This project will study some of these effects, from the formation of hurricanes to the curved paths of long-range ballistics to the misconceptions that create folklore.

### 2. BACKGROUND

2.1. **The Coriolis Force.** The following excerpt can be found at the web site

[http://www.usatoday.com/weather/\resources/basics/  
coriolis-understanding.htm](http://www.usatoday.com/weather/\resources/basics/coriolis-understanding.htm)

Pressure differences tend to push winds in straight paths. Yet winds follow curved paths across the Earth. In 1835, Gustave-Gaspard Coriolis, a French scientist, first described mathematically what's going on, giving his name to the Coriolis force.

In simple terms, as air begins flowing from high to low pressure, the Earth rotates under it, making the wind follow a curved path. In the Northern Hemisphere, the wind turns to the right of its direction of motion. In the Southern Hemisphere, it turns to the left. The Coriolis force is zero at the equator.

You might be wondering: If the Coriolis force turns winds to the right in the Northern Hemisphere, why do winds go counterclockwise around large systems, such as hurricanes, north of the equator? This happens because Coriolis is only one of the forces acting on air to cause winds. In simple terms, in the Northern Hemisphere, while the Coriolis force is pushing the wind toward the right, the pressure-gradient force, caused by air pressure differences, is pushing the air toward the center of the area of low pressure, and for various reasons is stronger than the Coriolis force.

Don't believe what you hear about Coriolis making the water in a sink or toilet rotate one way as it drains in one hemisphere, the other way in the other hemisphere. The Coriolis force is noticeable only for large-scale motions such as winds.

The best Web material we've found on the Coriolis force is on the bad meteorology Web site of Alistair Fraser of Pennsylvania State University.

His Coriolis FAQ answers a lot of questions, beginning with why winds move counterclockwise around storms in the Northern Hemisphere while the Coriolis force pushes moving objects to the right, and why it is correct to call it the "Coriolis force," instead of the "Coriolis effect." The text and diagram with the first question in the FAQ clear this question up.

The fact that the Coriolis force is zero at the equator and very weak near the equator, explains why tropical cyclones such as hurricanes and typhoons won't form on the equator even though the other factors there, such as warm ocean water, would make them likely. But, the idea that you don't have to worry about tropical

cyclones in the zone about 180 miles north and south of the equator isn't a sure thing, as Typhoon Vamei showed in December 2001.

**2.2. The Coriolis Effect.** The following excerpt can be found at the web site

[http://zebu.uoregon.edu/~js/glossary/coriolis\\_effect.html](http://zebu.uoregon.edu/~js/glossary/coriolis_effect.html)

Coriolis effect is an inertial force described by the 19th-century French engineer-mathematician Gustave-Gaspard Coriolis in 1835. Coriolis showed that, if the ordinary Newtonian laws of motion of bodies are to be used in a rotating frame of reference, an inertial force – acting to the right of the direction of body motion for counterclockwise rotation of the reference frame or to the left for clockwise rotation—must be included in the equations of motion.

The effect of the Coriolis force is an apparent deflection of the path of an object that moves within a rotating coordinate system. The object does not actually deviate from its path, but it appears to do so because of the motion of the coordinate system.

The Coriolis effect is most apparent in the path of an object moving longitudinally. On the Earth an object that moves along a north-south path, or longitudinal line, will undergo apparent deflection to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. There are two reasons for this phenomenon: first, the Earth rotates eastward; and second, the tangential velocity of a point on the Earth is a function of latitude (the velocity is essentially zero at the poles and it attains a maximum value at the Equator). Thus, if a cannon were fired northward from a point on the Equator, the projectile would land to the east of its due north path. This variation would occur because the projectile was moving eastward faster at the Equator than was its target farther north. Similarly, if the weapon were fired toward the Equator from the North Pole, the projectile would again land to the right of its true path. In this case, the target area would have moved eastward before the shell reached it because of its greater eastward velocity. An exactly similar displacement occurs if the projectile is fired in any direction.

The Coriolis deflection is therefore related to the motion of the object, the motion of the Earth, and the latitude. For this reason, the magnitude of the effect is given by  $2v \sin \theta$ , in which  $v$  is the velocity of the object,  $\omega$  is the angular velocity of the Earth, and  $\theta$  is the latitude.

The Coriolis effect has great significance in astrophysics and stellar dynamics, in which it is a controlling factor in the directions of rotation of sunspots. It is also significant in the earth sciences, especially meteorology, physical geology, and oceanography, in that the Earth is a rotating frame of reference, and motions over the surface of the Earth are subject to acceleration from the force indicated. Thus, the Coriolis force figures prominently in studies of the dynamics of the atmosphere, in which it affects prevailing winds and the rotation of storms, and in the hydrosphere, in which it affects the rotation of the oceanic currents.

**2.3. Myths Regarding the Coriolis Force.** The following excerpt can be found at the web site

<http://www.ems.psu.edu/%7Efraser/Bad/BadCoriolis.html>

Compared to the rotations that one usually sees (tires on a travelling automobile, a compact disc playing music, or a draining sink), the rotation of the Earth is very small: only one rotation per day. The water in a sink might make a rotation in a few seconds and so have a rotation rate ten thousand times higher than that of

the Earth. It should not be surprising, therefore, to learn that the Coriolis force is orders of magnitude smaller than any of the forces involved in these everyday spinning things. The Coriolis force is so small, that it plays no role in determining the direction of rotation of a draining sink anymore than it does the direction of a spinning CD.

The direction of rotation of a draining sink is determined by the way it was filled, or by vortices introduced while washing. The magnitude of these rotations may be small, but they are nevertheless gargantuan by comparison to the rotation of the Earth. I decided to include a picture of a draining sink, and the first one I tried in my house was found to drain clockwise (the opposite of what the silly assertions would have it do here in the northern hemisphere). This direction was determined entirely by the way the tap filled the sink. The direction of rotation of a draining toilet is determined by the way the water just under the rim is squirted into the bowl when it is flushed.

Is it possible to detect the Earth's rotation in a draining sink?

Yes, but it is very difficult. Because the Coriolis force is so small, one must go to extraordinary lengths to detect it. But, it has been done. You cannot use an ordinary sink for it lacks the requisite circular symmetry: its oval shape and off-center drain render any results suspect. Those who have succeeded used a smooth pan of about one meter in diameter with a very small hole in the center. A stopper (which could be removed from below so as to not introduce any spurious motion) blocked the hole while the pan was being filled with water. The water was then allowed to sit undisturbed for perhaps a week to let all of the motion die out which was introduced during filling. Then, the stopper was removed (from below). Because the hole was very small, the pan drained slowly indeed. This was necessary, because it takes hours before the tiny Coriolis force could develop sufficient deviation in the draining water for it to produce a circular flow. With these procedures, it was found that the rotation was always cyclonic.

### 3. PROJECT FOCUS QUESTIONS

Prepare an oral presentation as well as a written document which addresses the following:

- (1) Describe in quantitative terms the Coriolis Force.
- (2) Explain how this force is related to a rotating system.
- (3) Describe some of the effects of the Coriolis Force on ballistics, such as firing long range projectiles.
- (4) Describe some of the misconceptions about the Coriolis Force, such as the rotation of water in the flushing of toilets.