The Coriolis force: a geometric interpretation

ATM 210 – Fall, 2023 – Fovell

We observe the sun moving across our sky, having risen in the east, bound to set in the west. As a consequence, the amount of solar radiation received at the surface varies during the calendar day, reaching a peak around local noon, being entirely absent at night. The diurnal variation of heating drives local circulations, such as the sea- and land-breeze. Striking optical phenomena like red suns and green flashes occur when the sun is low in our sky. These phenomena are very real.

However, if we interpret the sun's motion as being due to its rotation about the Earth, our underlying explanation for these real effects is flat-out wrong. Of course, we appreciate that *we* are are moving and not the sun. However, rapid as it is (700 mph at Albany!) we cannot sense the Earth's rotation, and so it's just easier to pretend the sun is doing the moving. That is strictly an apparent, though very convincing, motion.

Importantly, our misinterpretation has no bearing on the phenomena described above. They are still real, even if our explanation for them is merely convenient and self-serving. The same holds true for the phenomena for which we credit (or blame) the Coriolis force. These include the facts that the large-scale wind does *not* blow directly from high to low pressure; that principal northern hemisphere (NH) surface ocean currents are clockwise (CW); that winds tend to blow from the west in midlatitudes, as well as from the east and the northeast in the polar and tropical latitudes, respectively; and that midlatitude and tropical cyclones (hurricanes) can and do form, but with the latter never appearing directly on the equator.

These are real and very important effects, which we usually explain through the agency of the Coriolis force. At worst, that's just lazy thinking, nothing more, similar to our other convenient fiction regarding air temperature and water vapor holding capacity. At best, it helps us explain what we <u>ourselves</u> observe, and in the simplest possible terms. The Coriolis force helps us make sense of what we sense.

Newton's first law and Coriolis circles

Newton's first law of motion presents a simple yet very powerful constraint on motions. It states that an object, once put into motion, continues moving in a straight line and at constant speed... *unless other forces are acting*. Can an object once propelled subsequently change direction? Yes, if some force appears to accomplish that. By that same token, if we see something curve, then it follows there must be a force impelling this deviation from straight-line motion. Note this well: if we see something curve, we have to explain the curvature. We have to identify a force.

Consider a rocket put into motion on the rotating Earth. We are observers located on that spinning sphere. Once launched, we see the rocket start curving, and we give the force causing that curvature a name: the Coriolis force.

That Coriolis force is acting to the object's right, following its motion, in the NH[1]. Thus, if we launch the rocket northward, it cannot continue traveling due north. Instead, we see it start curving eastward, the direction to the object's right. The deflection does not stop there. Once eastbound, the Coriolis force works to bend the object to the south. Once southbound, Coriolis encourages a westward deflection. Finally, the westbound rocket starts curving towards the north, the direction we wanted it to travel in the first place. The object is has begun describing CW circles, called *Coriolis* or *inertial circles*.

In the paragraph above, the operative words are **we see**. From our point of view (POV), the rocket constantly deviates from straight-line motion. Since we see curvature, there must be a force, and we dub this the Coriolis force. This all makes sense from our POV, because it explains what **we see**.

However, the rocket didn't actually curve at all. The rocket was launched and allowed the go on its merry way. No other forces have actually intervened. Thus, the rocket went straight, as Newton's first law insisted it must. Yet, **we saw** it curve – and we blamed the deflection on the Coriolis force. How can we see a rocket curve when in actual fact it went straight? There is only one answer: if the rocket didn't turn, **we did!**

North: now and later

Chicago is directly north of New Orleans, as indicated in Fig. 1. That's true morning, noon and night. What's more, the relative positions of those two cities never changes – at least that's what **we see**. However, that's not the view seen from space, a POV looking down on the Earth. Not if the Earth is rotating, that is.

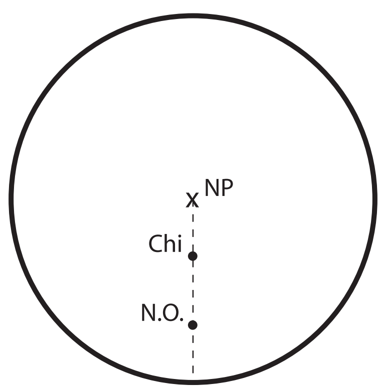

Figure 1: Chicago and New Orleans, seen from space.

Consider first a nonrotating Earth. If you launch a rocket from New Orleans to Chicago, and just let it go, no other real forces influencing its trajectory in the horizontal plane intervene. The rocket goes straight, and finds its target. Because we are not rotating, we also see the rocket go straight. It travels due north.

[1]It acts to the object's left in the southern hemisphere, and vanishes at the equator.

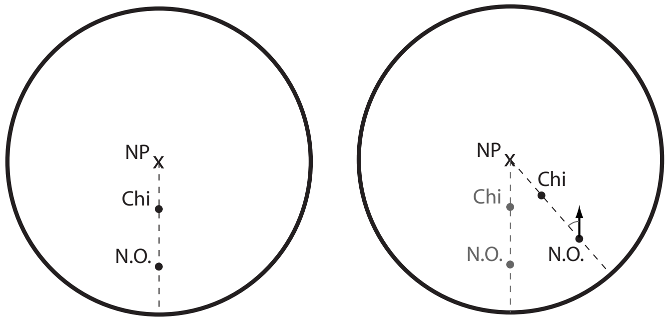

Figure 2: Chicago and New Orleans, now and later. What **we see** as a constant "north" shifts as the hours pass. A rocket launched northward from N.O. "now" goes straight, but appears to curve from our POV because we've redefined what "north" really is.

Yet, on a rotating Earth, what we call "north" is constantly changing – at least as seen from space. Figure 2 below depicts the relationship between our two cities as seen from above, both now and a few hours from now. The Earth is rotating counterclockwise (CCW) from this viewpoint, and both Chicago and New Orleans are being carried eastward. On a rotating Earth, the rocket still travels straight after launch. The rocket appeared to curve to our right because we ourselves turned CCW along with the Earth.

Rockets and winds

The upshot is that a rocket, once launched in a particular direction, cannot continue moving in that direction *by itself*. It would require nudging and guidance – additional forces – to compensate for the Earth's spin. Indeed, without such guidance, we cannot fire a rocket directly towards the pole and ever have it reach there. In the absence of other forces, the rocket would continue making endless inertial circles, effectively getting nowhere. From our POV, the rocket is turning; from its perspective, we're the ones who are turning. No matter. The rocket doesn't reach the pole.

If we can't do it with rockets, Nature can't do it with air. The equator-to-pole temperature difference is the fundamental driving force of our atmospheric circulation. Nature wants to create wind patterns that help reduce this thermal imbalance. On a nonrotating Earth, it at least has a chance of establishing a circulation resembling the local-scale sea-breeze. However, the Earth's rotation proves very frustrating to Nature. Outside of the tropics, air tends to blow either west-east or east-west, doing absolutely nothing about a north-to-south temperature imbalance.

When Nature gets frustrated, the result is storms. Heat imbalances in the vertical direction both provoke, and are at least partially ameliorated by, thunderstorms. Nature manages to at least partially slip the surly bonds of Earth's spin by conjuring up large-scale storms such as midlatitude and tropical cyclones. In the long run, these storms accomplish equator-to-pole heat transport, and help reduce the north-south heat imbalance.