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Giving Students a Better Understanding of the Concepts Behind the Coriolis Force

Ridge Cole
Utah State University

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Department of Physics

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Research Mentor: Boyd Edwards

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Abstract

The Coriolis force is a physical phenomenon that has proven difficult for students to understand for centuries. While the mathematical approach to teaching this phenomenon is well known and outlined, the concepts behind this force have proven to be very elusive to students. Through the use of modern technology and new ways of presenting these concepts, we hope to give students a clear understanding of the Coriolis force in the future.

Introduction

First suggested in 1679 by Sir Isaac Newton and Robert Hooke, shown mathematically by Gauss and Laplace in 1803, and shown to be the result of the sum of the centrifugal force and a "deflective force" by Gaspard Gustave Coriolis in 1835, the concepts behind the Coriolis force has caused many students confusion [1]. While students of upper-division classical mechanics classes learn how to manipulate Newton's second law in rotating frames using mathematics, they often cannot apply these ideas to an observer viewing a rotating frame from in inertial frame [2]. This interdepartmental project seeks to remedy this confusion with use of computer simulations, new lecture materials, and visualizations.

Theory

The mathematical approach to teaching how these different ideas and forces is well outlined in textbooks, such as *Classical Mechanics* by John R. Taylor. The conceptual approach to teaching the Coriolis force is not as well outlined. The Coriolis force addresses how gravity, the centrifugal force, the ellipsoidal shape of the earth, conservation of angular momentum, conservation of kinetic energy, and reference frames effect the movement (or apparent movement) of an object on the surface of the earth. How each of these forces or ideas affect the Coriolis force can be broken down into 12 points, each involving a new idea or force and how it effects the movement of a puck on the surface of a frictionless earth [3]. We have created lecture materials, software, and hands on visualizations to help teach these 12 points and how they affect the Coriolis force.

Process

As the current methods of teaching the Coriolis force have been shown to be ineffective [1], new methods need to be created. As stated before, these include computer simulations, new lecture materials, and visualizations.

The computer simulations come in the form of a new software titled “CorioVis” created by Dr. John Edwards of the Utah State University. This software is currently in a prototype stage, and features the ability to change from the sidereal to the geosynchronous point of view, different tracks to show the path from the geosynchronous and sidereal viewpoints, variable initial velocity and initial position, variable simulation speed, the choice between a spherical or elliptical earth (the elliptical earth is currently an approximation of an ellipse, but will eventually be a simulation of an ellipse). The current plan is to build on this groundwork to have a fully functional piece of software, capable of advanced Coriolis force simulations. It will eventually have a much more polished interface, more advanced controls, more detailed visuals, and more exact representations of how the Coriolis force effects movement.

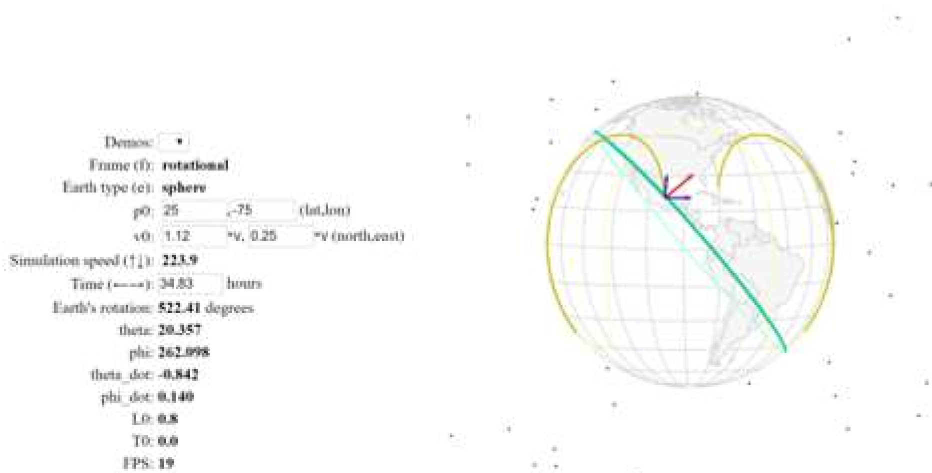

Fig. 1

Screenshot of the CorioVis software. The green line is the path seen by the sidereal observer, and the yellow line is the path seen by the geosynchronous observer. The left shows the

The new lecture materials primarily consist of a set of power point slides. These slides, created by me, are based on twelve fundamental ideas created by Jared Arnell, a grad student at USU. These fundamental ideas consist of progressively more advanced concepts. The simplest being the introduction of three reference frames (earthbound, geosynchronous, and sidereal), going through how an imaginary puck moves on a non-rotating spherical earth (this includes the introduction of a great circle, and important concept in the Coriolis force), how the puck moves on a rotating spherical earth, why the earth is not spherical but is an ellipse, how the puck stays at rest in the earthbound and geosynchronous viewpoints on an elliptical earth, how the conservation of angular momentum and angular velocity affect the movement of the puck, and the most advanced fundamental idea being how the puck would move if given an arbitrary initial velocity on the ellipse (in all the above cases, the earth is frictionless). The lecture slides explain how each of the 3 reference frames see the puck move through each of the viewpoints, with in depth explanations as necessary. As needed, CorioVis screenshots and links are included for clarity.

The final needed pieces are visualizations. Cade Pankey is creating a set of images (Fig.2) that show the force vectors for three points on the surface of increasingly eccentric ellipses. These are vital, as they give a visual representation for why objects can stay in one place on a frictionless, rotating ellipse. We have also created Styrofoam balls (Fig. 3) with lines drawn on them to help visualize the motion of the puck in various reference frames from a hands-on perspective. It can

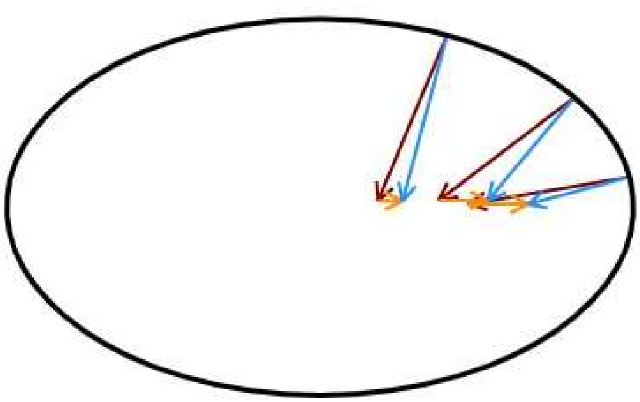

Fig.2
An ellipse with an eccentricity of 0.8. The red arrow is gravity, the yellow arrow is centripetal acceleration, and the blue arrow is apparent gravity.

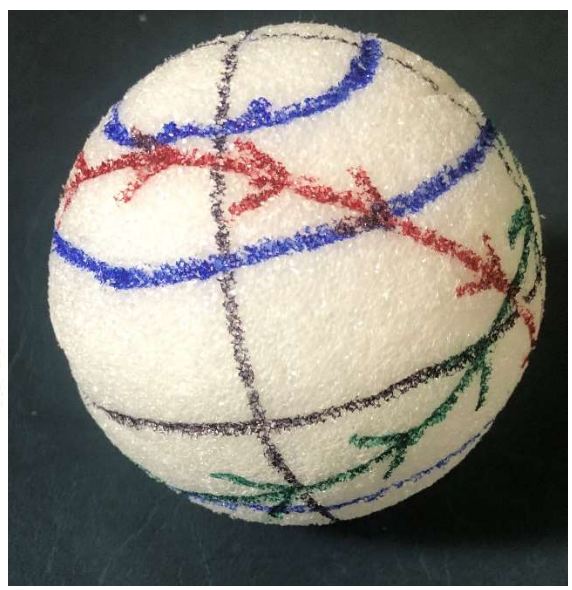

Fig. 3
A Styrofoam ball with latitude lines drawn on it (blue), equatorial and meridional great circles (black), and oblique great circles (red

and green) with arrows to help visualize
direction of travel.

be very difficult to visualize why the puck would move in a great circle, especially when the earth is rotating with the puck moving in a great circle from the sidereal reference frame. These balls are to help visualize such concepts.

Future Work

Thus far, this new method of teaching has not been tested. The lecture slides, software, and visualizations are all currently in the prototype or rough draft stage. Rough draft assessments have been created, by me, to test the effectiveness of our method verses the traditional method of teaching the Coriolis force. Dr. Edwards plans on using this new method to teach students at Utah State University's main Logan campus in a PHYS-3550 (intermediate classical mechanics) course. The students in this class are primarily STEM majors with strong backgrounds in mathematics and science. There are also plans in place to teach the Coriolis force to students in GEOL-1360 (introduction to earth science) at USU's regional campus, taught by Dr. B. Burger. These students are typically not majoring in STEM fields, and instead primarily major in Education. These different classes will allow the team to evaluate the effectiveness of the method to teach students of varying backgrounds and with differing levels of scientific knowledge. We hope to give science students everywhere a better understanding of the Coriolis force.

References

[1] A. Persson, History of Meteorology **2**, 1 (2005).

[2] A. Persson, Meteorological Applications **17**, 236 (2010).

[3] B. F. Edwards, J. Arnell, C. Pankey, J. M. Edwards, *Coriolis Force: Conceptual Understanding of Motion on our Ellipsoidal Earth*. Unpublished manuscript