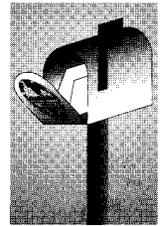


letters to the editor

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An Apparatus for Demonstrating the Inertial Oscillation

When teaching students about the Coriolis force, it is often helpful to show them a physical demonstration illustrating the effects of Coriolis accelerations. One such demonstration involves a rotating table across which objects may be rolled, thrown, or slid. An example of this type of demonstration, which was conducted at the University of Washington, consisted of a 12-inch-diameter plywood disk covered with carbon paper that was rotated by hand while a ball bearing was rolled across its surface. The influence of the apparent forces in the rotating frame of reference was revealed by the deviation of the ball-bearing trace from a straight line.

Although this type of demonstration is quite suitable for illustrating the action of apparent forces, it provides a poor model for particle (or air parcel) motion on the surface of the Earth. Objects moving without friction on the rotating turntable are subject to an unbalanced centrifugal force, whereas the centrifugal force acting on objects moving along one of the Earth's geopotential surfaces is balanced by a component of true gravity. The difference between these two situations becomes obvious if one considers the behavior of a frictionless puck launched at some small velocity by an experimenter riding on each platform. In the case of the rotating Earth, the puck undergoes an "inertial oscillation" that returns it periodically to the experimenter with a period of $2\pi|f|^{-1}$ (Durrant 1993; Holton 1992, p. 64). On the other hand, a puck launched by an experimenter on the rotating turntable will not generally return to the experimenter, and if it does return to the experimenter, it will do so only once. The behavior of the puck on the rotating table may be understood by noting that when viewed from a fixed frame of reference

the trajectory of the puck is a straight line and the trajectory of the experimenter is a circle. The circle and the straight line intersect in no more than two points, and if the puck is launched with an arbitrary initial velocity by the experimenter as it leaves the first intersection, it will generally not arrive at the second intersection at the same time as the experimenter. Even if the puck is launched at exactly the right velocity to arrive at the second intersection at the same time as the experimenter, the puck will then continue along its straight-line trajectory away from the circle and will never return to the experimenter again (see Fig. 1).

Thus, although it provides a nice general illustration of apparent forces, the rotating turntable model can be misleading to students trying to understand the role of apparent forces in a coordinate frame rotating with the Earth. One way to obtain a better physical model for motion on the rotating Earth is to deform the flat turntable into a paraboloidal dish rotating around a vertical axis such that the inward gravitational acceleration along the surface of the dish exactly balances the outward centrifugal acceleration. In the late 1950s, Professor Norman Phillips created such a paraboloidal dish at the Massachusetts Institute of Technology by placing a pie pan filled with slightly liquid cement on a rotating table and letting the ce-

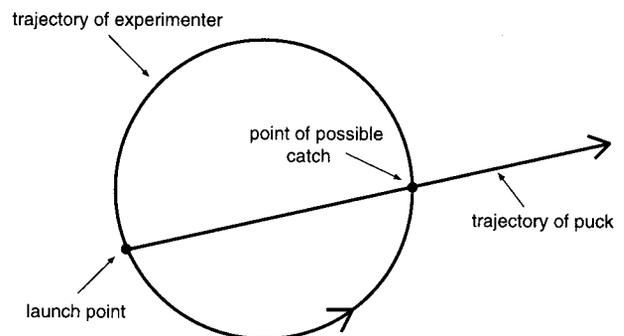


FIG. 1. Puck and experimenter trajectories for motion on a flat rotating turntable, as viewed from a fixed frame of reference.

ment harden while the turntable was left running overnight. He subsequently polished the cement surface to a very smooth finish and created a low-friction "puck" by filling a hollow plastic cylinder with liquid nitrogen. As the liquid nitrogen evaporated, it escaped through a hole in the bottom of the puck and supported the puck on a thin layer of gas. To obtain a picture of the puck's trajectory in the frame of reference rotating with the dish, Phillips drew circles on the surface of the paraboloidal dish and showed that the puck would follow these circles when given an appropriate initial velocity. Thanks to the substantial advances in electronics that have occurred since the 1950s, it is now possible to repeat Phillips's demonstration using a pair of inexpensive, miniature video cameras to simultaneously view the inertial oscillation in both the rotating and fixed reference frames. We recently constructed such an experimental apparatus in the Department of Atmospheric Sciences at the University of Washington. The remainder of this note will describe this apparatus and its use in the classroom.

A photo of the entire unit and a close-up of the miniature cameras and the rotating dish appear in Fig. 2. The puck travels within a 17-inch rotating parabolic dish driven by a variable-speed motor. From a pedagogical viewpoint, it would have been nice to follow Phillips's original strategy of creating a parabolic surface by rotating a dish of slightly liquid cement until the cement hardened, since this construction provides experimental confirmation that the free surface of a rotating fluid must deform into a paraboloid in order to be in equilibrium with the Earth's gravitational field. Nevertheless, we deemed it easier to purchase a commercially available parabolic dish and to drive

it at the appropriate speed (roughly 54 rpm) with a variable-speed motor. (We use a 24VDC variable-speed reversible Dual Servo Gearhead motor.) The aluminum dish is black anodized to reduce glare. The coupling between the dish and the motor includes a "rocking" adjustment that allows precise alignment of the center of the dish with the axis of the motor.

The view from the rotating frame of reference is captured by a miniature, black-and-white video camera mounted together with a transmitter for the video signal and a 12-V battery inside a 6-inch-diameter Plexiglas cylinder. The axis of this cylinder is aligned with the axis of rotation of the parabolic dish, and the camera unit is driven by a second 24VDC Dual Servo Gearhead motor. The video-signal receiver and its antenna are placed directly outside the rotating camera assembly to provide close coupled transmission of the video signal. A second miniature video camera is mounted adjacent to the rotating camera assembly to provide video imagery from the fixed reference frame. The video signals from these two cameras can be simultaneously displayed on two TV monitors to facilitate the comparison of the views from the fixed and rotating reference frames. The total retail price of the video transmitter and receiver and the two miniature video cameras was \$520.

Since it is difficult for us to gain easy access to small amounts of liquid nitrogen, we did not attempt to exactly replicate Phillips's puck but rather used a simple expendable puck consisting of a 1/2-inch-diameter disk cut from commercially available rods or "palates" of dry ice. The gas sublimating off the bottom of the disk almost eliminates the frictional coupling between the puck and surface of the parabolic dish.

Classroom demonstrations with this apparatus typically center around three examples. First, to orient the students, the puck is launched such that it is motionless in the rotating frame of reference (and appears to follow a circular orbit around the center of dish in the fixed frame). Second, the puck is placed on a trajectory that lies within a fixed vertical plane containing the axis of rotation of the parabolic dish. When viewed from the position of the miniature video cameras, this trajectory appears as a line segment in the fixed frame and a circle tangent to that line segment in the rotating frame (see Fig. 2 of Durran 1993). In the third example, the puck is again launched so that it appears to be motionless in the rotating reference frame and is then slightly perturbed. When viewed from the rotating reference frame, the perturbed puck appears to undergo inertial oscillations consisting of small cir-

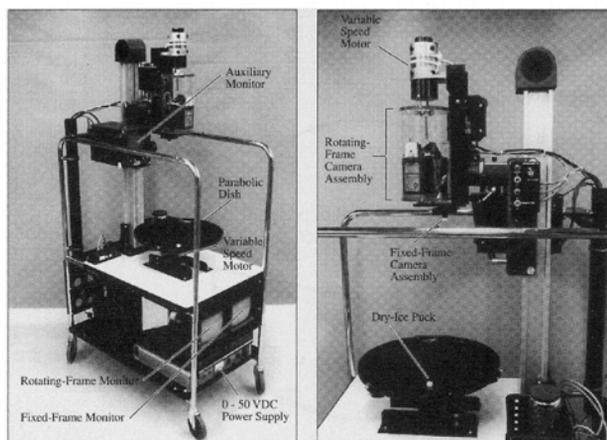


FIG. 2. The experimental apparatus.

cular orbits passing through the initial position of the unperturbed puck.

Once we actually began using the apparatus, we realized that if there were absolutely no frictional coupling between the puck and the underlying parabolic dish, it would not matter whether or not the parabolic dish was rotating. Thus, one could conceivably economize by motorizing only the unit containing the rotating-frame camera. Nevertheless, in practice it is handy to be able to switch the rotation of the parabolic dish on or off. The first of the previously described demonstrations (in which the puck is motionless in the rotating coordinate frame) is more easily accomplished with the dish spinning—indeed, the slight effects of friction help keep the puck motionless with respect to the rotating coordinate frame. On the other hand, the second demonstration is more easily conducted with the dish stationary since

the straight-line, fixed-frame trajectory is eventually modified by the slight frictional coupling between the puck and the rotating dish.

References

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