INSTRUCTOR NOTES
Accelerating reference frames: Rotating frames

Emphasis

This tutorial is the second of a series of three on accelerating reference frames. The emphasis here is on frames moving with purely rotational motion with respect to an inertial frame. The tutorial guides students to apply correctly the concepts of centrifugal, Coriolis, and transverse "forces" as fictitious "forces."

Prerequisites

It is recommended, though not required, that students have completed the tutorial *Accelerating reference frames: Inertial "force" and local acceleration due to gravity* before starting this tutorial. It is also recommended that the three aforementioned fictitious "forces" be introduced in lecture prior to the tutorial. Finally, one of the homework problems cycles back to ideas covered in the tutorial and tutorial homework *Simple harmonic motion.*

TUTORIAL PRETEST

The pretest poses two tasks dealing with force and motion as observed in a reference frame rotating at a constant rate relative to an inertial frame. The first task involves a puck on a carousel rotating clockwise relative to the ground. The students are told that, in the frame of the carousel, the puck is given a small shove toward the center of the carousel and are asked to give possible trajectories for the puck as viewed both in the carousel frame and the (inertial) frame of the ground. In the second task students consider a pebble that is dropped from a great height (the top of an empty elevator shaft in the Empire State Building). Taking into account the rotation of the Earth, students are asked to predict where (qualitatively) the pebble will land relative to the point on the floor (called point *P*) that lies directly beneath the release point.

Both tasks often prove difficult for many students. Even after lecture instruction on the Coriolis "force" students do not predict that the puck must pass to the left of the center of the carousel. Even students who recognize that the puck will miss the center of the carousel according to an observer in the carousel frame will predict incorrectly that the puck *will* pass directly over the center of the carousel according to an observer in the *ground* frame. This type of response suggests the failure to recognize that events observed in both frames must be consistent. Such responses also indicate the lack of understanding how velocity vectors in both frames must relate to each other *(i.e.,* according to $\vec{v} = \vec{v}' + \vec{\omega} \times \vec{r}'$*).* Finally, on the task about the falling pebble, students are free to answer by thinking about the motion in either an inertial frame—based on the inference that in such a frame the initial velocity of the pebble is not zero—or in an Earthbound reference frame—based on their knowledge of fictitious "forces." Either way, difficulties like those described for the task about the puck on the spinning carousel also arise here, leading many students to incorrectly predict that the pebble lands to the west (not to the east) of point *P.*

TUTORIAL SESSION

Equipment and handouts

Each group will need a whiteboard and set of markers, or a large sheet of paper. Each student will need a copy of the tutorial handout (no special handouts required).

Discussion of tutorial worksheet

Section I: Review of fictitious "forces"

The opening section offers a brief review of all types of fictitious "forces" encountered in the study of accelerating frames. Rather than prove the mathematical expressions of each "force" (which is left to the instructor), students interpret each expression in their own words by describing specifically under what conditions each "force" may become important in the analysis of any given situation.

Section II: Motion on a rotating plaform

The bulk of the tutorial resides in this section, in which students must apply their knowledge of fictitous "force" in situations similar to that described from the first pretest task. Students consider two pucks that move along the frictionless surface of a platform that rotates counter-clockwise at a constant rate relative to the lab (inertial) frame. They are guided through the reasoning necessary to draw qualitatively correct free-body diagrams for each puck in the platform frame and to predict the trajectory of each puck when viewed in either the platform frame or the lab frame. They are also guided to recognize how the trajectories in both frames for a given puck must relate to each other.

The checkpoint at the top of page 3 is vital for checking the results and explanations that students give for parts A – C of this section. Make sure students use appropriate right-hand rules to determine the directions the vector cross products in the expressions for the fictitious "forces." For example, do not accept memorized results such as "the centrifugal 'force' always points away from the axis" without having students show that this result comes from the triple cross product. In addition, some students may forget that each position vector $\vec{r}'$ must point away from the origin of the platform frame coordinate system, or they may forget the overall minus signs in the fictitious "force" expressions.

Students conclude the tutorial in part D by considering three other possible motions of the platform: (1) the platform rotates counter-clockwise more quickly than before (but still at a constant rate), (2) the platform spins clockwise rather than counter-clockwise, and (3) the platform spins counter-clockwise but with decreasing (not constant) angular speed. Students should be able to compare and contrast the free-body diagrams for the pucks in each of the above cases to the results they obtained for the original situation. As before, make sure students accurately interpret the vector expressions for each fictitious "force." For example, in the third situation—in which angular acceleration must be opposite in direction from angular velocity—some students may use that fact to state incorrectly that the transverse "force" must also be opposite in direction from the Coriolis "force."

TUTORIAL HOMEWORK

The homework contains a variety of problems that require students to apply the ideas covered in tutorial both qualitatively and quantitatively. (In addition, some of the problems from the tutorial homework *Accelerating reference frames: Inertial "force" and local acceleration due to gravity* involve rotating frames and may be assigned as well.)

1. Students are given a situation similar to those presented in tutorial, except they must in effect "work backwards." Given the trajectory of a puck as viewed in the frame of a rotating platform, students must deduce information about the motion of both the platform and the puck as viewed in the lab frame.
2. Students revisit the pretest task about the falling pebble.
3. This problem explores the notion of "simulated gravity" on a rotating space station. Students answer qualitative questions (similar to those about the falling pebble in Problem 2) and quantitative questions relating the size and angular speed of the space station to the amount of "simulated gravity" experienced by its occupants.
4. The final problem involves a simple harmonic oscillator as viewed on a rotating platform. This problem also contains both qualitative and quantitative questions, including one question in which students must apply their knowledge of the correct form of differential equation that applies to simple harmonic oscillators. (Prior completion of the tutorial and the tutorial homework *Simple harmonic motion* is recommended if this problem is assigned.)