OCEAN DYNAMICS (5350)

Lab #1: Solid Body Rotation (50 pts)[1]

Name: ________________________________ Lab Report Due: **Tuesday, 2 September**

Purpose

This lab introduces the concepts of solid body rotation, equipotential surfaces, and the modification of gravity due to centrifugal forces in rotating fluids.

Background / Theory

One can view the dynamics of a rotating fluid from two perspectives – the non-rotating (or inertial) reference frame and the rotating reference frame. The motion of fluid particles in a rotating ocean appears different to an observer *outside* of the rotating reference frame than to an observer *inside* the rotating reference frame. This makes sense when we consider the Earth's motion relative to the Sun. We know that in our solar system, the Sun's position is fixed and that the Earth rotates; however, from inside the rotating reference frame of the Earth, it appears as if the Sun revolves around the Earth. Thus, the first challenge in studying ocean dynamics is to understand the significance of working within a rotating reference frame.

An interesting property of rotating fluids is that, over time, they will achieve solid body rotation if shielded from external forces. Solid body rotation can be defined as the point at which there is no longer any relative motion between the fluid and the rotating body containing it. For any rotating, self-gravitating body (like the Earth) in solid body rotation, at least two forces are always present – the acceleration due to gravity and the outward centrifugal acceleration.

[1] Adapted from GFD Lab Experiments presented in *Atmosphere, Ocean, and Climate Dynamics: An Introductory Text* by J. Marshall and R. A. Plumb, 2008.

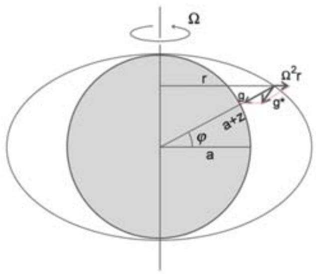

FIGURE 1: A spherical body, when subject to rotation, will adjust its equipotential surface, over geologic time, to become an oblate spheroid. Their equatorial radii exceeding their polar radii, the Earth and Jupiter are both examples of oblate spheroids.

You may remember from physics that an equipotential surface is defined as one to which the force of gravity is everywhere perpendicular and equal. On a rotating, spherical body (shaded gray in Figure 1), the force of gravity alone acts normal to the surface and downward toward the center of the sphere. The sum of the centrifugal acceleration and gravity results in *measured* or *effective gravity*, which creates a new equipotential surface resembling an ellipse in two dimensions, or an oblate spheroid in three dimensions.

Procedure

1. You will work together to complete this lab; however, each person must submit their own lab report. See the “Lab Report” section for requirements.

2. Ensure the turntable is level. Center the clear, square acrylic fluid tank on the turntable. Fill about half the tank with water.

3. Begin rotating the tank at 10 rpm. Immediately drop a paper dot anywhere in the tank but the center and watch it in the monitor. What do you observe the dot doing?

4. Let the tank continue to rotate uninterrupted for 5 minutes. Drop another paper dot into the tank and watch it in the monitor. What do you observe the second dot doing? How is it different from your observations of the first dot?

What do you observe about the surface of the water in the tank?

5. Increase the rotation rate of the tank to 15 rpm. Let the tank rotate uninterrupted for 5 minutes. What do you observe about the surface of the water in the tank?

6. Being careful not to hit the camera post, position your hand over the tank in the field of view of the camera and look at the monitor. What do you observe?

7. Increase the rotation rate of the tank to 20 rpm and allow the fluid to achieve solid body rotation. Using the metal spatula, drop a few crystals of potassium permanganate into the exact center of the tank and observe them as they fall to the bottom of the tank. Next, drop a few more crystals into the tank about halfway between the center and a corner of the tank and observe. What do you notice about the descent of the crystals at this location? (You may repeat this process if needed in other parts of the tank.)

Questions

Refer to Figure (1) to answer questions (1) through (3) and (10):

1. Assume that Figure (1) depicts the Earth (shaded circle) just after it has achieved solid body rotation. Define (in words) all the quantities in the figure (Ω, r, a, z, φ, g, g^*, and $\Omega^2 r$).

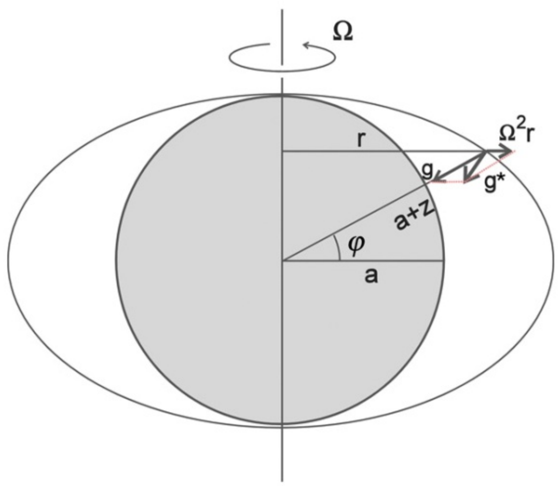

FIGURE 1

2. If $z << a$, then we can say $a+z \sim a$. Given this approximation, define r in terms of a and φ.

3. If $\mathbf{\Omega}$ and $\mathbf{r}$ are vectors, what does the vector quantity $\mathbf{\Omega} \times \mathbf{\Omega} \times \mathbf{r}$ represent?

4. What accounts for the difference in the motion of the paper dots in steps 3 and 4 of the lab procedure?

5. How do you explain the shape of the fluid surface in steps 4 and 5? Why did it take on the shape it did?

6. What is the relationship between the surface shape and the rotation rate of the tank? Which planet would you expect to have a larger equatorial bulge – the Earth or Jupiter – if Jupiter's period of rotation is 9 hours?

7. Explain the reason for the motion of your hand in the monitor in step 9.

8. Explain how the sinking potassium permanganate crystals illustrate the same concepts as Figure (1).

9. Do you think your fluid ever actually achieved perfect solid body rotation? Why or why not?

10. **EXTRA CREDIT (5 points):** If the following equation describes the height of a equipotential surface, z^*, at a given latitude,

$$z^* = z + ((\Omega^2 a^2 \cos^2 \varphi)/(2g)),$$

write an equation to find the height of the water in the rotating tank at any radius from the center of the tank. Given that the height of the water at the exact center of the tank is 10 cm and $\Omega \sim 1$ s^{-1}, compute the water's height at r = 0.30 meters.

Concept Map

Create a concept map which correctly shows the relationships between the following terms (you can add terms if you like):

SOLID BODY ROTATION	CENTRIFUGAL ACCELERATION
GRAVITY	EFFECTIVE GRAVITY
REFERENCE FRAME	ROTATING
INERTIAL	OBLATE SPHEROID
ROTATION RATE	PARABOLIC
EQUIPOTENTIAL SURFACE	FLUID
PERPENDICULAR	

Lab Report

Your lab report must contain the following:

1. A typed cover sheet with the name of the lab, date submitted, and your name.

2. An executive summary, or abstract, of the lab. The abstract should address the theory, methods, observations, and results/conclusions in 10 sentences or less. The abstract must be typed and single-spaced.

3. Complete answers to the lab questions (1-9, 10 is extra credit). Your answers may be typed or handwritten, or both. Be as thorough as you can.

4. Your concept map (handwritten or computer-generated).

Your lab report will be graded on both presentation (neatness) and content. Show pride in your work.