Lab #1
Statics: Force on an Inclined Planar Surface
CEE 3310 Fall 2017

Safety
The major safety hazard in this laboratory is a shock hazard. Given that you will be working with water and items running on standard line voltages (the pump and the computer) you should pay attention to the possibility of electric shock. If water spills on the desktop, please clean it up IF there is no risk of shock. If water gets near a 110 Volt electrical connection (i.e. a wall outlet or anything connected to it) DO NOT clean it up. Seek a TA, Cowen, or one of the CEE technicians (Tim Brock, Paul Charles, or Cameron Willkens, who have offices across from the lab) for help.

The lab has many research tools that are potentially dangerous in un-trained hands. We implore you to not touch anything that you have not been invited to use in the CEE 3310 labs.

Particularly important, if you are about to enter the lab and you notice that the "Laser in use" sign is illuminated. DO NOT ENTER. Knock loudly and see what is going on or find a TA, one of the CEE technicians, or Cowen.

If you enter and you see a cyan blue or greenish laser beam light DO NOT LOOK AT IT. Turn away and ask loudly if it is O.K. to enter or leave and seek out a TA, one of the CEE technicians, or Cowen. This should not occur but if it does follow the above procedures.

Always work with a minimum of two people.

Objectives
In this laboratory you will measure surface forces acting on an inclined circular plane surface located in a small tank. You will compare measured values of force with theoretical values. You will also investigate the difference between the centroid, the center of pressure, and the line of action of the resultant force.

Theory
Because pressure increases with depth the pressure acting on a submerged surface is a function of depth. The distance from the point where the resultant pressure is calculated to the line of action is (make sure you see why! – note θ is defined relative to the vertical and hence $\cos\theta$ is the appropriate term):

$$y_{RC} = \frac{\gamma \cos\theta}{p_c}\frac{I_{xc}}{A} \qquad 1$$

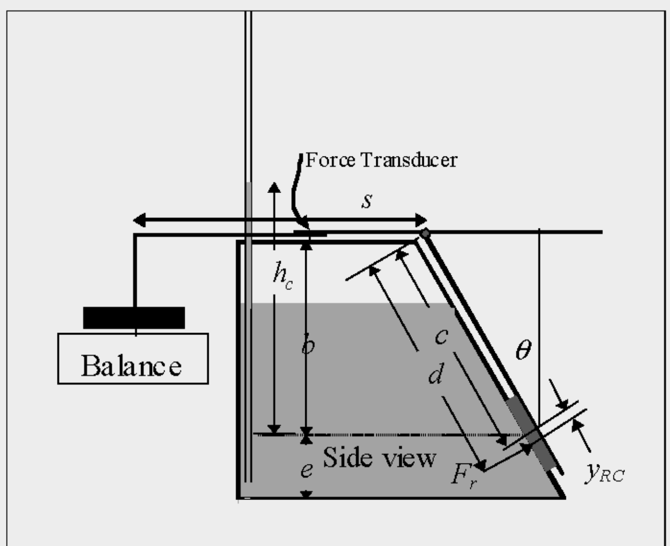

Figure 1. Schematic drawing of the experimental apparatus used to measure surface forces.

where A is the area of the port. The second moment of a circle is:

$$I_{xc} = \frac{\pi}{4}R^4 = \frac{A}{4}R^2 \qquad 2$$

Substituting equation 2 into equation 1 and solving for the distance along the submerged surface plane between the centroid of the circular surface and the location of the resultant force, we have

$$y_{RC} = \frac{\gamma \cos\theta}{p_c}\frac{R^2}{4} \qquad 3$$

The distance c is equal to the distance from the hinge to the centroid of the circular port; the distance d is equal to the distance from the hinge to the line of action of the circular port and y_{RC} is the distance from the centroid to the line of action, i.e.,

$$d = c + y_{RC} \qquad 4$$

The force acting on a submerged surface is

$$F_R = p_c A = p_c \pi R^2 \qquad 5$$

The moment caused by the water pressure in the tank will be transferred by the "y-shaped" aluminum arm, basically a lever, to the electronic balance. The electronic balance will give a reading of mass (in grams). A force (*Fw*) can be calculated from the mass by

$$F_w = Mg \qquad 6$$

Based on the sum of the moment equation, we know that the moment from the weight must be equal and opposite of the moment from the pressure

$$F_w s = F_r d \qquad 7$$

Since the apparatus will be balanced prior to the experiment, you do not need to worry about the weight of the aluminum arm. Finally, solving for the registered mass M at the balance we have:

$$M = \frac{F_r}{g}\frac{d}{s} \qquad 8$$

Experimental Methods

The apparatus consists of an enclosed tank with a circular port fitted with a circular plug that does not contact the port (i.e., it fits just inside the port) that is covered with a thin membrane (Figure 1). A matching circular port mounted on a hinge supports the membrane. The membrane transmits pressure from the water to the plug. Although the port is hinged its motion is constrained by the balance and by stops so that it always touches the membrane.

Water can be added to the tank by using the provided red pump (which is of centrifugal type). It is important that the centrifugal pump not be operated dry. The pump relies on water for lubrication and the pump will be damaged in about 60 seconds if it is run without water inside it! You will not have to worry too much about this problem for this particular lab because the pump intake is submerged in a bucket of water.

A valve is present to control the flow of water. Note that the valve handle points inline with the tubing when it is open, and points perpendicular to the tubing when it is closed. Also note that the unlabeled tubing leads to the bucket. Use the switch on the power strip that ONLY the pump is plugged into to turn the pump on and off. You can drain the tank by gravity by simply opening the valve and leaving the pump off. If you want to hold a level of water you will need to close the valve to the pump. Do NOT leave the pump running with the valve closed, as this will damage the pump. Make sure before starting the lab that the bucket containing your pump is at least half way full of water.

The peristaltic pump is used to provide air pressure to the facility. During this lab, please turn OFF the peristaltic pump when you are not pumping air in or out of the tank. The tubing connecting the peristaltic pump to the facility also has a T-fitting and a valve. When you open this valve the headspace in the tank is exposed to atmospheric pressure. When you close this valve the peristaltic pump controls the air pressure.

General Procedure:

1) Drain the water in the tank to below the level of the port and make sure the air valve is in the open (flowing) position (exposing the tank to atmospheric pressure).

2) Zero the electronic balance.

3) Begin filling the tank with water. When the tank is filled to the desired level, close the water valve and turn off the pump with the power strip switch.

4) (Trials 2-4 only). For trials requiring pressures other than atmospheric, close the air valve. The pump direction can be reversed with the motor direction switch (pump away from the door where you enter) or simply by flipping the flexible tube in the pump head to exit off the opposite side of the head (must do this for pump near the door). To maintain a constant air pressure, you may try turning off the peristaltic pump, but if the apparatus leaks air (which it will most likely do), you will need to try to maintain the desired gage pressure by cycling the air pump on/off or running it continuously at a slow flow rate. Although you are asked to reach "approximate" gage pressures, it is imperative that you record the actual gage pressure you reach (i.e., we said approx 5 cm... if you get 6.3 cm, record 6.3 cm).

5) Maintain the water level/air pressure for 10 seconds and record the balance reading (approximate average you saw during the 10 s).

6) Accurately measure the vertical distance from the centroid of the port to the free surface (i.e., where the water surface is at atmospheric pressure). Note: sometimes the water surface inside the tank is not at atmospheric pressure.

7) Repeat steps 3 through 7 for trials 1 through 4. Turn off the power strip that powers the pump when you are done.

The measured values of the apparatus parameters are given in Table 1.

Table 1. Apparatus measurements.		
Parameter	***Description***	***Value***
r_s	Radius of the plane circular port	3.7 cm
c	Slant distance between the hinge and the center of the port.	16.5 cm
b	Vertical distance between the center of the port and the outside top of the tank	13.8 cm
θ	Angle between the vertical and the port surface	30 deg
s	Horizontal distance from hinge to electronic balance	34.5 cm
e	Vertical distance between the bench-top and the center of the port	7.8 cm

Table2. Suggested trials.					
Trial	**Water level in tank**	**Air pressure in tank**	h_c	$M_{measured}$	$M_{calculated}$
1	Top of port	Atmospheric			
2	Top of port	5 cm of water gage			
3	5 cm above port	Atmospheric			
4	5 cm above port	-5 cm of water gage			

<u>Check Out Questions:</u>

1) Measure the registered mass at for each trial and record the actual height of the water column h_c in the vertical clear tube.
2) Calculate the expected mass $M_{calculated}$ at the balance based on hydrostatics.
3) Make a plot (Excel or Matlab) showing a comparison between the measured masses on the scale versus your calculated values based on hydrostatics. How does your calculated estimate compare to the measured value? How do you explain any differences?
4) Explain why M changed between the first 2 cases even though the free surface didn't move.
5) In general as you fill and drain the tank to fill in the table above and cover and uncover the port, observe how the force (weight on the scale) responds. Over the course of your efforts watch this carefully, when is the variation of force linear with depth? When is the variation non-linear with depth? Why!

Feel free to play with the apparatus a bit when you are done!