Rotational Equilibrium

Materials: *Torque balance table, mass sets and hangers, rulers, and clean paper*

1 Purpose

The purpose behind this experiment is to learn about and experiment with torque balancing. We all do this each day as we go through our daily lives (walking and sitting is a force and torque balancing experiment).

2 Introduction

2.1 Torque Defined

Torque (τ) is the rotational equivalent of force and is a vector (direction does matter). Fig 1 identifies key parameters referred to throughout the text in this section.
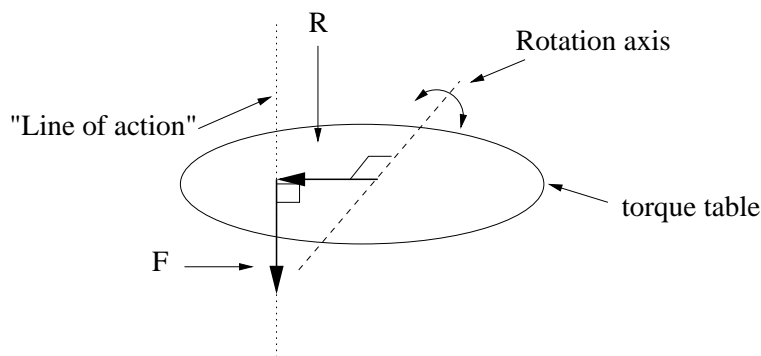

Figure 1: *This diagram identifies some key components relating to this exercise and description of the principles relating to torque.*

To define torque, we need an object with a chosen rotational axis. A force $\vec{F}$ is then applied along some "line of action" which acts at a point a vector distance $\vec{R}$ from the axis of rotation. The torque is then the vector product of the force and the vector distance.

$$\vec{\tau} = \vec{R} \times \vec{F} \tag{1}$$

Using the rules for the cross product (a.k.a. the vector product), the magnitude of the torque can be calculated by the following expression.

$$|\vec{\tau}| = RF \sin \theta \tag{2}$$

where R and F are the magnitudes of the vectors $\vec{R}$ and $\vec{F}$. The angle is defined as the angle between the two vectors. Expressly, this just represents the component of $\vec{R}$ which is perpendicular to the vector $\vec{F}$. The direction is defined by using the conventional right handed coordinate system and is mutually perpendicular to both $\vec{R}$ and $\vec{F}$. The right-hand-rule (RHR) can be used to determine the direction of the rotation from a visual point-of-view. This is done by wrapping one's four right-hand fingers and pointing them in the direction of $\vec{R}$ and then bending them to align with the force $\vec{F}$. Then extend your thumb out and now it points in the direction of the torque. Notice that is direction is the orthogonal (90°) direction relative to the rotating plane of the force and vector distance.

By convention the sign on the torque is "+" for counter-clockwise rotations in the plane (torque pointing toward you) and "−" for clockwise rotations (torque pointing away from you) as they are view by the one performing the calculation. Please be aware that vector products are not commutative which

means that your friend looking at you will specify the opposite direction to the torque. This convention is standard and unless you otherwise specify I will assume you are working with the right-handed coordinate system. Lastly, we need to work out the units on the torque. Inspecting Eq (1) above, we can see that the units on the torque are meter×Newton or in short hand $m \times N$. Note that since torque is a vector product and results in a vector that this is fundamentally different than the unit for work. Do not confuse them.

3   Procedure/Data Collection/Analysis

Today's experiment will have you calculate and test a total of six (6) different combination of mass values and placements as prescribed in table 1. For each setup:

1. Calculate the expected mass(es) necessary to balance the system at the prescribed location(s). *Note:* Your instructor will demonstrate how to show your calculations – be sure to follow their instructions, keep your calculations well labeled, neat and organized.

2. Experimentally determine the mass required to balance the system by adding mass to each location until the table is balanced (record these data).

3. Calculate a percent difference between each theoretically determined mass and your experientially determined mass. In this case, use:

$$\%Diff = \frac{m_{exp} - m_{th}}{m_{th}} \times 100\% \tag{3}$$

4. Create a table to summarize your results. This should include your values for each experimentally and theoretically determined mass (i.e.: any '∗' in table 1) and the calculated percent difference for each. *Hint: This is an excellent time to use formulas in Excel. If you do not already know how, ask!*

Table 1: This table identifies *total* mass to be used ($m_{\#}$; including the mass of hanger) at each location ($x_{\#}$ and $y_{\#}$). A '∗' indicates a mass that you are to determine theoretically and experimentally. The '–' indicates that particular mass is not used for that setup.

Setup →		A	B	C	D	E	F
	m_1 [kg]	0.150	0.090	0.150	0.100	0.300	0.100
Mass 1	x_1 [m]	+0.100	0.000	+0.150	+0.150	+0.150	+0.150
	y_1 [m]	0.000	-0.250	0.000	+0.150	+0.150	0.000
	m_2 [kg]	∗	∗	0.120	∗	∗	0.125
Mass 2	x_2 [m]	-0.150	0.000	0.000	-0.050	-0.100	-0.200
	y_2 [m]	0.000	+0.075	+0.075	0.000	+0.050	0.000
	m_3 [kg]	–	–	∗	∗	∗	∗
Mass 3	x_3 [m]	–	–	-0.075	0.000	0.000	0.000
	y_3 [m]	–	–	0.000	-0.050	-0.125	+0.200
	m_4 [kg]	–	–	∗	–	–	∗
Mass 4	x_4 [m]	–	–	0.000	–	–	+0.075
	y_4 [m]	–	–	-0.150	–	–	-0.150

4   Questions

There are no additional questions prescribed by this handout for this laboratory exercise. Be sure to completely address any additional questions or parts as prescribed by your instructor.