Torque & Rotation Simulation

At-Home | One Week | Summary Submission

Introduction

This experiment explores the key kinematic parameters of a system rotating about a central point. That system will be a simulated seesaw on which chosen masses can be placed in chosen locations. The concept of torque and its dependency on both mass and position will be illustrated by predicting and testing an arrangement of these objects such that equilibrium is maintained. Additionally, the practice of experimental design will be reinforced by developing a method to find the mass of an unknown object indirectly using the concepts noted above. Finally, the established relationships between mass, position, and torque for the system in equilibrium will be extended to a disequilibrium context in which rotational kinematics will be used to calculate the system's motion, both rotational and translational. In this way, an intuition for rotational kinematics is developed and gradually extended into a comprehensive model which relates masses, positions, torques, and angular motion for a composite system.

Theory

Just as objects which accelerate do so as the result of forces, objects that rotationally accelerate do so as the result of torques. The torque τ that a force F exerts on a rotating object depends on the distance l of the moment arm (the vector from the fixed point the object is rotating about to the force) and the angle θ between the direction of the force and the moment arm. The equation below summarizes this relationship.

$$\tau = lFsin\theta$$

Sometimes, the force acting on the object is perpendicular to moment arm. *In that specific case* the angle in the equation above is 90°, and it becomes even simpler.

$$\tau = lF$$

Just as Newton's second law relates net force to the acceleration of an object, the rotational version of Newton's second law relates net torque to the angular acceleration α of an object.

$$\tau_{net} = \tau_1 + \tau_2 + \tau_3 + \cdots = I\alpha$$

In comparing Newton's second law to Newton's second law for rotation, we've established that torques are analogous to forces and angular acceleration is analogous to acceleration, leaving the moment of inertia I as analogous to mass.

This parameter is dependent on both the mass of the object, its shape, and the point about which the object is rotating. Because it's dependent on all these things, formulas for common shapes are usually referenced to calculate the moment of inertia. The equation for the moment of inertia of a uniform rod of mass m and length L rotating about its center is given below, as well as that of an object of mass m rotating about some external point a distance l away.

$$I_{rod} = \frac{1}{2} m_{rod} L^2$$

$$I_{obj} = m_{obj} l^2$$

To connect rotational kinematics to translation kinematics: every point on an object with an angular acceleration also has a tangential acceleration – in addition to rotating, that point can be said to be accelerating in the direction it's moving in that instant. Rotational acceleration α can be related to the tangential acceleration a using the moment arm l, as shown below. Similar relationships exist to relate other rotational parameters to their translational counterparts.

$$a_t = \alpha l$$

Procedure

This experiment is performed in an online simulation, accessed using the link below.

https://phet.colorado.edu/sims/html/balancing-act/latest/balancing-act_all.html

To access the simulation and formalize your results, you'll need:

- A device with internet access
- Microsoft Word (or equivalent) to write up your summary

Getting Started with the Simulation

1. On your device, access the PhET simulation called "Balancing Act" using the link provided in the section above. On the landing page, select the "Balance Lab" option.

2. Before diving in, make sure the boxes for “Mass Labels” and “Level” in the “Show” panel are both checked and that the box for “Rulers” in the “Position” panel is checked.

This simulation lets you to drag multiple objects of different masses onto the seesaw and then observe the effect of these masses on its rotation after removing the supports (the switch at the bottom of the page removes and replaces the supports). Get some practice placing a few objects, removing the supports, and observing the effect on the seesaw’s rotation.

Activity 1: Balance & Net Torque

1. Place three objects (masses 5 kg, 15 kg, and 30 kg) onto the seesaw in locations that you determine so that there is no rotation after the supports are removed. Take a screenshot of the balanced seesaw without the supports to include in your summary.

2. Determine the torque exerted on the seesaw by each of the objects above and justify the locations you chose to balance it by calculating the net torque.

3. Place three objects (locations 1.75 m and 1.25 m on one side, 0.75 m on the other) onto the seesaw with masses that you determine so that there is no rotation after the supports are removed. Take a screenshot of the balanced seesaw without the supports to include in your summary.

4. Determine the torque exerted on the seesaw by each of the objects above and justify the masses you chose to balance it by calculating the net torque.

Activity 2: Mystery Objects

You’ll notice that some of the objects you can place are “mystery objects”, the masses of which are not given. We’ll be using those in this activity.

1. Design an experiment that would let you determine the mass of an unknown object by placing it onto the seesaw along with two other known masses.

2. Perform your experiment! Place one of the mystery objects onto the seesaw along with two objects of known mass and use your method to determine the mass of the mystery object.

3. Before moving on, you should verify that the method you designed works and the result you found is right! One way to do that is to use the mass you calculated to predict where to place the mystery object along with a single *new* known mass to balance the beam. If you place the

two objects in those locations and the beam is balanced as you predicted, your calculation of the mystery object's mass must be correct!

4. Repeat steps ones and two to determine the masses of two more mystery objects.

Activity 3: Rotational Kinematics

For the first trial in activity two, imagine that one of the three masses (you pick which one) is suddenly removed from the beam after it is balanced in the way you've designed.

1. Calculate the moment of inertia of the new system (which includes the seesaw and the two remaining objects). Treat the objects as point masses and the seesaw as a uniform rod with a mass of 10 kg.

2. Calculate the net torque on the seesaw and the angular acceleration of the system all in the instant after the chosen mass disappears.

3. Using the result above, calculate the tangential accelerations of each of the two remaining masses in the instant after the chosen mass disappears.

4. Repeat steps one and two for the remaining trials from activity two.

Analysis

In your submission, you will need to include:

Activity 1

- Two screenshots of the beam balanced without supports: one for the first part of the activity in which the masses were given, and one for the part in which the positions were given.

- Two tables, one for each part of the activity, which state the locations, masses, and torques contributed by each of the three objects placed on the seesaw.

Note: In reporting all torques, angular accelerations, and tangential accelerations, **make sure that your values include an indication of direction,** either with a sign (+ or -) or word (CW / clockwise and CCW / counterclockwise) as appropriate.

Activity 2

- For each of the three trials, include a table which states the locations, masses, and torques contributed by each of the three objects placed on the seesaw – make sure to indicate very clearly which one was the mystery object whose mass you determined yourself!

Activity 3

- For each of the three trials, include a table which states the moment of inertia of the system, the net torque of the system, the angular acceleration of the system, and the tangential accelerations of the two remaining objects. Make sure you state which mass you chose to remove and clearly label the tangential acceleration values for each of the remaining objects!

Discussion

As *parts* of your discussion, please make sure to include:

Activity 2

- Describe the experimental method you came up with to determine the mass of a mystery object. What physics equations or concepts does this method invoke?

- How did you verify that your method was effective and that the mass values you determined were accurate without the ability to weigh them directly?

Activity 3

- Discuss how the moment of inertia of the system was determined and how this was used to calculate the angular acceleration and tangential accelerations.

- Clearly, the angular acceleration you calculated is relevant for at least the instant after one of the objects is removed from the seesaw. Would that angular acceleration remain constant as the seesaw continued to rotate? If so, how do you know? If not, what is changing that would cause the angular acceleration to also change?

You'll also need to discuss error. This is a simulation, so the results you're seeing come from calculations carried out behind the scenes by the computer – and the computer uses exactly the type of equations that you are using when you analyze these systems! In discussing uncertainty and error, first discuss the uncertainty associated with a simulation like this one: think about limits to how precise the results you're seeing are, what determines those limits, and how the precision could be improved if you had full control of the way the computer was performing these calculations. Also, please briefly discuss potential sources of error if this same experiment were to be performed using real objects and a real seesaw (Hint: discuss a possible experimental design and what tools you would need to measure the values – what errors could be associated with the design/measurement tools).

FAQ's & Recommendations

How should I prepare for lab time?

You only have so much time in lab each week, so proper preparation makes a huge difference in what you're able to accomplish! Read the handout ahead of time so that you can ask clarifying questions immediately and get started as soon as you arrive!

What goes in my lab notes?

The purpose of lab notes is to enable your or a colleague to reconstruct what was done and why after you've left the lab and are performing analysis or writing a submission.

- You can use any form you like to record experiment information: notebook, spreadsheet, etc.
- They don't have to be neat, in complete sentences, etc., but they do have to be useful!
- Make sure to take detailed notes about your setup, how to use the equipment, what results you found, measurements related to the environment you may need, etc. You may not be able to get back into the lab later in the week if you miss something, so record as much detail as possible!
- When storing multiple data files while in lab, make sure to name the files clearly so they're easy to find later.

When should I work on the experiment and analysis?

We strongly recommend doing the lab as early in the week as possible, rather than waiting until it is almost due. This is just so that, if you run into trouble and need help, you'll have plenty of time to talk to your TA and get issues resolved before the deadline.

How do I turn in my results?

After leaving lab, performing your analysis, and completing your submission, you're ready to turn in your work!

- Every lab session requires submission of either an assignment, summary, draft report, or report.
- Collaborate with your partners on data collection, analysis, and writing.
- Turn in a single group submission and make sure the names of all group members are included.
- Upload your submission to Canvas/Brightspace as a .pdf by the deadline in the course calendar.
- Other than the spreadsheet assignment, you will not upload any spreadsheets. Just copy and paste figures and other elements from your spreadsheet into your formal submission as needed.

Where can I get help?

Your lab TA can answer questions during the lab, by email, or by setting up a time to meet. You can also ask advice from lab partners and/or other students.

General DO's and DON'T's

- *DON'T* break the equipment – always be careful when using lab supplies!
- *DO* consult with your lab TA before leaving a lab session about your experimental method, the validity of your results, and any confusion you have about the analysis process.
- *DON'T* forget to record all the parameters and measurements for your experiment, including saving files.
- *DO* be creative in your experimental design and enjoy!