ROTATIONAL DYNAMICS

How does net torque affect the angular acceleration of a rotating object with constant rotational inertia?

- Experimentally determine the mathematical relationship between net torque and angular acceleration of a rotating object.

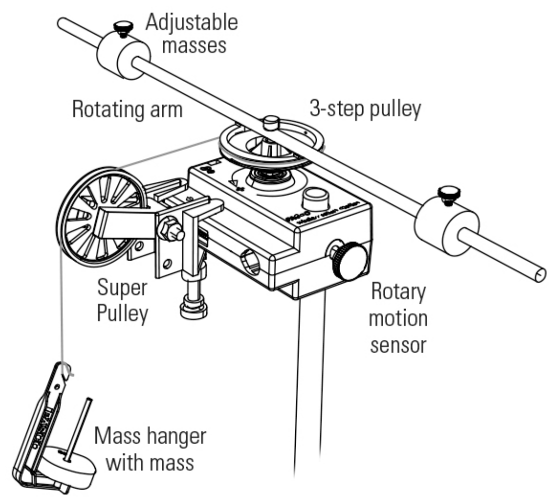
Materials and Equipment

- Data collection system
- PASCO Wireless Rotary Motion Sensor
- PASCO Rotational Inertia Accessory
- PASCO Super Pulley with Clamp
- Stainless steel caliper
- Balance, 0.1-g resolution, 2,000-g capacity (1 per class)
- Table clamp or large base
- Support rod, 60-cm
- Mass and hanger set, 0.5-g resolution
- Scissors
- Meter stick
- Thread

Safety

Follow regular laboratory safety precautions.

Procedure



1. Measure the mass of the rotating arm m_{arm} by itself, the mass of each sliding mass M_1 and M_2 by itself, and the length l of the rotating arm. Record these values at the top of the Data Analysis section below.

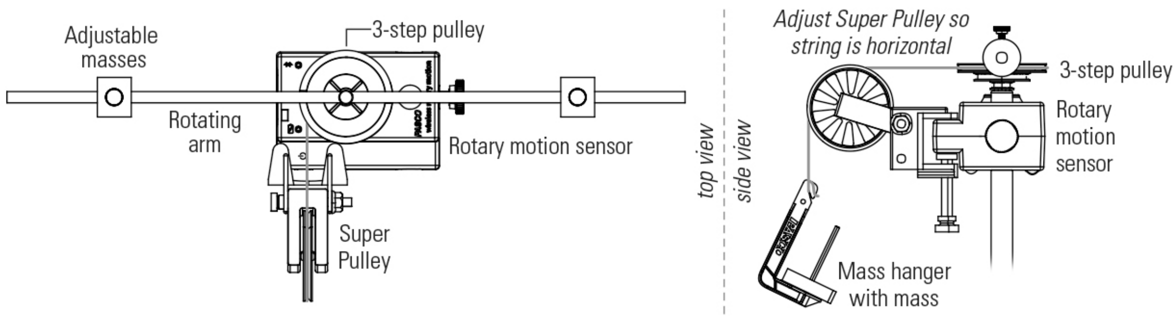
2. Attach the rotary motion sensor to the top of the support rod using the rod clamp on the sensor.

3. Mount the Super Pulley to the rotary motion sensor using the Super Pulley clamp.

4. Invert the 3-step pulley on sensor so that the large diameter pulley is on top. Mount the rotating arm to the rotary motion sensor.

5. Cut a section of thread approximately 70 cm long, and then attach one end of the thread to the largest pulley groove on the 3-step pulley, and the other end to the mass hanger. Run the thread from the 3-step pulley over the Super Pulley, allowing the mass hanger to hang freely.

6. Adjust the position of the Super Pulley so that the section of thread between the top of the Super Pulley and the point at which it meets the 3-step pulley is straight and horizontal, see figures.



7. Adjust the sliding masses along the rotating arm so the distance between the center of each mass and the axis of rotation is 16.0 cm. Tighten the thumbscrews on the masses so they do not slide.

8. Connect the wireless rotary motion sensor to the data collection system, and then create a graph display of Angular Velocity on the y-axis with Time on the x-axis.

10. Add 45 g of mass to the 5 g mass hanger, resulting in a total of 50 g of mass hanging from the thread.

11. Wind the thread counterclockwise around the largest pulley groove on the 3-step pulley until the hanging mass is just below the Super Pulley. Hold the rotating arm in place.

Data Collection

1. Begin data recording, and then release the rotating arm (from rest). Collect data until the arm has completed at least two full revolutions.

2. Stop data recording and then carefully stop the rotating arm.

3. Change the amount of mass on the hanger: Repeat the previous steps four more times using an additional 50 g each time.

4. Record the hanging mass used in each trial into Table 1 in units of kilograms.

5. Use the tools on your data collection system to determine the slope of a linear fit to your Angular Velocity versus Time data during the time when the arm was rotating freely for each trial. Record this as the *angular acceleration* of the rotating arm in Table 1 for each trial.

6. Use the stainless steel caliper to measure the radius of the largest groove on the 3-step pulley. Be sure to measure the part of the pulley the thread encircles, not the outside edge of the pulley. Record this value in units of meters in the Data Analysis below.

Questions and Analysis

Mass of rotating arm (kg): m_{arm} = ____________________

Mass of sliding mass 1 (kg): M_1 = ____________________

Mass of sliding mass 2 (kg): M_2 = ____________________

Length of rotating arm (m): l = ____________________

Pulley groove radius (m): r = ____________________

Table 1: Varying net torque with constant rotational inertia

Trial	Hanging Mass (kg)	Net Applied Force (N)	Net Applied Torque (N·m)	Angular Acceleration (rad/s^2)
1				
2				
3				
4				
5				

1. Calculate the magnitude of the net force applied to the pulley $\Sigma F_{\text{applied}}$ for each trial using the equation below. Note that the magnitude of the net force applied to the pulley was not equal to the weight of the hanging mass, but rather, to the tension F_T in the thread.

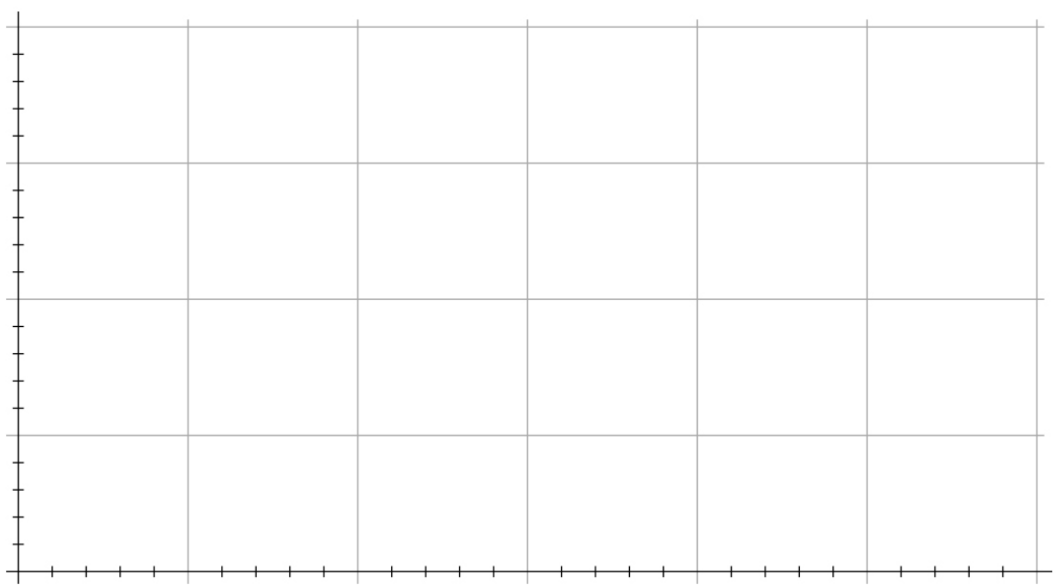
$$\sum F_{\text{applied}} = F_{\text{T}} = mg - m(\alpha r)$$

where m is the Hanging Mass value in each trial, α is the Angular Acceleration in each trial, r is the radius of the pulley groove, and g is earth's gravitational acceleration 9.8 m/s^2. Record the result for each trial in Table 1 in units of newtons (N).

2. Calculate the net applied torque in each Part 1 trial: Multiply the net applied force for each trial in Table 1 by the radius of the pulley groove. Record the result for each trial in Table 1 in units of newton-meters (N·m).

3. Plot a graph of *net torque* versus *angular acceleration* in Graph 1. Be sure to label both axes with the correct scale and units.

Graph 1: Net torque versus angular acceleration with constant rotational inertia



4. Draw a line of best fit through your Graph 1 data. Determine and record the equation of the line.

   Best fit line equation: ____

5. Use the equations at right to calculate the total rotational inertia I_{total} of the rotating arm system. R represents the distance between the center of the sliding mass and the axis of rotation and M is the sliding mass.

$$I_{total} = I_{arm} + I_{mass\ 1} + I_{mass\ 2}$$
$$I_{arm} \approx \frac{1}{12} m_{arm} l^2$$
$$I_{mass} \approx MR^2$$

   Rotational Inertia (kg·m^2): ______________________________

6. How does your calculated rotational inertia value compare to the slope of your Graph 1 data?

7. In your experiment, which variables were held constant? Which variables increased, or decreased?

8. How did changing the net torque applied to the system affect its angular acceleration?

9. Based on your data, what is the mathematical relationship between net torque and angular acceleration (proportional, inverse, squared, et cetera)? How do you know?

10. From your results, can you predict a mathematical expression that relates net torque τ_{net}, rotational inertia I, and angular acceleration α? Explain how your data supports your prediction.