Lab 3: Dynamics

Introduction

This lab has two purposes. First, starting with the prelab questions, you’ve already addressed increasingly difficult versions of a standard exam–level force problem about a cart and pulley. Today you’ll test your answers experimentally. In addition, you’ll do experiments and answer questions that highlight some of the subtle conceptual aspects of Newton’s laws, and how these relate to common–sense force intuitions.

I. Cart & hanging mass

1. In this first experiment, you’ll test your prelab prediction about the acceleration.

   ♦ Obtain a disk that’s around 20 grams for the hanging mass. Then use a scale to measure $m_{\text{cart}}$ and $m_{\text{hang}}$.

      Measure: $m_{\text{cart}} = \underline{\hspace{2cm}} \quad m_{\text{hang}} = \underline{\hspace{2cm}}$

   ♦ Calculate the predicted acceleration. Start with the expression from your prelab derivation, which you’ll include with this writeup. Include units with each numerical value that you substitute into the original expression.

      Predicted acceleration: $a = \underline{\hspace{2cm}}$
♦ Open the Dynamics Lab 1A file in the “Dynamics Lab” folder on the desktop.
♦ Remove the “brake” from the cart if there’s one attached.
♦ Before you start collecting data, practice giving the cart a push away from the pulley. You’d like the cart to travel pretty far along the track before it reverses direction, but it must not bump into the stop at the end of the track.
♦ Once you know how hard to push the cart, collect your data. Adjust the scales of the velocity and acceleration graphs so that the data are clear. The easiest way is to measure the value of the acceleration directly from the graph of Acceleration vs. Time. You may use the $x=?$ icon in the toolbar to assist you. You can also measure the acceleration by finding a slope (of which graph?). Write in the table below how you determined the acceleration for each trial, and use each method at least once.
♦ Run the experiment several times, and record your data in the table below. Then compute the average acceleration for those trials.

<table>
<thead>
<tr>
<th></th>
<th>Acceleration (units?)</th>
<th>How measured?</th>
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<tbody>
<tr>
<td>Trial 1</td>
<td></td>
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<tr>
<td>Trial 2</td>
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<tr>
<td>Trial 3</td>
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<tr>
<td>Average</td>
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2. By what percentage does the measured acceleration differ from the predicted acceleration? Show your calculation.

3. List some reasons you think your predicted and measured acceleration disagree. What could you do to improve the experiment?
4.  (a) Consider the interval after you the cart leaves your hand, and while it is moving away from the pulley. Is the tension in the string greater than $m_{\text{hang}}g$, equal to $m_{\text{hang}}g$, or less than $m_{\text{hang}}g$? Explain. [Hint: First think about the direction of the acceleration of the cart during this interval. Then think about the direction of the acceleration of the hanging mass, and the direction of the net force that must thus be acting on it.]

  (b) As the cart moves back toward the pulley, is the tension in the string greater than, less than, or equal to what it was when the cart was moving away from the pulley? Explain.

  (c) (i) Use your work from the prelab questions to find the tension in the rope in terms of $m_{\text{cart}}$, $m_{\text{hang}}$, and $g$. (ii) Is your expression consistent with your answers to (a) and (b) above?
5. Now you will repeat the experiment, with the following twist: After the cart has reversed direction and traveled about half way back towards the pulley, catch the hanging mass, allowing the string to go slack. In other words, you’ll “turn off” the tension force while the cart is traveling back toward the pulley.

- **Prediction:** Let “towards the pulley” be the positive direction, and neglect friction. Sketch predicted graphs of position, velocity, and acceleration versus time.

![Graphs of position, velocity, and acceleration](image)

- Open the file “Dynamics Lab 1B.”
- Run the experiment. Change the scale of the graphs, if needed, to see the results more clearly.
- Sketch your observations on the second set of axes. Do not erase your predictions. Omit the beginning segment of the graph when your hand was still pushing the cart.
II. Newton’s laws and force intuitions

The following series of questions is designed to help you develop a deeper intuitive understanding of some subtle aspects of Newton’s laws.

6. (Quick Prediction) On this question, write down your immediate gut reaction; don’t calculate.
   A car cruises down the highway at constant velocity 50 mph. The backwards force of wind resistance and friction have a combined strength of 5000 newtons. The car’s engine causes a forward force to be exerted on the car. Is this forward force less than 5000 newtons, equal to 5000 newtons, or greater than 5000 newtons? Answer immediately, and don’t continue until you have done so.

7. Most people initially guess that the forward force must be greater than the 5000-newton backward force, or else the car wouldn’t go forward. (Even if you personally didn’t have that intuition, you can probably see why most people would say that.) Deeper reflection reveals, however, that the forward force must equal the backward force. Explain why.

8. Instead of abandoning the commonplace intuition from question 6, it’s better to reconcile that intuition with Newton’s second law, as we saw two weeks ago.

   (a) Before reaching cruising speed, when the car was speeding up from 0 to 50 mph, was the forward force greater than, equal to, or less than the backwards force? Explain.

   (b) Most people have the rough intuition that a “net forward force is needed to make an object move forward.” How can we alter—refine—that intuition so that it agrees with Newton’s second law? Answer in your own words, in a way that will make sense to you later.
III. Coefficient of friction

In this section, with the brake still attached to the cart, you’ll return to the first experiment (i.e., cart moves along track while connected to hanging mass). After thinking about how friction changes the graphs, you’ll figure out the coefficient of friction between the cart and the track.

10.* (Prediction) If you give the cart a brief push away from the pulley, what will the position, velocity, and acceleration graphs look like? This is just like question 5, except there’s friction, and you don’t catch the hanging mass.
11. Explain why the acceleration is smaller in magnitude after the cart reverses direction. *Hint*: Draw a free-body diagram (FBD) of the cart when it’s moving away from the pulley (after your hand stops pushing it), and a separate FBD of the cart when it’s moving toward the pulley.

12.* Using the data on the computer screen, determine the coefficient of kinetic friction between the cart and the track. The coefficient of kinetic friction ($\mu_k$) is related to the kinetic friction force ($f_k$) by the equation $f_k = \mu_k N$. Show your work below. *Hint*: When we take friction into account, the tension in the string is different as the cart moves in the two directions. Can you see why?
13. An airplane of mass 5000 kg flies in a straight line at steady speed of 70 m/s. Wind resistance pushes backwards on the airplane with a force of 2000 newtons.

Is the forward force that the engine exerts on the airplane greater than, less than, or equal to 2000 N? Explain.