Relating Force to Linear Motion: Newton's Second Law (10/20/06)

(completion time: approx. 2 h)

Introduction

A physical "law" is a fundamental principle that underlies our understanding of how the physical world works. Newton's second law of motion describes the relationship between the acceleration of an object, the mass of the object, and the net force acting on the object. In this lab you will use a simple system of pulleys, strings and weights to investigate this relationship for linear motion.

Equipment

- dynamics cart with mounted force & acceleration sensors
- 1.2 m track with pulley
- string with loops on ends (approx. 31 in.)
- mass hanger (approx. 50g)
- 3 slotted masses (50g each)
- mass (black, rectangular)
- triple beam balance

Before the Lab

Read the sections in your text describing Newton's Laws. You should learn how to draw a force diagram and determine the vector sum of all the forces (i.e. the *net* force) on an object.

Newton's Second Law:

Based on careful observation and comparison of numerous measurements and calculations, Isaac Newton found that the acceleration of an object is directly proportional to and in the same direction as the net force on the object, and inversely proportional to the mass of the object: $a \propto \frac{F_{net}}{m}$. If the proportionality constant is chosen to be one, then this relationship becomes a vector equation that defines the unit of force in terms of the chosen units of mass and acceleration: $\vec{F}_{net} \equiv m\vec{a}$. If mass is measured in kilograms and acceleration in m/s/s, then the unit of force is called a Newton.

Experiment 1: Push and Pull

In this activity you will familiarize yourself with the force sensor and the acceleration sensor and verify Newton's second law for the case of linear motion:

$$F_{net} = ma\,.$$

Computer and Experiment set-up:

- Open the Data Studio program, choose "Create Experiment", and connect to the Workshop 500 interface. (If the computer can't find interface, click *choose interface* and select the 500.)
- Select the Acceleration Sensor and connect it to Channel A on the 500 interface
- Change acceleration units from "g" to units in "m/s/s" and change sampling rate to 50 Hz.
- Select Force Sensor (not the one for student) and connect it to Channel B on the interface.
- Select a force vs. time graph (i.e. Click on "graph" and drag up onto "force".).

- Add acceleration vs. time to that same graph (i.e. Click on “acceleration” and drag it to some point on the force vs. time graph and let go.) The window should now show two graphs on top of each other: force versus time and acceleration versus time.

Testing and zeroing the sensors

With the cart at rest and the force sensor undisturbed start the program and let it run. You should see two horizontal straight lines for the values of force and acceleration.

IMPORTANT:

- Zero the values of force & acceleration by pressing the TARE buttons on the two sensors. You should see the values on the graphs go to zero.
- Test the force sensor by pushing and pulling on the hook while holding the cart at rest. Notice how the force changes on the graph. (NOTE: If the graph of the acceleration changes instead of the force, there is a good chance that you mixed up the connectors, when you plugged them into the interface!!!! Fix it!!!) Does the acceleration change?
- Test the acceleration sensor by abruptly moving the cart back and forth without touching the force sensor. Watch the acceleration graph change. Does the force change significantly?

Activity:

For this activity, you will push and pull the cart back-and-forth on the dynamics track with your hand touching only the hook of the force sensor. The acceleration sensor will measure the acceleration of the cart, while the force sensor will measure the force you exert on the cart hook.

1. The mass of a typical cart plus sensors is given as M = 845g. Record this value in the data table below.
2. Start a new run and record about 10-20 back-and-forth motions while alternately pushing and pulling the cart by the hook on the force sensor. One cycle should take about 1 s while covering a distance of about 25 - 40cm.
3. When you are satisfied that you have good plots of F vs. t and a vs. t on the screen, **print** the graphs.
4. Now make a graph of Force versus Acceleration, using the *same* data points, as follows:
   - Make a Force versus Time graph.
   - Left Click on the “Time” label and change to “Acceleration”. **Print** this graph.

Analysis and Further Measurement

Make a linear fit to the Force versus Acceleration.

→ choose “Fit” from the graph menu and then “Linear”

Record the slope (m) on the data table below. What physical property does the slope represent?

→ Put the black bar (500g) on the cart and repeat the experiment. Record the data on the same Force vs. Acceleration graph with the earlier run still visible. Repeat analysis. **Print** the graph!

Data Table *(Remember, change units to kg!)*

Cart with sensors:	
Given Mass of Cart Plus Sensors:	Percent difference between given mass and measured slope:
Slope:	

Cart with sensors + 500g bar:	
Given Mass of Cart Plus Sensors Plus 500g Bar:	Percent difference between given mass and measured slope:
Slope:	

Questions:

1. How is the force related to the acceleration?

   Compare the minima and maxima of the force vs. time graph to the minima and maxima of the acceleration graph. How are they related?

2. Describe how you applied force to make the cart move back and forth?

   Draw sketches of the cart at the turning points and at the center of the track and show the direction of the applied force in each case.

3. At which point in the movement is the magnitude of the force maximal?

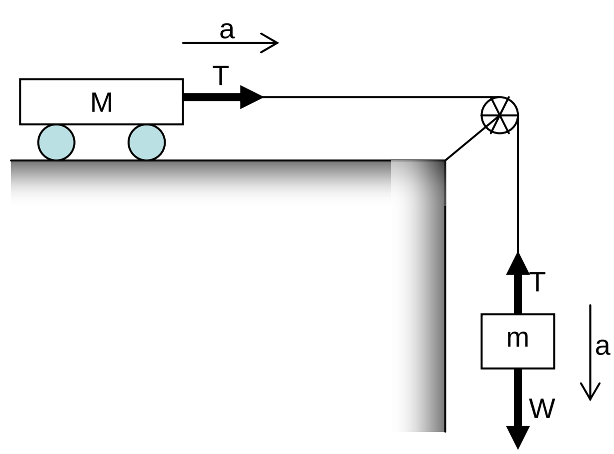
   At which point in the movement is the magnitude of the force minimal?

4. How do you interpret the force versus acceleration graphs for your measurements?

Experiment 2: Acceleration due to Hanging Mass

Theory

Consider two masses connected by a string over a pulley as shown. One mass, *M*, consists of a cart with sensors resting on a horizontal track. The other mass, m, is hanging freely and is subject to a downward force due to gravity (i.e. its weight): $W = mg$, and an upward force due to the tension T in the string. The masses of the string and pulley as well as the frictional resistance of the cart wheels and the pulley are assumed to be negligible.



Cart at Rest: When the cart is held stationary, there is no net force on the hanging mass, so the tension in the string is given by: $T = W;$

Cart accelerating: Since the length of the string does not change, the cart (with sensors) and the hanger accelerate at the same rate, *a*, (see figure).

→ From the **free body diagram of the hanging mass**, we get:

$$W - T = ma,$$ where *m* is the hanging mass.

→ Assuming the frictional and rolling resistance of the cart to be negligible,
a **free body diagram of the cart** yields:

$$T = Ma.$$ where *M* is the total mass of the cart and sensors.

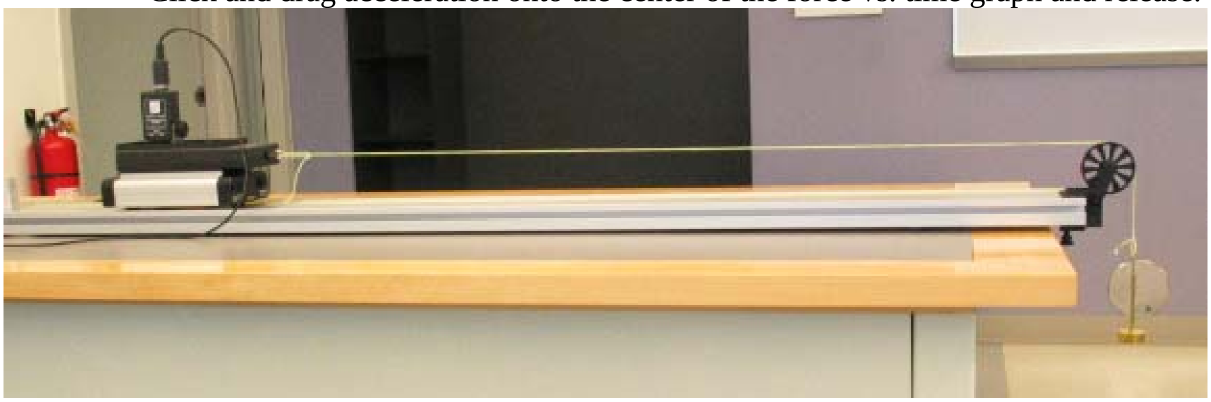
Required Derivation

Combine the two preceding equations to express the tension and the acceleration as functions depending only on *m, M,* and *W*. These formulas will later be used to calculate the theoretical values for *T* and *a*.

$a =$ $T =$

Experimental and Computer Setup

1. Attach a pulley to track, as shown in the picture, making sure it is centered.
2. Attach a total of *~100g* as a hanging mass (50g hanger + 50g slotted mass) to the string.
3. Create a graph for force vs. time and acceleration vs. time on the same timescale as follows:
   - Make a graph of force versus time.
   - Click and drag acceleration onto the center of the force vs. time graph and release.



Procedure

1. Move the cart (with sensors) to the far end of the track, away from the pulley.
2. Click on the Start button, then, about three seconds later, release the cart.
3. **Catch the cart before it smashes into the pulley!**
4. Click on the Stop button.

(NOTE: Your graphs should look somewhat similar to the graphs in Appendix A on the last page.)

Analysis

1. Using a triple beam balance, verify the value of the hanging mass "m" and record the value in the Data Table below. Also, record the given 845g total mass of the cart and sensors..
2. Determine the **tension T at rest**
   - In the force vs. time diagram, highlight the data points measured before release of the cart by clicking and dragging with the "+" tool (4^{th} from the left in the menu) over the data points.
   - Obtain and record the *Mean* value of the force during this period by clicking on the statistics button (Σ) and "Show All".
3. Calculate and record the **weight *W* of the hanger** from $W = mg$.
4. Determine the **tension, *T*,** measured during acceleration:
   - Highlight the relevant data points on the force graph. Click on Σ, and *Show All*.
   - Calculate the *Mean* value of the tension during acceleration and record its magnitude (i.e. absolute value) in the Data Table.

5. Determine the experimental **acceleration *a***:
   - Highlight the relevant data points on the acceleration graph. Click on Σ and *Show All*.
   - Record the magnitude of the *Mean* value of your measured acceleration.
6. Calculate the values for T and a from your previously derived equations.

NOTE: Be sure to print all graphs needed for your write-up before deleting them.

Additional Measurements

- Add the black rectangular mass to the cart. Repeat measurements and analyze data. [NOTE: Mass of black rectangular bar is given as 500g]
- Leave black bar on cart but add a 100g slotted mass to the hanger to a total of ~200g. Repeat the measurement and analysis of the data.

Data Table

Run 1 (use mass units of kg)

m, hanging mass: ***M***, total Mass of Cart and Sensors:	
T measured with cart at rest: ***W*** of mass hanger, calculated:	Percent difference:
T measured during acceleration: ***T*** during acceleration, calculated:	Percent difference:
a measured: ***A*** calculated:	Percent difference:

Run 2: Mass Added to Cart (use mass units of kg)

m, hanging mass: ***M***, total mass of cart, sensors and 500g bar :	
T measured with cart at rest: ***W*** of hanger, calculated:	Percent difference
T measured during acceleration: ***T*** during acceleration, calculated:	Percent difference
a measured ***a*** calculated	Percent difference

Run 3: Mass Added to Hanger (use mass units of kg)

m, hanging mass: ***M***, total Mass of Cart and Sensors:	
T measured with cart at rest: ***W*** of hanger, calculated:	Percent difference
T measured during acceleration. ***T*** during acceleration, calculated:	Percent difference
a measured: ***a*** calculated:	Percent difference

Questions

1. How do acceleration and force vary if the hanging mass changes but cart mass remains the same?

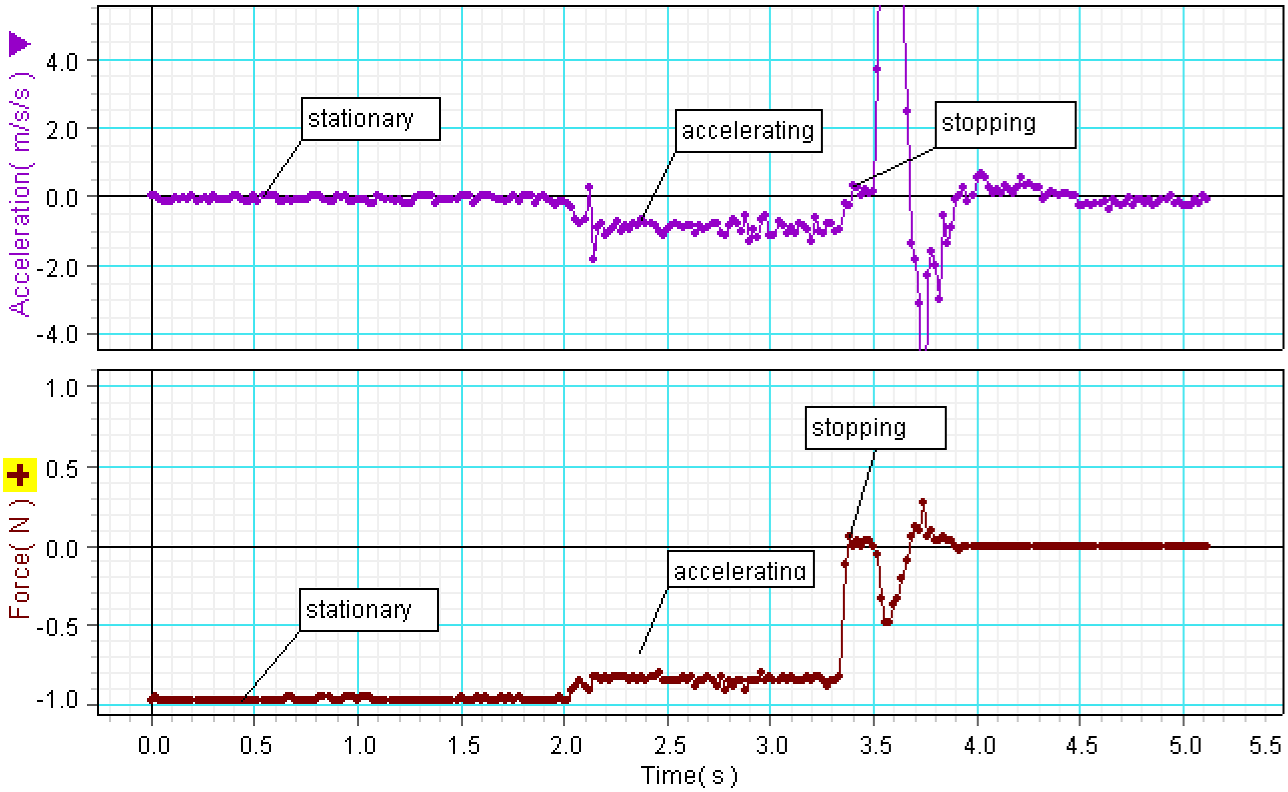
2. How do acceleration and force vary if the cart mass changes but hanger mass remains the same?

3. What are some possible reasons for any differences between the measured and calculated values?

4. In run 1, by how much is the force on the cart reduced when you release the cart?

   How is this value related to the acceleration?

Appendix A – Sample graphs of F vs. t and a vs. t for Acceleration due to Hanging Mass


Acceleration(m/s/s)
4.0
2.0
0.0
-2.0
-4.0
stationary
accelerating
stopping
Force(N)
1.0
0.5
0.0
-0.5
-1.0
stopping
accelerating
stationary
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
Time(s)