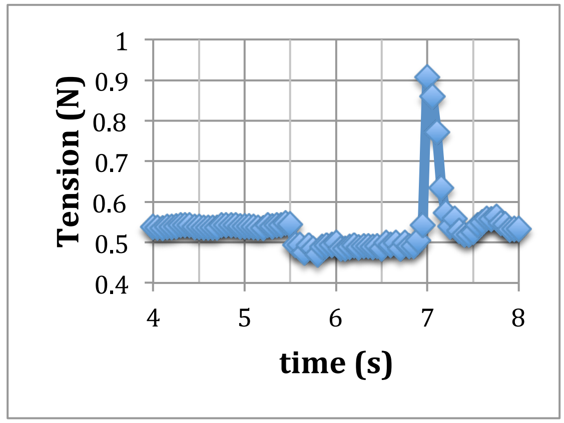
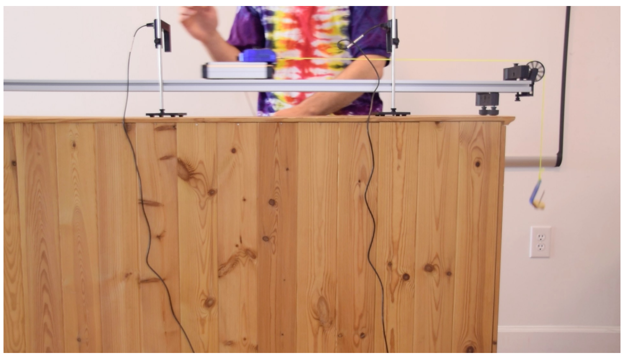
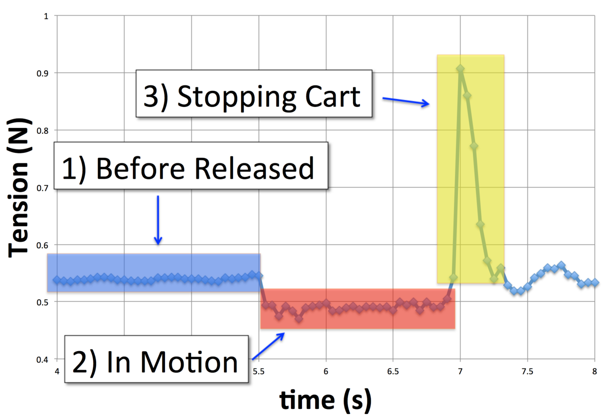
Flipping Physics Lecture Notes:
Force vs. Time on a Dynamics Cart

This is an extension of a previous lesson:
Introductory Newton's 2nd Law Example Problem and Demonstration.
www.flippingphysics.com/second-law-problem.html

A yellow string is attached to a 0.613 kg cart and a 0.0550 kg mass. The cart is placed on a horizontal track and the string is placed over a pulley. The tension as a function of time before and after the cart is released is show in the graph to the right.







There are three main parts of the motion we are going to analyze.

1) Before the cart is released.
2) While the cart is in motion.
3) While the cart is being stopped.

We start by drawing the free body diagrams. Notice there are two free body diagrams because there are two objects in motion, the cart and the mass hanging. So both the cart and the mass hanging have a free body diagram.

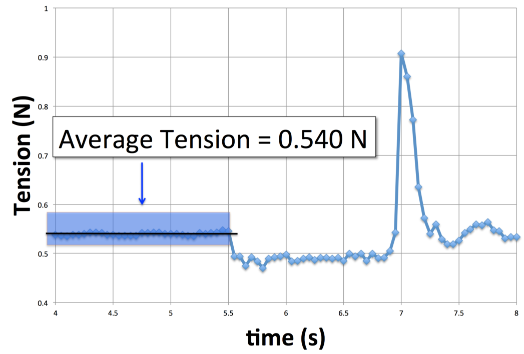
Note: Because it is the same string and the pulley has negligible mass and friction, the force of tension at either end of the string is the same. In other words, the force of tension in both free body diagrams has the same value. Which means the tension force in our graph applies to both free body diagrams. Before we analyze the situation by using Newton's Second Law of Motion: $\sum \vec{F} = m\vec{a}$, we need to identify a direction. The cart will accelerate to the right and the mass hanging will accelerate downward, however, they will have the same acceleration because they are attached by the string. Therefore we call the cart and mass hanging, the System. Let's identify the positive direction as the direction the cart and mass hanging move. (Which I already identified in the picture.) Let's call this the String Direction.

Let's sum the forces *on the mass hanging, in the direction of the string, during part* ***one***, before I release the cart:

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow F_{g_h} = F_T + m_h a \Rightarrow F_T = F_{g_h} - m_h a = m_h g - m_h a = m_h \left(g - a\right)$$

$$F_T = \left(0.055\right)\left(9.81 - 0\right) = 0.53955 \approx 0.540 N$$

This is a theoretical prediction of the Tension force in the string and it matches our experimental values.

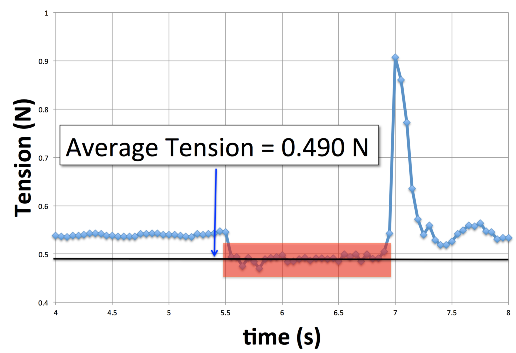


Let's sum the forces *on the mass hanging, in the direction of the string, during part* ***two***, after I release the cart, while the cart is accelerating. In the previous lesson we determined the acceleration of the cart and mass hanging: $a = 0.786389 \dfrac{m}{s^2}$

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow F_{g_h} = F_T + m_h a \Rightarrow F_T = F_{g_h} - m_h a = m_h g - m_h a = m_h \left(g - a\right)$$

$$\Rightarrow F_T = \left(0.055\right)\left(9.81 - 0.786389\right) = 0.496299 \approx 0.496 N$$

Notice this is close to the experimental value, however, not quite the same.

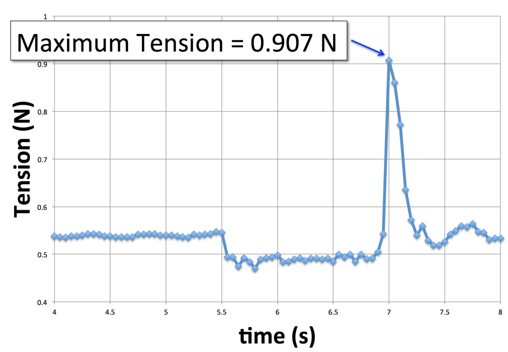


Also notice that the tension force in the string changes, even though the free body diagram of the forces acting on the mass hanging does not change. Why? Because the acceleration of the mass hanging changes.

Now let's sum the forces *on the mass hanging, in the direction of the string, during part* ***three***, while I am stopping the cart. Notice the force is not close to constant, so let's sum the forces at the point when there is the maximum tension in the string.

$$\sum F = F_{g_h} - F_T = m_h a \Rightarrow a = \frac{F_{g_h} - F_T}{m_h} = \frac{m_h g - F_T}{m_h} = \frac{\left(0.055\right)\left(9.81\right) - 0.907}{0.055}$$

$$\Rightarrow a = -6.680909 \approx -6.68 \frac{m}{s^2}$$



This is the maximum acceleration of the cart. Notice it is an instantaneous value and not an average value like we determined in the first two parts.