Purpose:
What is the relationship between tension force and weight for a cart that is being held on a hill?

Plan Diagram:

Theory:
In this lab, we are looking at the relationship between tension force and weight force for a cart that is being held on a hill. We expect that as more weight is added to the cart, the tension force would increase. With a cart on an incline, it makes sense that the tension would increase with weight because the horizontal value of the weight force would increase, which would equal the horizontal tension force to keep the cart still. Based on the incline, we know that the tension force should be proportional to the (sin) of the weight force for the cart to remain static (Knight, Jones, & Field, 2013, p. 123).
**Cart on a Hill: Not Moving**

FBD:

- **N on C, by B**
- **T on C, by R**
- **W on C, by E**

**FIG 1**

T = tension force  
W = weight force  
N = normal force  
C = cart  
R = rope  
B = board (incline ramp)

<table>
<thead>
<tr>
<th>Force</th>
<th>By</th>
<th>On</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Earth</td>
<td>Cart</td>
<td>-wsinθ</td>
<td>-wcosθ</td>
</tr>
<tr>
<td>Normal</td>
<td>Track</td>
<td>Cart</td>
<td>0</td>
<td>+N</td>
</tr>
<tr>
<td>Tension</td>
<td>String</td>
<td>Cart</td>
<td>+T</td>
<td>0</td>
</tr>
</tbody>
</table>

**X-Component**

\[ \sum F_x = ma_x, \quad (a=0) \]
\[ ma_x = -w\sin\theta + T \]
\[ T = W\sin\theta \]

**Y-Component**

\[ \sum F_y = ma_y, \quad (a=0) \]
\[ ma_y = -w_y + n = ma_y \]
\[ n = W\cos\theta \]
Expected Values/Graph:

<table>
<thead>
<tr>
<th>Weight (N)</th>
<th>Tension (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4226</td>
</tr>
<tr>
<td>2</td>
<td>0.8452</td>
</tr>
<tr>
<td>3</td>
<td>1.2678</td>
</tr>
<tr>
<td>4</td>
<td>1.6904</td>
</tr>
<tr>
<td>5</td>
<td>2.113</td>
</tr>
<tr>
<td>6</td>
<td>2.5356</td>
</tr>
<tr>
<td>7</td>
<td>2.9582</td>
</tr>
<tr>
<td>8</td>
<td>3.3808</td>
</tr>
<tr>
<td>9</td>
<td>3.8034</td>
</tr>
<tr>
<td>10</td>
<td>4.226</td>
</tr>
</tbody>
</table>

These are the predicted values from our calculations. This is what our data should look like, with a direct relationship between weight and tension, where one increases stably with another with $\theta=25^\circ$.

Example Calculation:

\[ T = w \sin \theta \]
\[ T = 1 \text{N} \sin(25^\circ) \]
\[ T = 0.4226 \text{N} \]
“One way an object can have \( a = 0 \) is to be at rest. An object that remains at rest is said to be in static equilibrium” (Knight, Jones, & Field, 2013, p. 132). Based on the equation \( T = w \sin \theta \), it seems reasonable that \( T \) & \( W \) will have a direct relationship as long as \( \theta \) is kept constant. We see this in our graph of predicted values. As \( W \) is increased, \( T \) increased in increments of \( \sin 25^\circ \) or \( 0.4226 \) N. The table of predicted values and graph both show this trend and we expect our actual values to correspond with this trend.

**PROCEDURE:**
Cart on a Hill: Not Moving

Equipment:

- Cart with wheels (assumed no friction)
- Track
- String
- Force-meter (0-5N)
- Balance
- Weights
- Protractor and weighted string
- Clamp

1. The cart was measured to get the initial mass value (that was calculated into a weight value. \( w=mg \)).
2. The ramp was set up at a 25-degree incline for the horizontal and was clamped in place. The incline can be decided before the experiment, or can be measured out as the experiment is set up and recorded as whatever value works at that time.
3. We placed the cart on the ramp with a string attached to it, and the force-meter tied onto the string. The string was held parallel to the ramp so as to correlate to our free body diagram on page 2 FIG 1. The cart is kept at rest throughout the entirety of the experiment.

![Diagram of cart on a ramp with string and force-meter]

(note: all other forces are kept constant, to the best of our knowledge)

4. We then held the cart at still on the ramp and noted the reading on the force-meter.
5. We then added mass in the form of weights (in 50g or 100g increments) and recorded the mass and took another force measurement. We repeated this process until we had data that spanned to the upper end of our force-meter’s range.

**ANALYSIS:**

As you can see from the FIG 1 page 8, the predicted values are very close to the actual values, which show that our experiment was successful. The line of our actual values graphed is parallel to the predicted values graph. As most of the values are just slightly less than we predicted, there could have been a slight calibration error in the force-meter that would make the tension force data all appear slightly less than it actually was. Also, the trend of our data exactly matches what we predicted, which shows that the relationship between the weight and force is a directly
proportional relationship with one variable increasing stably as the other variable increases. Per the chart of values and graph, each time the weight is increased, the tension force responds by increasing at a stable rate (proportional to the amount of weight added).

The equation for the line of our actual values graphed is as follows:

Using points (8.5 N, 3.5 N) and (5.0 N, 2.0 N)
Slope= [(3.5 N-2.0 N) / (8.5 N-5.0 N)]
Slope= 0.429

\[
y = mx + b \\
T = 0.429(w) + b \\
2.0N = 0.429(5.0N) + b \\
b = -0.145 \\
T = 0.429(w) -0.145N
\]

As you can see from the equations above, the theoretical values and actual values have the same slope and so are parallel graphs. The slope also indicates that if you increase the weight force by one newton, that the tension force will be increased by 0.429 N, which shows a directly proportional relationship.

Our predicted values match our actual values and the only discrepancy is with the vertical intercept. The vertical intercept would, in reality, be at (0,0) as with no mass (to convert into weight) there would be no object to pull on the string to create tension and thus no force would exist. Both of our values are negative, and very close to zero considering the magnitude of forces we are using. It makes sense that our theoretical values differ slightly from our experimental values, and the discrepancy is so small (less than 0.15 N) that is does not invalidate our experiment in the least.

**CONCLUSION:**

The relationship between the tension force and the weight of a cart held still on a ramp can be defined as a directly proportional relationship. As we found, with the slope of our actual values graphed, when the weight of the cart is increased by one newton, the tension force in the string is increased by 0.429 N. The data collected, and the graph of this data both show the direct proportionality as there is a constant trend in the positive direction for the horizontal and vertical coordinates. The linear equation we found for our actual values is \( T = 0.429(w) -0.145N \) and this equation, being linear with a positive slope, will generate a directly proportional graph.
### FIG 1

**Calculations for weight in the data table:**

\[ F = mg \]

\[ W = 394.3 \text{g} \times (9.8 \text{m/s}^2) \times \frac{1 \text{kg}}{1000 \text{g}} \]

\[ W = 3.864 \text{ N} \]
Uncertainty for Mass (theoretical)
Average Value: 394.3g
Uncertainty: 394.3g ± 0.5g

Uncertainty for Tension (theoretical)
Average Value: 1.6N
Uncertainty: 1.6N ± 0.1N
References


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