Natalie Doyle
Physics Honors
Philhour 6*
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Lab Write-Up:
Verifying the Concept of Force Vector Components

Problem:

How is Newton's second law, that a = Fnet/m, experimentally verified by comparing forces and accelerations of a "frictionless" vehicle with different masses and different angles of force?

Abstract:

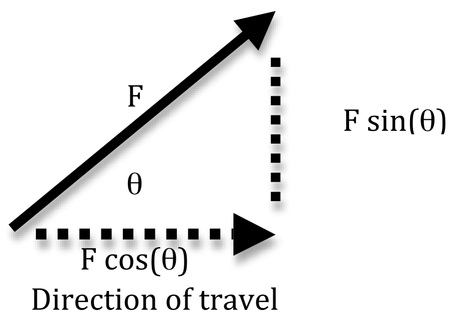
This purpose of this lab was to verify Newton's 2nd law, that acceleration equals the net force divided by the mass (a = Fnet/m), by determining how changes in mass as well as changes in the direction of the force vector can determine acceleration. This experiment verified that Newton's 2nd law equation could be used to predict accelerations of fan carts with different weights and with the fan at different angles, as well as to predict the force emitted in the forward direction by the fans at different angles, with very low error.

Introduction:

This lab tested Newton's 2nd law, that states that a = Fnet/m. Formal explanation of this law states, "the change of motion is proportional to the motive force impressed; and is made in the direction of the right (straight) line in which that force is impressed." In layman's terms, this law means that unbalanced forces acting on an object cause the object to accelerate, due to a net force on the object. A "net force" is defined as the vector sum of all the forces acting on an object. If the forces acting on an object cancel out (for example, if one pushes a ball with 10 N in one direction, and someone else pulls 10 N on the same ball in the opposite direction), the object is in equilibrium, which means that the net, or addition, of all the forces acting on the object is zero. When the net force is zero, the object does not accelerate. Instead, it is at rest, or at a constant velocity.

Inertia is the resistance an object has to a change in its state of motion (changes in velocity). When the mass of an object increases, its inertia increases, causing the object to resist changes in state. For this lab, we measure the weight of objects (in Newtons) and calculate mass (in kilograms). To do this, we used the equation F(g) = mg, where F(g) equals the force of gravity (the weight) in Newtons, m equals the mass of the object in kilograms, and g is the gravitational constant, 10 m/s^2.

One must also understand basic trigonometry to break down force vectors into the component in the direction of travel. The following diagram shows that a force, F, at an angle θ to the direction of travel results in a force equal to F cos(θ) in the direction of travel.



This experiment attempts to measure the acceleration of a low-friction fan cart under several different masses as well as different applications of force to the cart's direction of travel.

Hypotheses:

1) I hypothesize that when we apply constant force and vary the mass, the acceleration will be inversely proportional to the mass, consistent with Newton' 2^{nd} law, a = Fnet/m.
2) I hypothesize that the cart's acceleration will be directly proportional to the cosine of the angle of the force, since the fan cart is on a unidirectional, supposedly frictionless track. It is only the component of force in the direction of travel that will determine acceleration, because acceleration is a vector and Newton's 2^{nd} Law states that force equals mass times acceleration (here we hold mass constant).

Materials:

- Fan cart
- Aluminum track
- Range finder
- Force probe
- Logger Pro software and computer
- 2 large books
- Different weights

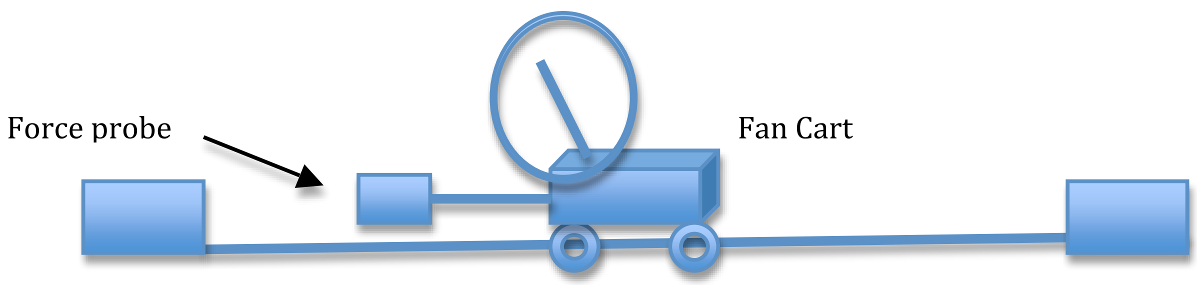
Controls and Variables:

To control this experiment my group used the same fan cart and the same track. We also made sure the force probe was properly calibrated. In the first part of the experiment, the force was held constant, the mass was the independent variable, and acceleration the dependent variable. In the second portion of the experiment, force was again held constant, mass was constant, the independent variable was the angle of the application of the force, and the acceleration was the dependent variable.

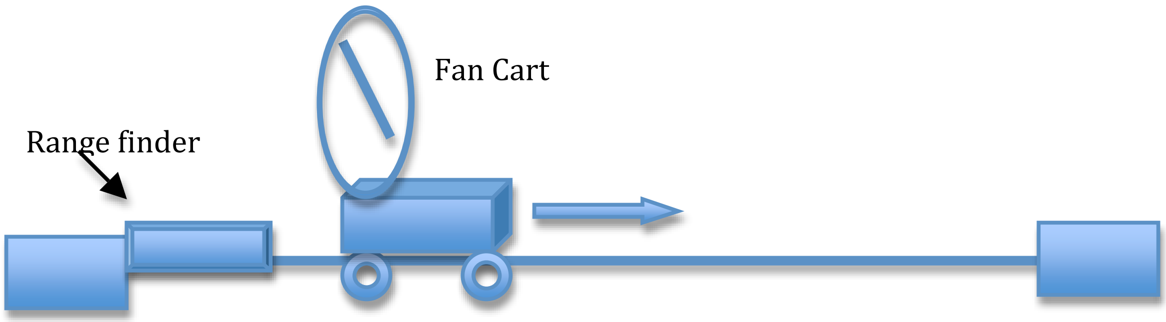
Experimental Procedure:

First, we measured the weight of the fan cart using a force probe, making sure the force probe was properly calibrated and zeroed. From this weight, we determined the cart's mass: m = W/g. We then set up the frictionless track on a flat surface, with books at each end to stop the fan cart, and we set the fan cart on the track.

Next, we measured the force. We connected the force probe to the fan cart, then turned the fan cart on its "high" setting and measured the force the fan produced. We were careful to hold the force probe horizontal to the track, so that the force probe measured only the force in the forward direction. The force probe with the Logger Pro software graphed the force, and we used the mean value of force to minimize the variability of measuring force.



After we had found the mass of and the force produced by the fan cart, we predicted the acceleration of the fan cart. We used the formula a = Fnet/m and plugged in the values we had for Fnet and m (mass), and predicted the acceleration of the fan cart in accordance with Newton's 2^{nd} law. We then tested the acceleration of the fan cart to compare this result with our predicted outcome. We set objects at either end of the track, so to stop the fan cart, and put a sonic range finder at one end of the track. We turned the fan on "high" and held the fan cart still, at the end of the track with the sonic range finder, then released the fan cart, stopping it at the end of the track. Using the Logger Pro software, we assayed the acceleration of the fan cart by taking the slope of the best-fit line the program produced. We saved our value and printed out our graph.



We repeated this again, this time using a weight on top of the fan cart. We found the new weight (F(g)) of the fan cart with the added weight and the force produced by the fan cart with the weight, using the methods described above. We then predicted the acceleration of the fan cart using Newton's 2nd law. We then measured the acceleration of the fan cart with the weight using the Logger Pro software and printed out our graph. We then repeated this with another weight.

Since our experimental values were different than our predicted values, we calculated the percent difference/ discrepancy of our experiment. We used the equation:

$$\% \text{ difference} = \frac{\text{difference between experimental and theoretical values}}{\text{average of experimental and theoretical values}} \times 100$$

We then tried to identify all the possible errors in our experiment, and the percentage by which these errors could account for our percent difference, and found our new percent discrepancy. Note: our honors physics class expects about a 10% discrepancy.

We then tilted the fan at 60° away from straight. We measured the force again (using the force probe in the way described above), and compared this to the predicted value, then measured the acceleration, which should be less than the acceleration of the fan in the straight direction. We tested other angles as well, specifically 45° and 30°, and compared their forces in the forward direction with their predicted forces in the forward direction.

Predicted Results

For the first part of this lab, which measured the acceleration of a fan cart on a track in the forward direction, my group hypothesized values for the acceleration of the fan cart, using the values we knew for the Fnet and the mass. We hypothesized that the cart would accelerate faster when it had a lighter mass, and that it would accelerate slower when it carried a heavier mass. We reasoned this because in the formula a = Fnet/m, when one increases the m, the a decreases.

a) Predicted acceleration for fan cart with no weight → a = fnet/m → a = .26/.58 → a = 0.448 m/s^2

b) Predicted acceleration for fan cart with 500 g weight → a = fnet/m → a = .4/1.08 → a = 0.370 m/s^2

For the second part of the lab, which measured the acceleration of and force produced by the fan carts in which the force was at an angle, we predicted both the forces in the forward direction and the acceleration of the fan cart with these different angles. We hypothesized that the acceleration of the fan cart was inversely proportional to the fan's angle; the larger the angle, the slower the acceleration of the fan cart. We reasoned this because the larger the angle of the fan, the more sideways motion the fan cart has, and this sideways motion takes away from the forward force vector and consequently accelerates the fan cart less.

a) 60°
   a. Force produced in forward direction → F cos(60°) → .26 cos(60°) → 0.13 N
   b. Acceleration forward → a = Fnet/m → a = .13/.58 → a = 0.224 m/s^2

b) 45°
   a. Force produced in forward direction → F cos(45°) → .26 cos(45°) → 0.184 N
   b. Acceleration forward → a = Fnet/m → a = .184/.58 → a = 0.317m/s^2

c) 30°
   a. Force produced in forward direction → F cos(30°) → .26 cos(30°) → 0.225 N
   b. Acceleration forward → a = Fnet/m → a = .225/.58 → a = 0.388m/s^2

Experimental Results: (See attached graphs)

Note: Data for force derived from the mean of all values found on Logger Pro.
Data for acceleration derived as the slope of the best-fit line of the graph produced by Logger Pro.

Data for fan cart with no weight, all motion in forward direction
(Corresponds to attached graph titled "Fan with no weight of angle change (0º)")

Weight	5.8 N
Mass	.58 kg
F net	0.26 N
Theoretical Acceleration	.26/.58 = 0.448 m/s^2
Actual Acceleration	0.450 m/s^2
% discrepancy vs. predicted for acceleration	0.4%

Data for fan cart with .2 kg, all motion in forward direction
(Corresponds to attached graph titled "Fan cart with 200 g weight added")

Weight	7.8 N
Mass	0.78 kg
F net	0.33 N
Theoretical Acceleration	0.33/.78 = 0.423 m/s^2
Actual Acceleration	0.415 m/s^2
% discrepancy vs. predicted for acceleration	1.9%

Data for fan cart with 1 kg, all motion in forward direction
(Corresponds to attached graph titled "Fan cart with 1 kg weight")

Weight	15.8 N
Mass	1.58 kg
F net	0.19 N
Theoretical Acceleration	0.19/1.58 = 0.120 m/s^2
Actual Acceleration	0.1215 m/s^2
% discrepancy vs. predicted for acceleration	1.2%

Data for fan cart with no weight at 60°
(Corresponds with attached graph titled "Fan at 60 degrees")

Predicted Force (x direction): .26 cos(60°) = 0.13 N
Experimental force (x-direction) = 0.15 N
Percent discrepancy force: 14.3%

Predicted acceleration → a = Fnet/m → a = 0.13/0.58 →.224 m/s^2
Experimental acceleration: 0.26 m/s^2
% discrepancy: 14.9%

Data for fan cart with no weight at 45°
(Corresponds with attached graph titled "Fan at 45 degrees")

Predicted Force (x direction): .26 cos(45°) = 0.184 N
Experimental force (x-direction) = 0.17 N
Percent discrepancy force: 7.9%

Predicted acceleration → a = Fnet/m → a = 0.184/0.58 →0.317 m/s^2
Experimental acceleration: 0.30 m/s^2
% discrepancy: 5.5%

Data for fan cart with no weight at 30°
(Corresponds with attached graph titled "Fan at 30 degrees")

Predicted Force (x direction): .26 cos(30°) = 0.225 N
Experimental force (x-direction) = 0.263 N
Percent discrepancy force: 15.6%

Predicted acceleration → a = Fnet/m → a = 0.225/0.58 →0.338 m/s^2
Experimental acceleration: 0.416 m/s^2
% discrepancy: 7.0%

Analysis of Results, Experimental Error, Conclusions:

In general, my group's results supported Newton's 2nd law and agreed with our hypotheses. The percent discrepancy by which our measurements deviated from our theoretical values could be explained in all occasions but one. I quantified the data in order to explain the discrepancies.

In the first part of the lab, in which my group measured the acceleration of the fan cart with no additional weights, then the acceleration of the cart with different weights added (with all force still going forward), we identified the following sources of error:

1) 2% for using 10 m/s^2 instead of the more accurate 9.8 m/s^2 for our gravitational constant
    a. 9.8-10 = 0.2 → 0.2/10 = 0.02 → 2%
2) 1% for rounding → we rounded to the thousandths place.
3) 1.4% for the fan not being turned to exactly x°
    a. 5° margin for error → 5/360 = 0.013 → 1.4%

So, total % error for this part of the experiment was:

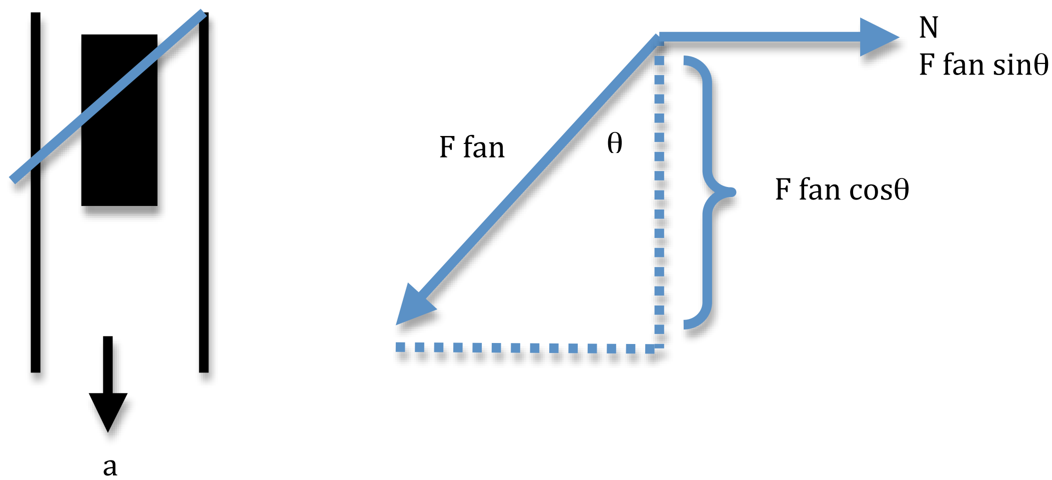
$$\sqrt{2^2 + 1^2 + 1.4^2} = 2.64\%$$

2.64% accounts for all of the error in our first measurements, since our percent error for the fan with no weight, .2 kg, and 1 kg were, respectively, 0.4%, 1.9%, and 1.2%. This shows that our data aligned with Newton's 2nd law, that a = F/m, since this equation predicted our outcomes to within the 2.64% estimated experimental error. Thus, my hypothesis that when we applied constant force and varied the mass, the acceleration would be inversely proportional to the mass, was verified by our data.

Sources of error for second experiment, in which we turned the fan at specific angles, were:

1) 2% for using 10 m/s^2 instead of the more accurate 9.8 m/s^2 for our gravitational constant
    a. 9.8-10 = 0.2 → 0.2/10 = 0.02 → 2%
2) 1% for rounding → we rounded to the thousandths place.

3) 1.4% for the fan not being turned to exactly x°
    a. 5° margin for error → 5/360 = 0.013 → 1.4%
4) Friction forces against the side of the track [1]
    Diagram:



This diagram shows the breakdown for the backwards and sideways forces of the angled fan. F fan shows the total force vector, but F fan cosθ shows the component of the force that actually acts on the fan cart. The sideways component, F fan sinθ, is transferred into sideways motion, which pushes the cart against the side of the track. Kinetic friction acts to slow the cart down, and the normal force, also F fan sinθ, acts to push the cart back onto the track. However, this experiment assumes that the friction is zero. However, friction does exist because of the sideward force of the wheels against the track.

I found the force of kinetic friction for plastic (the wheels) on aluminum (the track), to be $\mu k = 0.3$, and calculated the percent discrepancy in acceleration between our theoretical value, which accounts for no friction, and a new value (calculated below) that shows the acceleration changed by the friction component.

Calculations:

a. % error due to friction for **60° → 69.9%**
    i. $a = \frac{F}{m}$
    ii. $a(\text{no friction}) = \frac{F\ fan\ \cos\theta - \mu k\ F\ fan\ \sin\theta}{m}$
    iii. F fan = .26 N
    iv. θ = 60º

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[1] Friction, the resistance that one surface encounters when it comes in contact with another, can slow a moving object down.

v. μk for plastic on aluminum = 0.3
   1. a(no friction) = $\frac{0.26 \cos(60^\circ) - (0.3)(0.26 \sin(60^\circ))}{0.58}$
   2. a(no friction) = 0.108 m/s^2

vi. Find percent error between a(no friction) and a(theoretical)
   1. A(theoretical) = 0.224 m/s^2
   2. A(no friction) = 0.108 m/s^2
   3. $\frac{0.224 - 0.108}{(0.224 + 0.108)/2}$ x 100 = **69.9%**

b. % error due to friction for **45° → 35.7%**

i. a = $\frac{F}{m}$

ii. a(no friction) = $\frac{F\ fan \cos\theta - \mu k\ F\ fan \sin\theta}{m}$

iii. F fan = .26 N

iv. θ = 45º

v. μk for plastic on aluminum = 0.3
   1. a(no friction) = $\frac{0.26 \cos(45^\circ) - (0.3)(0.26 \sin(45^\circ))}{0.58}$
   2. a(no friction) = 0.222 m/s^2

vi. Find percent error between a(no friction) and a(theoretical)
   1. A(theoretical) = 0.317 m/s^2
   2. A(no friction) = 0.222 m/s^2
   3. $\frac{0.317 - 0.222}{(0.317 + 0.222)/2}$ x 100 = **35.3%**

c. % error due to friction for **30° → 5.2%**

i. a = $\frac{F}{m}$

ii. a(no friction) = $\frac{F\ fan \cos\theta - \mu k\ F\ fan \sin\theta}{m}$

iii. F fan = .26 N

iv. θ = 30º

v. μk for plastic on aluminum = 0.3
   1. a(no friction) = $\frac{0.26 \cos(30^\circ) - (0.3)(0.26 \sin(30^\circ))}{0.58}$
   2. a(no friction) = 0.321 m/s^2

vi. Find percent error between a(no friction) and a(theoretical)
   1. A(theoretical) = 0.338 m/s^2
   2. A(no friction) = 0.321 m/s^2
   3. $\frac{0.338 - 0.321}{(0.338 + 0.321)/2}$ x 100 = **5.2%**

So, percent error total for the measurement of acceleration of the fan at 60º was:

1) 2% for using 10 m/s^2 instead of the more accurate 9.8 m/s^2 for our gravitational constant
2) 1% for rounding → we rounded to the thousandths place.
3) 1.4% for the fan not being turned to exactly x°
4) Friction forces against the side of the track → % error due to friction for 60° → 69.9%

$$\sqrt{2^2 + 1^2 + 1.4^2 + 69.9^2} = 70.0\%$$

70.0% more than accounts for all of the error in this experiment, which was 14.9%, so this data supports Newton's 2nd law.

Percent error total for the measurement of acceleration of the fan at 45º was:

1) 2% for using 10 m/s^2 instead of the more accurate 9.8 m/s^2 for our gravitational constant
2) 1% for rounding → we rounded to the thousandths place.
3) 1.4% for the fan not being turned to exactly x°
4) Friction forces against the side of the track → % error due to friction for 45° → 35.3%

$$\sqrt{2^2 + 1^2 + 1.4^2 + 35.3^2} = 35.4\%$$

35.4% accounts for all of the error in this experiment, which was 5.0%, so this measurement also helps back up Newton's 2nd law.

Percent error total for the measurement of acceleration of the fan at 30º was:

1) 2% for using 10 m/s^2 instead of the more accurate 9.8 m/s^2 for our gravitational constant
2) 1% for rounding → we rounded to the thousandths place.
3) 1.4% for the fan not being turned to exactly x°
4) Friction forces against the side of the track → % error due to friction for 30° → 5.2%

$$\sqrt{2^2 + 1^2 + 1.4^2 + 5.2^2} = 5.8\%$$

5.8% does not account for all of the error in this experiment, which was 7.0%. So, this portion of the experiment produces results that, corrected for estimated experimental errors, fall 1.2% short of verifying Newton's 2nd law. Though I quantified all the error in this experiment to the best of my abilities, I am sure a more experienced physicist could quantify additional errors. So, though I know that since I have quantified all the sources of error I could and that this number is not larger than the error I got in the experiment that I have “made a discovery,” I hesitate to jump to that conclusion because Newton’s laws are so fundamental to the field of physics, and because all of my other data backs up this law. So, though I cannot find any other error, I know there must be additional error I did not find, so was not able to quantify. I can expect that if I had found additional errors, that this would change the experimental error so that the experimental error would be greater than my percent discrepancy, so my results would be more acceptable and explainable. Overall, however, my results verified Newton’s 2nd law.

Recommendations

I feel this experiment was a good test of this law, but I also think that one could improve this experiment in the future by using a fan cart with wheels made of a different substance, like Teflon, that had a smaller coefficient of kinetic friction with aluminum. This would cause a significant decrease in the amount of friction imparted by the wheels hitting the side of the track, since the difference between the coefficient of kinetic friction between aluminum and plastic and aluminum and Teflon is 0.37, which changes the experimental error from around 50 or 60% to around 4 or 5%, making the experiment significantly more accurate. Also, one could improve this experiment by using a more streamlined fan cart in order to further reduce the air resistance acting on the cart and resisting and reducing the cart’s velocity and acceleration.