Timmy Bartos
Annie Hanley-Miller
Ethan Fahnestock

Testing the Conservation of Momentum with a Cart and Dropped Masses

Results (part 1)

Mass of Cart: 2.691 kg

Table 1.1: Calculations and Measurements

Dropped on Cart	Peak Velocity	Average Deceleration After Drop (m/s^2)	Actual Mass (kg)	Predicted Mass (kg)	Percent Error (%)	Change in Velocities During Drop (m/s)
1kg Mass	0.76 m/s	-0.084 m/s^2	1.0 kg	0.93 kg	6.85%	0.18 m/s
Brick	0.79 m/s	-0.06 m/s^2	1.775 kg	1.59 kg	10.4%	0.26 m/s
Box of Masses	0.79 m/s	-0.076 m/s^2	2.244 kg	2.12 kg	5.33%	0.30 m/s
Textbooks	0.86 m/s	-0.124 m/s^2	4.440 kg	3.95 kg	11.11%	0.44 m/s

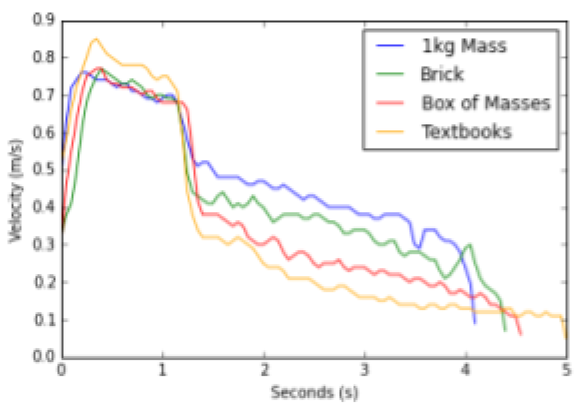

Figure 1.1: Velocities of Trials Over Time

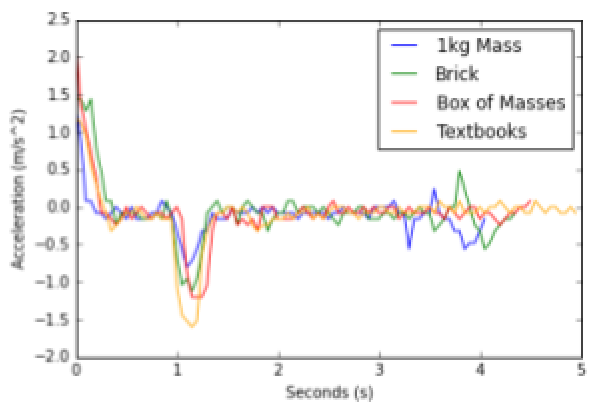

Figure 1.2: Accelerations of Trials Over Time

Results (part 2)

Figure 1.1 shows the measured velocities of each trial over time. The trials for the 1kg mass, the brick, and the box of masses all reached a similar velocity from their initial push. The textbook trial reached a higher velocity from its initial push. Especially towards the end of the recorded data, almost every trial had outliers. Figure 1.2 shows the accelerations of the carts over time. Again there are outliers towards the end of the trials. A running mean was used to smooth out both graphs. A running mean averages together a group of adjacent values in a list, starting at one end and going to the other. Adjacent values in this case are velocities recorded next to each other on the spark timer tapes. This was used to decrease the severity of outliers without replacing them with invented values.

The changes in velocities during the drop were calculated using velocities pulled before and after the drop was observed. The values were chosen as close to the 'drop' as possible, without being in the velocity transition period caused by the dropped mass.

The average deceleration after drop column in Table 1.1 was found by averaging the difference between adjacent velocities recorded between two and three seconds after the cart was pushed. During this time period, the only force changing the velocity of the cart was friction, and this time period excludes any outliers that occurred towards the end of the recorded data.

Discussion

The purpose of the lab was to prove the conservation of momentum. The law of conservation of momentum is that the total momentum of an isolated system of bodies remains constant. In this lab, the objects in the 'collision' start separate and then join as one, so $m_1V_1+m_2V_2=(m_1+m_2)\bullet V'$. The left side of the equation represents the mass and velocities of the separate objects before the 'collision', while the right side represents the masses of the objects together and the resulting velocity after the ‘collision’. The objects dropped on the cart weren’t supposed to have any horizontal velocity, so when solving for the mass of the dropped object, the formula can be simplified to:

$$\frac{m_1 \cdot V_1}{V'} - m_1 = m_2$$

In this experiment the different masses were tested to prove the conservation of momentum. Objects were dropped on a moving cart and as the mass increased, the post-drop velocity of the cart decreased, which was due to the conservation of momentum. The objects dropped were: a 1 kg mass, a brick, a box of masses, and three textbooks. The larger the mass added to the cart, the larger the decrease in velocity because as the mass goes up, the velocity must go down to retain the pre-collision momentum. Each trial showed that as the added mass increased, the $\triangle$V increased, which was expected because of the conservation of momentum.

However, there were sources of error in this experiment. Primarily, when the objects were dropped onto the carts, they could have been given small amounts of horizontal velocity by the person dropping them. To help minimize this, the objects were dropped with a hand on each side, but some horizontal velocity was still probable. Secondly, the landing position of the dropped mass was not be controlled. For each trial, the object landed on a different part of the cart (farther forward/backwards etc.). Depending on where it lands, it may have tipped the cart and changed its path, which may have changed the angle the spark tape was pulled at, and the recorded results. On a side note, adding a mass to a system can change the center of mass, but because the center of mass was somewhere on the cart system, measuring the velocity of the cart measured the velocity of the center of mass, so the velocities work with in the conservation of momentum equations. Small errors may have been caused by the drop height or the change in pull of spark tape. These errors are further explained below, but if they were existent, they would have been very small. They are only mentioned because if this experiment were performed in the future, they could be taken into account if the experimenter desired more accurate results.

The outliers near the end of the recorded data as mentioned in the results, is likely due to someone trying to stop the cart. This could have been in the form of tapping the cart. Some outside force had to have caused the outliers, if the data is valid, because nothing changed within the system that would result in an acceleration. These outliers don't affect the calculations, but in the future should be understood, as they could occur during other parts of the trial, which could affect the data.

The results in this lab were limited by the measurement of the spark timer tape. The distance between three sets of dots were measured to the nearest millimeter, but to increase the accuracy one could measure each set of dots. More measurements would decrease the significance of outliers, and allow a more accurate measurement of near-instantaneous velocity.

In addition to deriving the deceleration during the drop, the average deceleration after the drop was found. This deceleration was likely due to friction and air resistance. This measurement was after the drop, so the mass of the cart would be combined with the mass of the dropped object. The force of friction is μmg, and changes with the mass. If you compare the work done by friction to kinetic energy ($mv^2/2$), you find that the masses cancel. The same thing happens if you convert the force of friction into an acceleration, the masses cancel. This means that no matter the object, if the coefficient of friction is the same, the objects will decelerate at the same rate. This isn't what the data states, as ignoring the 1kg trial, each deceleration rate seems to get larger as the mass increases. The box of masses is about half the mass of the textbooks, and it experienced roughly half the deceleration. This suggests either inaccurate deceleration rates, or a difference force influencing the deceleration rate that would be proportional to the mass of the cart, such as a slanted floor. An average pre-drop deceleration could not be accurately measured with the limited data available before the drop. If this lab was repeated, one could wait longer before dropping the mass. With more time before the drop, an accurate deceleration could be found for the cart before the extra mass was added. Comparing this to post-drop decelerations, the influence of the mass on the amplitude of deceleration could be analyzed, and the forces decelerating the cart could be better understood.

The large percent error with the textbooks trial may in part be due to the inaccuracy of the original mass measurement of the three textbooks. Due to time and scale limitations, only one textbook was weighed, and the resulting mass was multiplied by three to get 4.440 kg. This mass would be off if the three textbooks didn't weight the same amount.

Lastly, the predicted masses were always less than the measured mass. This would suggest that there was something that was consistently inaccurate, and the prediction errors were not due to simple measuring problems (there would likely be predicted masses above the actual value), although if the mis-measurement was constant it would be possible. Only two measured variables could cause this trend, the measured masses, or the measured velocities. One of the many possibilities is that the mass of the cart wasn't measured properly, as this would affect every trial's results in the same way.

Table 1.2: Potential Errors

Drop Height	The higher and heavier the object was dropped, on contact, would change the normal force, affecting friction for that brief moment, and changing the velocity lost through the drop.
Change in Spark Tape Pull	The spark tape was torn ahead of time and left to sit behind the timer to be pulled through by the cart when it was pushed. It is likely that the configuration of the tape behind the timer was different for each trial. As the tape was pulled through the timer, it may have had to flatten out twists in the tape, which would apply a force against the velocity of the cart. This would only be a problem because of the inconsistency between trials.