Experiment 4:
Momentum and Impulse

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DISCUSSION

Mass of glider w/ accessories	0.2022kg$\pm$ 0.00015 kg
Width of flag	0.0395m $\pm$ 0.0005 m

Table 1. Measurements Used in Experiment. The glider's mass measurement was obtained by measuring relative to two objects whose masses were also measured with a $\pm 0.00005\ kg$ uncertainty each, giving another measurement with a $\pm 0.00005\ kg$. This was then added together.

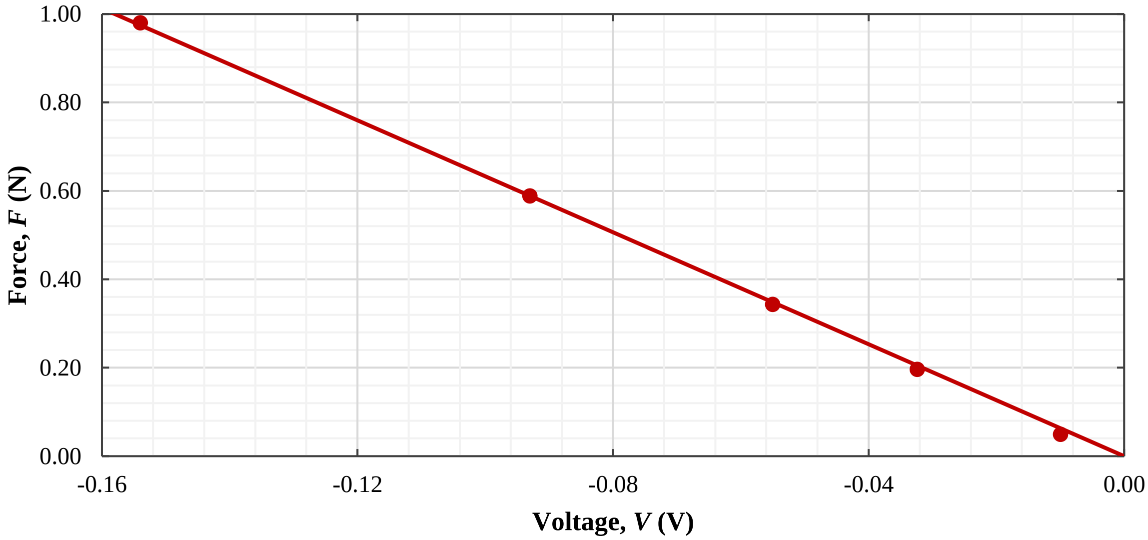

Figure 1. Calibration of Force Sensor. After the sensor is tared, a weight of mass m is hung from the hook of the sensor, generating a certain amount of voltage. The measurement of voltage is plotted opposite the force applied by the hanging mass, $F = mg$, where $g = 9.8m/s^2$. This was done for five different hanging masses and the results are plotted as force vs. voltage. The red line fitting the data has the equation $F(V) = (-6.458 \pm 0.013)\frac{N}{V}V - 0.01V$, which was found through Excel's linear regression tool. The calibration constant that will thus be used for voltage-force conversion is $(6.458 \pm 0.013)\frac{N}{V}$. The negative sign is omitted, since the slope was obtained through tension whereas the rest of the experiment involves compression (and the force is considered positive in both contexts.

Trial	Initial Velocity, v_i (m/s)	Final Velocity, v_f (m/s)	Initial Momentum, p_i (N·s)	Final Momentum, p_f (N·s)	Impulse, Δp, (N·s)
1	-0.680 $\pm$ 0.0005	0.1420$\pm$ 0.0005	-0.1374$\pm$0.0001	0.0287$\pm$0.0001	0.1662$\pm$0.0002
2	-0.854 $\pm$ 0.0005	0.1381$\pm$0.0005	-0.1726$\pm$0.0001	0.0279$\pm$0.0001	0.2005$\pm$0.0002

Table 2. Calculation of Impulse for Momentum Change method* For each trial, the initial and final velocity of the glider were recorded by the photogate when the flag on the glider blocked the sensors. Since it is known that the glider moves in the opposite direction post-collision, a negative sign is added to the initial velocity for each trial (to get a positive value). The measurements of velocities and mass of the glider are then used to calculate the impulse.

*Brief explanation of the formulas used for the uncertainties:
Since the photogate's timing uncertainty is much smaller than fractional uncertainty of the flag's width, the uncertainty for the velocity is just assumed to be the same as that of the flag width. Since $p = mv$, the uncertainties for p_i and p_f were found using m, δm, and the corresponding values of v and δv with equation ii.23 from the lab manual:

$$\delta p = p_{best}\sqrt{\left(\frac{0.00009}{0.2022}\right)^2 + \left(\frac{\delta v}{v_{best}}\right)^2}$$

Since $\Delta p = p_f - p_i$, the uncertainty was found using equation ii.22:

$$\delta \Delta p = \sqrt{\delta p_f^2 + \delta p_i^2}$$

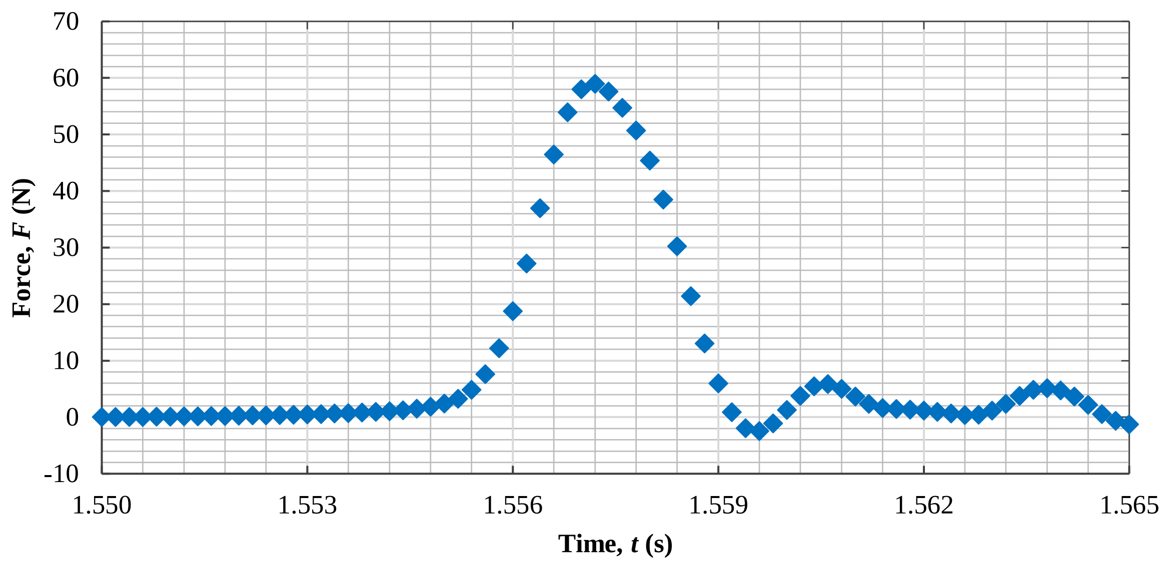

Figure 2. Impulse in Glider-Force Sensor Collision, Trial 1. During a run, the glider was gently pushed toward the sensor; after colliding with the sensor, the glider moves away from the sensor. The time range plotted above was selected from a larger range of sensor output vs. time data to focus on the output during the collision. The output voltage was then converted to the compression force on the sensor by multiplying each value by $(6.458 \pm 0.013)\frac{N}{V}$, the force calibration constant determined from Figure 1. The average of the first 5 ms worth of force values was averaged for the force baseline; this value was then subtracted from all the force value to have the curve start at approximately 0 N before the collision. This is so the impulse calculated is accurate and relates to the effects of the glider-sensor collision only. The curves past $t = 1.56\ s$ is ignored as it is due to the ringing of the sensor as opposed to real-time compression.

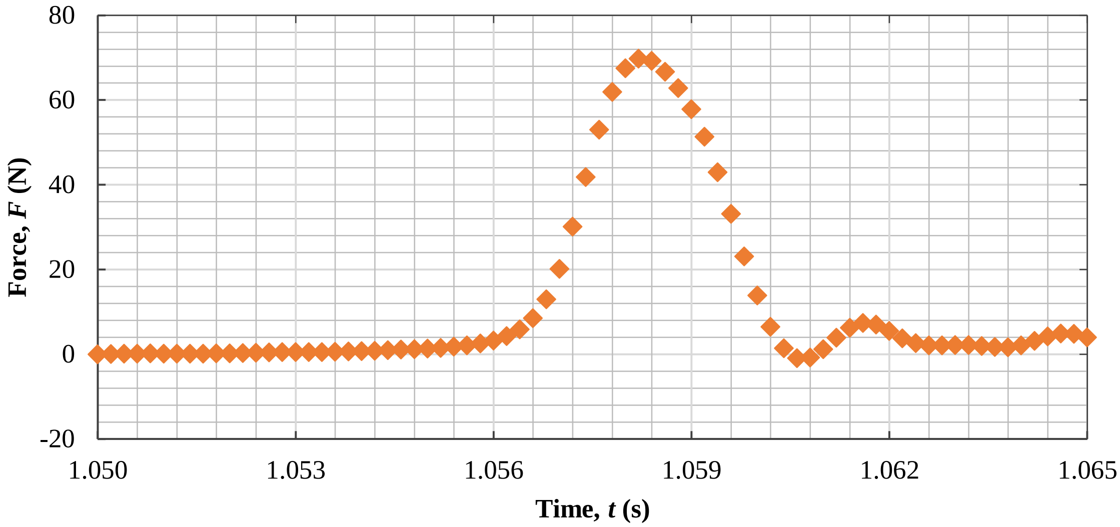

Figure 3. Impulse in Glider-Force Sensor Collision, Trial 2. During this run, the glider was again gently pushed toward the sensor with a little more force to increase the initial velocity. The data points were processed in the same way as described in Figure 2, where only the data focusing on the collision is selected. The output voltage is converted to force using the calibration constant $(6.458 \pm 0.013)\frac{N}{V}$. The average of the first 5 ms worth of force values was averaged as subtracted from all the force values to level the curve near 0.

Determining Impulse through Force-time data:
Based on the lab manual, another method of finding impulse is integrating force with respect to time, or $\Delta P = \int dt\, F(t)$. While this calls for a single continuous integral, something that can't be performed with a set of points, we can use Reimann sum integral. This method numerically integrates the data by separately evaluating blocks of data between successive points; these are then summed to approximate the evaluation of the integral. Such an approximation is appropriate for our data since our sample rate was 5.0 kHz, giving us many short time intervals that approach 0. We therefore approximate the integration through the mathematical formula
$\Delta P \approx \Delta t \sum_{i=1}^{n} F(t_i)$.

The above function is performed on Excel by first evaluating the force for each output voltage point as mentioned in Figures 2 and 3. Then using the SUM() function, the sum of all these force values are found, giving us the value for $\sum_{i=1}^{n} F(t_i)$. This value is then multiplied by 0.0002, which is Δt due to our sampling rate. This gives us the best value for the impulse for each run.

The uncertainty is estimated by assuming the fractional uncertainty of the integration is that same as that of the calibration constant.

For trial 1, the calculated impulse was 0.1519$\pm$0.013 N·s.
For trial 2, the calculated impulse was 0.1843$\pm$0.013 N·s.

Trial	Method 1: Impulse (N·s) by Momentum Change	Method 2: Impulse (N·s) by Force Integration
1	0.1662 ± 0.0018	0.1519 ± 0.013
2	0.2005 ± 0.0022	0.1843 ± 0.013

Table 3. Measurement of Impulse for both Trials through both Methods. The measurements in Trial 1 agree as the lower bound of the first value (down to 0.1644 N·s) and the higher bound of the second value (up to 0.1649 N·s) overlap. For trial 2, the lowest possible value for method 1 is 0.1983 N·s and the highest possible value for method 2 is 0.1973. While they do not overlap, they are within 0.001 N·s of each other for agreement. This can be attributed to a systematic error or not calculating the correct uncertainty.

Introduction

The science behind all systems generally revolves around the forces that act on them. The effect of these forces is commonly measured by the energy they contribute to a system. The issue with such a measurement, however, is there are non-conservative forces in real-world situations. This often leads to energy dissipation, and it becomes difficult to confidently track the energy distribution in a system in order to verify the conservation of energy. In contrast, the law of conservation of momentum is relatively easier to track and predict because unlike how kinetic energy may convert to heat, linear momentum must be conserved during collision. Since this phenomenon is simpler to account for in systems, it thus becomes important to understand how to compute and analyze momentum.

In this experiment, collision between a glider and force sensor is observed to gain understanding of momentum and impulse. While impulse is defined as the change in momentum, it is said to be equivalent to the integration of the force exerted during the collision with respect to time. This idea is tested by measuring impulse in two ways. The first records the constant velocity of the glider before and after the collision, which are used to calculate the initial and final momentum; the difference in these values gives us the impulse. The second method approximates the integration of force through obtaining the force sensor's output voltage during the collision. The output is converted to force at every time recorded and the Riemann sum of these values yield the impulse. Comparing the results of these two methods will ideally verify their equivalence and will provide the understanding on how to analyze the momentum of a system based on their known components.

Word Count: 285

Methods

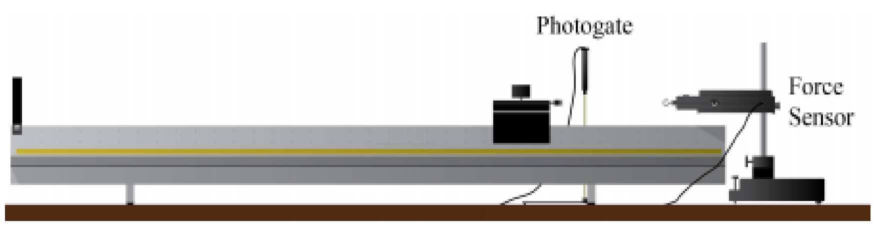

Figure 4. Set up of Experiment. Figure reproduced (with permission) from Fig. 1.1 by Campbell, W. C. et al. Physics 4AL: Mechanics Lab Manual (ver. May 12, 2017). (Univ. California Los Angeles, Los Angeles, California).

Before setting up the experiment as shown above, the force calibration constant for the force sensor is determined. This is done by hanging a weight on the force sensor vertically to observe how the gravitational force affects the sensor's output voltage. First, the Pasco Capstone program is set up to obtain data from the sensor. After connecting the force sensor to the interface, the corresponding analog channel is set as "User Defined Sensor" on the Tools/Hardware Setup page. The "Digits" icon is clicked on and the precision for the data is set to at least ten. After the sensor is tared and recording begins, a weight is hung on the sensor and the best voltage value is written down. Five different weights are used—the mass of each weight is measured to calculate the tension exerted on the sensor by each weight. The difference tension values are plotted against the corresponding voltage values on Excel and the linear regression tool is used to obtain the fitted line for data. The slope of this equation gives the calibration constant, which is used for the force integration method.

While two methods are used to calculate impulse, the data for both are obtained in one run. The experiment is set up in the configuration shown in Figure 4. After the air track is levelled and its blower is turned on, the force sensor is set up at the end of the track using clamps and a rod on the table. This is set so that a small foam bumper on the glider collides with the sensor's hook instead of the glider itself. The photogate sensor is set up near the sensor so that the glider's flag (rectangular block) could completely pass through the photogate before colliding, but it does not take to long for the glider to pass the photogate post collision. The mass of the glider with all of its accessories is recorded as well as the width of the glider's flag, which is used for the photogate's calculation of speed.

The hardware is setup on Pasco Capstone by choosing "Photogate" for the corresponding channel on the Tools/Hardware Setup page. Since force sensor is still set up from the calibration, it is left as is. Then, on "Timer Setup", a new Pre-Configured Timer is created for "one photogate (single flag)". We check speed for measurement and input the glider's flag width for flag spacing. A table is created with three columns: Time (s), User Defined (V), and Speed (m/s). The User Defined Sensor is set to have a sampling rate to 5.00 kHz and recording should be in "Continuous Mode". Both settings are on the Controls palette. While this sometimes gave over 10,000 points due to a slow trigger finger, the small Δt and high number of points led to a lower uncertainty. After setting this up, the experiment is ready to be run.

In a run, the glider, placed before the photogate and force sensor, is gently given a push so that it glides towards the photogate. The record button is pressed right before the flag of the photogate gets to the photogate and is stopped after the glider collides with the force sensor and passes the photogate again. This is done twice with ideally two different initial velocities.

The entire table of data is copied onto Excel to be safe. However, using the Scope feature on Capstone and zooming in to find the curve or the collision, the important time range of data can be estimated and recorded on Excel. This only pertains to the first two columns of time and sensor output which are used for force integration. The third column of data should just have two measurements of speed. The photogate does not measure direction, but it is known that the glider was in the opposite direction after collision. Therefore, a negative sign should be added to either velocity (not both). To get a positive impulse and be consistent with the force integration, the sign is added to the initial velocity.

The impulse for each run is first calculated using the definition the impulse is change in momentum. This is done by finding the initial and final momentum using the two velocities and the formula $P = mv$. The impulse is $\Delta P = P_f - P_i$. The impulse for each run is then calculated again using the integration of force method. After selecting the desired time range of data and converting sensor output voltage to force using the calibration constant, the first few seconds of force are averaged. This is then subtracted from all force values to base the curve at 0 N. The integration is approximated using Riemann sum where all the force values from under the curve are summed and multiplied by Δt. The impulse calculations from each method for each trial are then displayed in a data for comparison. Ideally, the calculations overlap and agree for each run.