Experiment 4: Momentum and Impulse

Deborah Liu UID: 205140725

2019/5/7 Lab Section 5, Tuesday 8 am

TA: Jingwen Zhang

Lab Partner: Benjamin Ming Hoe Koh

2. Discussion

The measured value for the mass of the glider is:

$$M = 0.19700 \pm 0.00005 \text{ kg}$$

The width of the photogate flag is:

$$L = 0.0380 \pm 0.0005 \text{ m}$$

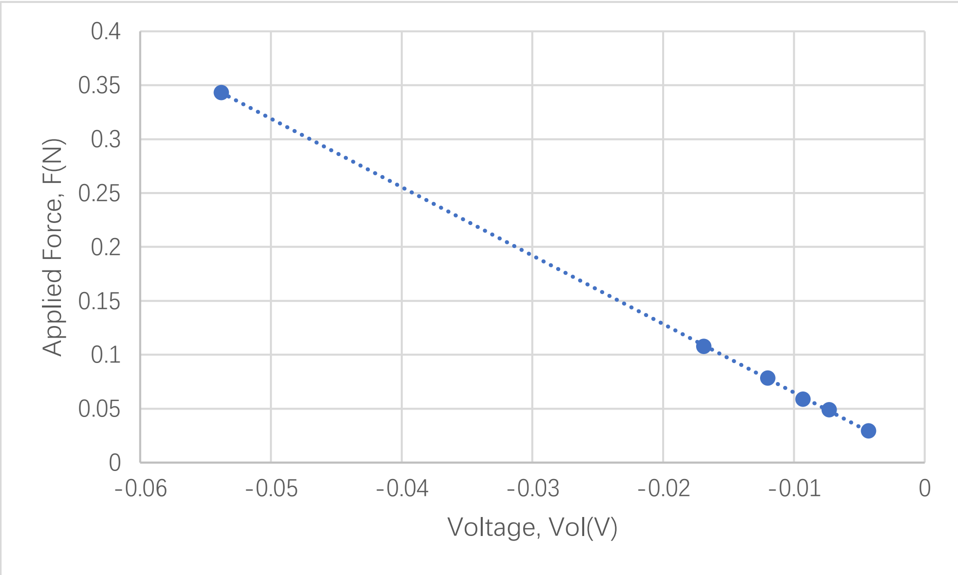


Figure 1. Calibration of force sensor. The blue dots represent the force corresponding to different output voltage. The best fit line is F=aV+b, where $a = -6.35 \pm 0.03$ N/V, $b = 0.0016 \pm 0.0007$ N. The small intercept indicates that the force sensor is well calibrated. Since we calibrate sensor with pulling force but use it to measure compression force in later part of the experiment, we will use the absolute value of a to convert the output voltage of the sensor into force.

Since the fractional uncertainty of speed is equal to the fractional uncertainty of photogate flag, the uncertainty of speed can be calculated with the following equation:

$$\delta v = |v_{best}| \times \frac{\delta L}{L_{best}}$$

Using the photogate speed method, the impulse is given by:

$$\Delta P_1 = M(v_f - v_i)$$

Where v_f is the final velocity and v_i is the initial velocity. Notice that the photogate only measures the speed of the glider. So, in this experiment, we define the direction of the final velocity to be positive and the initial velocity to be negative.

The uncertainty of the impulse calculated based on photogate speed method is given by:

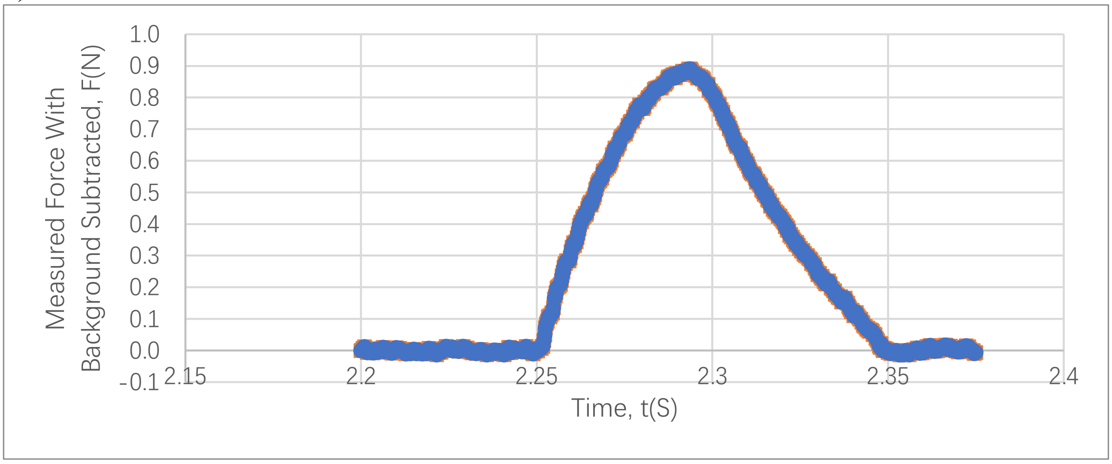
$$\delta \Delta P_1 = \sqrt{((v_f - v_i)\delta M)^2 + (-M\delta v_i)^2 + (M\delta v_f)^2}$$

The following table presents the calculated impulse based on the photogate speed measurement:

Trial	Initial Velocity, v_i(m/s)	Final Velocity, v_f(m/s)	Impulse, ΔP_1(Ns)
1	-0.132±0.002	0.100±0.001	0.0458±0.0004
2	-0.142±0.002	0.108±0.001	0.0493±0.0005

Using the force sensor, we obtained two plots of force vs. time graphs:

a)



b)

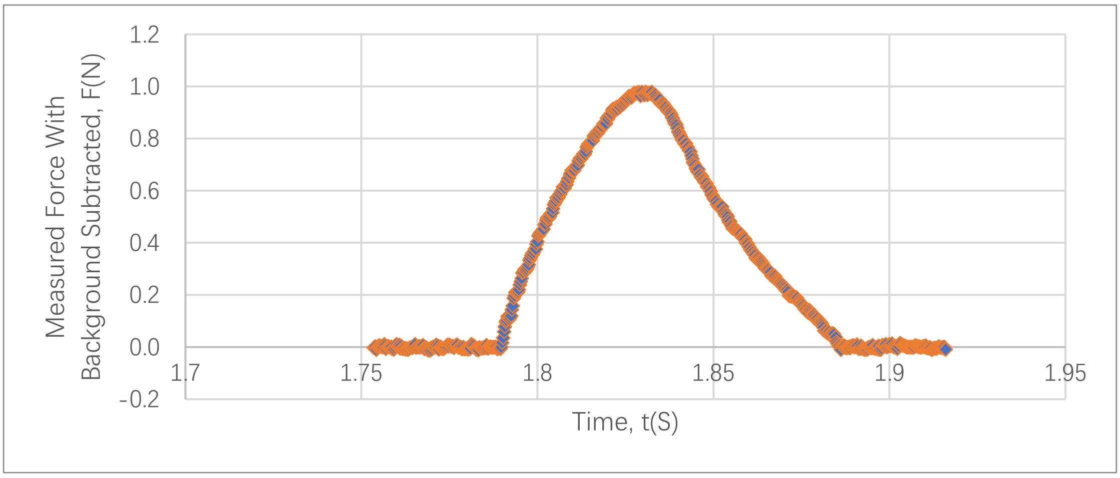


Figure 2. Calculating impulse with integration method. a) Trial 1. b) Trial 2. The figure only presents the data collected right before, during and right after the impact between the glider and sensor. 500 data points collected before the impact are averaged to give the baseline of force sensor, which is subtracted from the data in the plot. The area under the curve provides the impulse of the glider.

To calculate the impulse, the integral of the force as a function of t is taken to give the area under the curve in Figure 2 and 3. The integral is given by the Riemann's sum formula in the lab manual:

$$\Delta \mathrm{P}_2 = \Delta t \sum_{t=1}^{n} F(t_i)$$

where $\Delta t = t_{i+1} - t_i$.
The uncertainty of the impulse is given by:

$$\delta \Delta P_2 = |\Delta P_{2best}| \times \frac{\delta a}{a_{best}}$$

In trial 1, the impulse is:

$$\Delta P_2 = 0.0475 \pm 0.0002\ Ns$$

In trial 2, the impulse is:

$$\Delta P_2 = 0.0511 \pm 0.0002\ Ns$$

The table below demonstrates the results from two different methods for both trials:

Trial	Impulse by photogate speed method, ΔP_1(Ns)	Impulse by integral method, ΔP_2(Ns)
1	0.0458 ± 0.0004	0.0475 ± 0.0002
2	0.0493 ± 0.0005	0.0511 ± 0.0002

From the table, we can tell that the results from two methods are very close, despite that the integral method gives slightly higher impulse. One possible cause of the disagreement is unleveled air track. As the glider move towards the force sensor, it might accelerate, causing the actual initial speed becomes larger than the measured. As the glider bounces back, it decelerates so that the actual final speed is also larger than the measured value. Therefore, the photogate speed method might get smaller impulse than the actual value. On the contrary, the integral method measures force within much shorter distance and time, so the acceleration due to unlevel air track would be less significant, resulting a more accurate measurement.

Mini-Report

Introduction

The momentum of an object is its mass times velocity. The change of momentum is impulse, whose time derivative is force. The concepts of momentum and impulse help us understanding the motion of objects, from launching rockets to catching a baseball. In this experiment, we are trying to find the impulse of a glider during a collision. To obtain the impulse, we could examine the momentum of the glider before and after the collision, then subtract the first one from the latter one. We could also measure the force during collision as a function of time, then integrate the force with respect to time to get impulse. In this experiment, we will apply both methods. The glider will go through a photogate before and after the collision, from which we get its speed difference and thus calculate the momentum change. The glider will collide with a force sensor, which records the compression force during the impact, allowing us to later take integration with respect to time.

(word count:166)

Methods

In this experiment, the glider will move on a horizontally leveled air track. The air flowing on the surface of the air track will make a "cushion" between the glider and the track, allowing the glider to move nearly without friction. There is a flag of length L on top of the glider and a bumper on the side of the glider. The glider, together with the bumper and the flag, has mass M. L is measured by a meter ruler with uncertainty 0.05cm, and M is measured by a scale with uncertainty 0.05g. A photogate is used to measure the speed of the glider. It records the length of time Δt blocked by the flag, then divide L by Δt to give the speed of the glider. A force sensor is used to measure the compression force during the collision. The sensor will measure the force applied on its "hook" and convert the measured value of force into output voltage. The measurement has frequency f. That is, the force sensor will measure the force every $\frac{1}{f}$ second, then record the time and the output voltage at every measurement. The photogate and the force sensor are connected to the DAQ system, where the recorded speed, time and voltage are exported for later analysis.

The force sensor must be calibrated at the beginning of the experiment. It is hanged in the way that its hook points vertically downwards. After taring the sensor, different masses will be hanged on the hook, resulting different output voltage. Since the voltage is converted from the applied force on the hook, which in this case equals to the gravity force on the mass, we will record the corresponding force to each output voltage and find out their correlation. This will allow us to convert the output voltage back to the force in later part of the experiment.

The setup of the experiment is shown in the following picture.

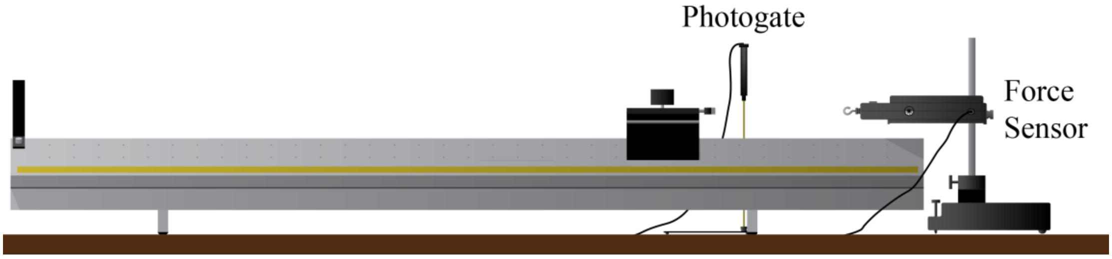


Figure 3. The setup of the experiment. The glider will be placed on the air track on the left side of the photogate. The height of the photogate allows only the flag on the glider to block it. The height of the force sensor is set in the way that the bumper on the side of the glider will collide horizontally with the hook on the sensor, providing a horizontal compression force. The distance between the photogate and the force sensor must ensure that when the bumper touch the hook, the flag on the glider is no longer blocking the photogate. There is almost 0 friction on the air track. Figure reproduced (with permission) from Fig. 4.1 by Campbell, W. C. *et al.*[1]

Before each trial starts, the force sensor will be tared to minimize the base voltage output. The measurement frequency is chosen to be 4kHz. When the measurement starts, the experimenter gives a gentle push to the glider towards right so that it glides with constant velocity through the photogate. The photogate will record the glider's speed as $|v_i|$. Ideally, $|v_i|$should be less than 0.2m/s, which ensures the glider will not hit the force sensor so hard that the sensor moves. During the collision, the force sensor should remain at its original position. After that, the glider bounces back towards the left and go through the photogate again. This time the photogate will record its speed as $|v_f|$. The measurement is then ended.

In this experiment, we conducted two trials with different initial velocity v_i.
To avoid systematic error, the air track must be leveled. Otherwise the glider will accelerate as it moves to the right and decelerate as it moves to the left. The photogate recorded speed will therefore be smaller than the actual speed before and after the collision, resulting the calculated momentum change to be smaller than the actual value. The force sensor must be aligned with the air track. Otherwise, a part of the impact force will not be recorded by the force sensor, as it only detects compression and pulling forces. This will cause smaller measured impulse than the actual value. The flag on the glider must also be aligned with the air track and the photogate. If it is tilted, the block time will become shorter and result larger measured speed, causing the calculated impulse to be larger than the actual value.

Bibliography

1. Campbell, W. C. *et al*. Physics 4AL: Mechanics Lab Manual (ver. June 27, 2018). (Univ. California Los Angeles, Los Angeles, California).