Lab #1

Newton's Third Law – Proving an Equal but Opposite Contact Force Through Colliding Model Carts of Varying Mass Combinations

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I. INTRODUCTION

Among Isaac Newton's three Laws of Motion, the Third Law declares that "actioni contrariam semper et æqualem esse reactionem: sive corporum duorum actiones in se mutuo semper esse æquales et in partes contrarias dirigi." (Newton, 1687, p. 49) The Third Law, from Latin, translates to how all forces occur in pairs, which are equal in magnitude and opposite in direction within inertial frames.

From the recoil experienced from operating a firearm to a head-on collision from two vehicles, Newton's Third Law has countless implications in reality. In the latter example, the two vehicles travel in opposite directions. Regardless of the mass and speed of each vehicle, both vehicle will receive a force identical in magnitude but opposite in direction during collision.

The following experiment has been conducted to prove Newton's Third Law from simulating head-on collisions using model carts with differing combinations of masses. The installed force sensor on each cart will register the force experienced before, during, and after each collision. Depending on the accuracy of the force sensors, the net force from the collisions should equate to approximately zero and thus, prove the Third Law.

Variables

The table in *Figure 1* identifies the types of variables used in the experiment.

Dependent	Independent	Controlled
1) Speed of carts	1) Collision force (N)	1) Length of track (1.00±0.005 m)
2) Mass of carts		2) Frequency of collection (2 kHz)

⮝ **Figure 1**

II. EQUIPMENT AND METHODOLOGY

Procedure

The experiment apparatus consists of the Pasco Scientific Newton's Laws Experiment Set along with a computer which runs the Pasco Capstone Software. Initially, the aluminum track is leveled using a spirit level. The two track-end stops are then fastened 1±0.005 meter apart using a measuring tape on the aluminum track and the two carts are placed in between. The force sensors, one on each cart, are then connected to the Universal Interface which is connected to the computer. With the Capstone Software running and the collection frequency set to 2 kHz, four runs were conducted by colliding the two carts under varying conditions. Before each run, the record data button on the computer and the calibration button on the force sensors are pressed.

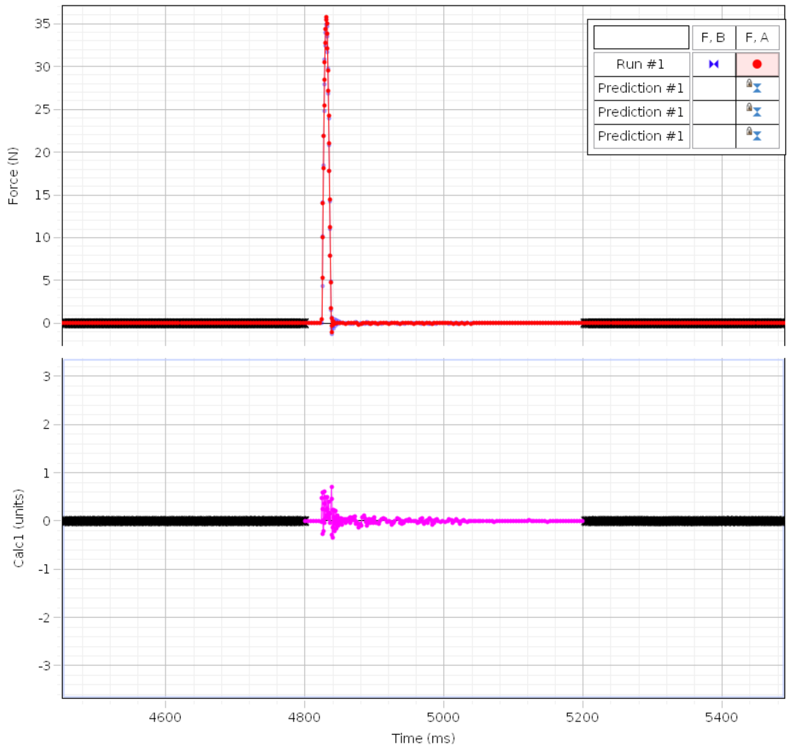
Run #1 involves releasing both carts of the same mass, positioned at the two magnetic ends[1] of the track, simultaneously[2] from rest. Run #2 involves releasing one cart under magnet repulsion and colliding it onto the other cart of the same mass under magnetic attraction by the other end of the track. Thus, this collision is between an object in motion with another at rest. Run #3 and #4 are identical to Run #1 and #2, respectively, apart from adding two 1 Kg masses onto one of the carts in motion.

A few seconds after each collision, the recording of the force sensor data is terminated. Finally, using a span of around 800 data points, the change in force contact[3] and the change in force bias[4] data are graphed.

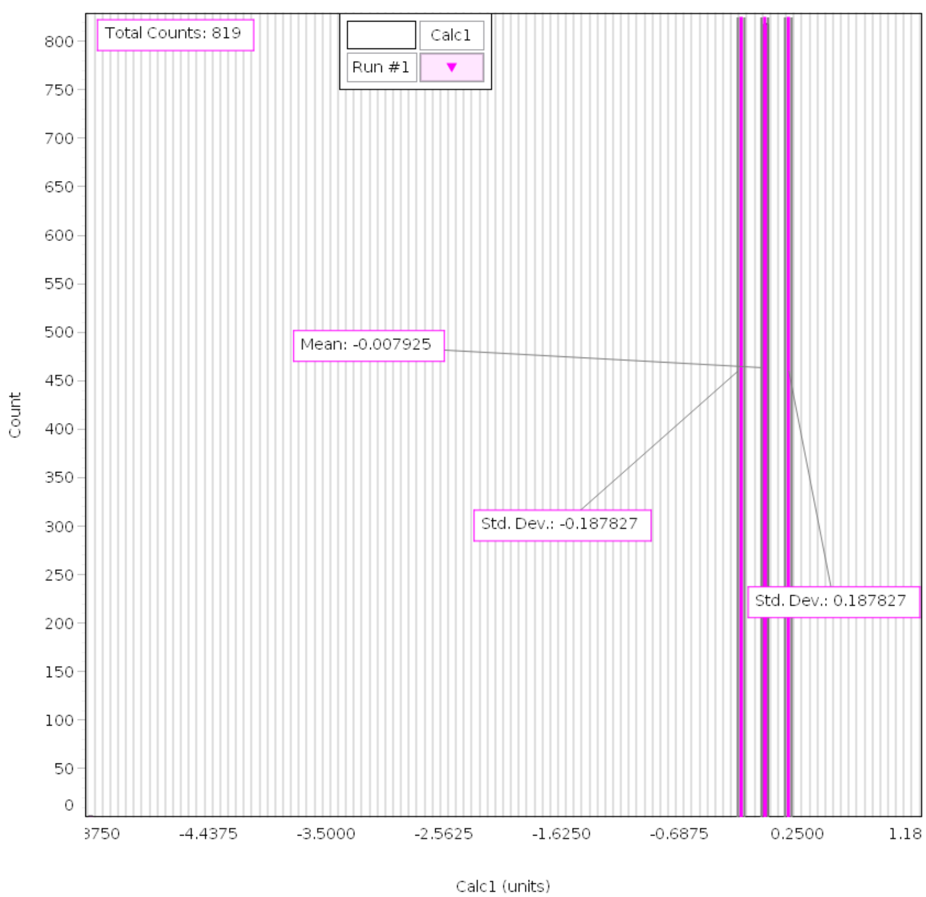
III. OBSERVATIONS

A raw force and net force data over time graph (*Figure 2*), a histogram depicting the change in force bias (*Figure 3*), and another histogram depicting the change in force contact (*Figure 4*) for the Run #1 are included below. Data for the other three runs are omitted due to close similarity and for concision.

[1] The carts are simply released with its acceleration subject only by the force of repulsion between the magnets on the cart and at the ends of the track.
[2] The carts are released after a verbal countdown. While there will be a delay between the release of the first and second carts due to human reaction time, this will not affect the net force during collision in any way.
[3] Net force calculated from the raw force data from the two force sensors.
[4] Change in the force data recorded by the two force sensors before collision (~400 data points) and after collision (~400 data points) totalling to around 800 data points. Its mean value is used as bias uncertainty.

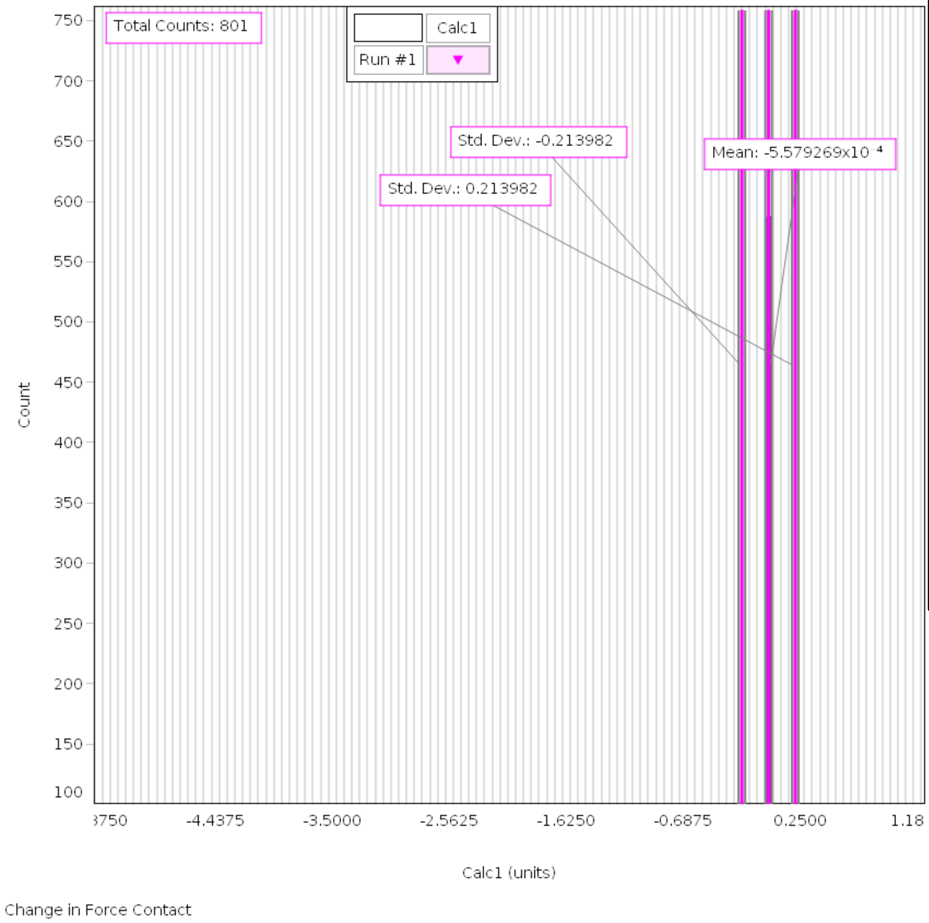


▲ **Figure 2:** *Force versus time graph (top) where F.A is Force Sensor A and F.B is Force Sensor B. Net force versus time graph (bottom).*



Change in Force Bias

▲ **Figure 3:** *Histogram representing the net force experienced before collision.*



$$(S_z)^2 = (S_x)^2 + (S_y)^2$$

Figure 5: *where S_z is the combined standard deviation, S_x and S_y are the individual standard deviations.*

$$u_s = \frac{s}{\sqrt{N}}$$

Figure 6: *where u_s is the statistical uncertainty, s is the standard deviation, N is the number of trials.*

Figure 4: *Histogram representing the net force experienced during collision.*

IV. DISCUSSION AND EVALUATION

Per *Figure 2*, the force versus time graph at the top illustrates a close overlap between the force registered by Force Sensor A (red) and Force Sensor B (blue). This indicates a close resemblance of the change in magnitude of the force experienced by both carts during the collision process, which is consistent with Newton's Third Law of Motion. The peak registered is around 36 N by both force sensors at the same time interval. While the forces experienced by the two carts are opposite in direction, the force versus time graph identifies only positive force values due to the limitation of the force sensors where only magnitude is registered. Thus, the force sensors register force as a scalar quantity instead of a vector. Nevertheless, this does not hinder the accuracy nor precision of the raw data.

Evaluating Run #1, the mean change in force bias is -7.93E-3 N (*Figure 3*) while the mean change in force contact is -5.58E-4 N (*Figure 4*). Since force bias represents the base values recorded by the force sensors, subtracting it from the change in force contact results to 7.37E-3 ±0.3 N. The uncertainty value is obtained by first finding the combined standard deviation from *Figures 3 & 4* using the formula outlined in *Figure 5*. Finally, the formula in *Figure 6* is used to obtain the uncertainty value with $N = 1$ since only one trial is conducted for each Run. The net force of Run #1 suggests a zero net force after considering its uncertainty.

Using all the data gathered from Run #1 to Run #4, the mean net force equates to 8.33E-3 ±0.2 N using equations listed in *Figures 5 & 6*. Similarly to the analysis of Run #1, the range of the mean net force from the uncertainty falls within the net force of zero.

V. CONCLUSION

The processed data sufficiently validates the Third Law by obtaining a mean net force of 8.33E-3 ±0.2 N when modelling the collision between two carts among four runs. The experiment identifies the consistent zero net force recorded using force sensors from colliding two carts of differing mass and motion combinations regardless of the contact force's magnitude.

Relevant Limitations

The slight inconsistency of the bias uncertainty constitutes to a systematic error which skews the precision of the mean change in force contact values among the four runs.

Realistic Improvements

The accuracy of the mean net force can be increased by using a pair of carefully calibrated force sensors with a higher measurement accuracy. Furthermore, more trials could be conducted for each run and more runs could be conducted for other scenarios such as a three-way collision and measuring the net force for the individual x- and y-components. All this will reduce bias uncertainty and the standard deviation values, resulting in a lower overall uncertainty.

References

Newton, I. (1687). *Philosophiæ Naturalis Principia Mathematica*. Manuscript submitted for publication, Cambridge University Library, Londini. Retrieved September 23, 2017, from https://cudl.lib.cam.ac.uk/view/PR-ADV-B-00039-00001/49.