Recoil Experiments Using a Compressed Air Cannon

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Recoil Experiments Using a Compressed Air Cannon

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Ping-Pong vacuum cannons, potato guns, and compressed air cannons are popular and dramatic demonstrations for lecture and lab.[1-3] Students enjoy them for the spectacle, but they can also be used effectively to teach physics. Recently we have used a student-built compressed air cannon as a laboratory activity to investigate impulse, conservation of momentum, and kinematics. It is possible to use the cannon, along with the output from an electronic force plate, as the basis for many other experiments in the laboratory. In this paper, we will discuss the recoil experiment done by our students in the lab and also mention a few other possibilities that this apparatus could be used for.

At the beginning of the fall semester, one of our majors returned to campus with a homemade compressed air cannon. The device is constructed primarily of PVC pipe and uses an electronic switch to fire the cannon. The cannon has a muzzle length of 1.63 m and an inside diameter of approximately 10 cm. A short movie of the cannon in use can be seen online.[4] Small projectiles can be placed in the muzzle, using paper towels as wadding if necessary. After seeing the cannon in action and recognizing the inherent appeal to students and faculty of shooting things, it was decided to use the cannon as the basis for a laboratory activity in an algebra-based introductory physics course.

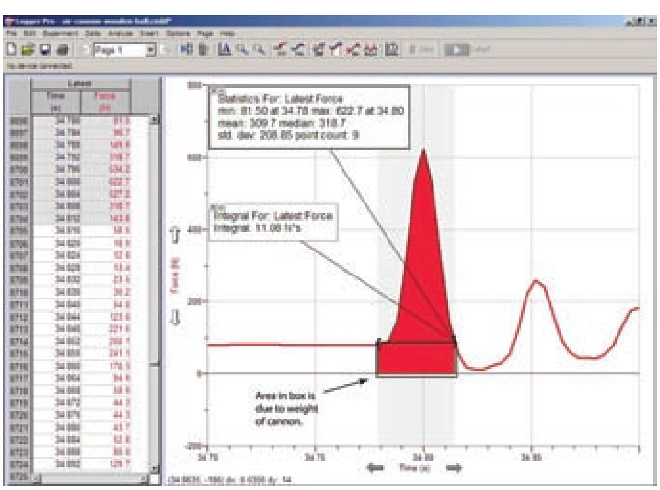

Fig. 1. The force plate output for a typical firing sequence. The boxed region represents the area due to the weight of the cannon.

In this lab, students were asked to go outside and with the help of the instructors fire the cannon while using an electronic force plate to measure the recoil of the cannon when it was fired. The force plate was connected to a computer and the data were collected and analyzed using the LabPro software. From their data, the students were asked to calculate the muzzle velocity of the projectile. During the lab we used a small rubber ball as the projectile. We also experimented with a larger wooden ball independently. This portion of the lab was intended to facilitate individual learning with little need for intervention or direction from either the professor or the peer instructor in the lab. The students had seen a similar textbook problem before doing the lab where the raw numbers were given to them. In this problem, they used the impulse to work out the final velocity of the projectile. Since this is an algebra-based class, they used the following form of the impulse-momentum relation, which could be

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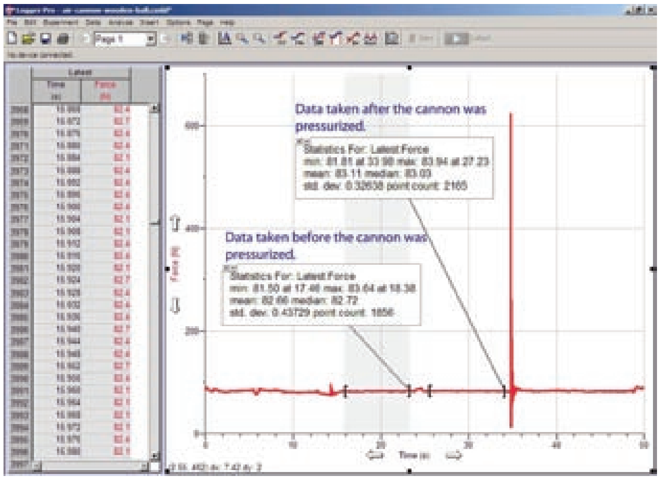

Fig. 2. Force plate output showing pre- and post-pressurization forces for the air cannon, from which the mass of the air put into the cannon can be determined.

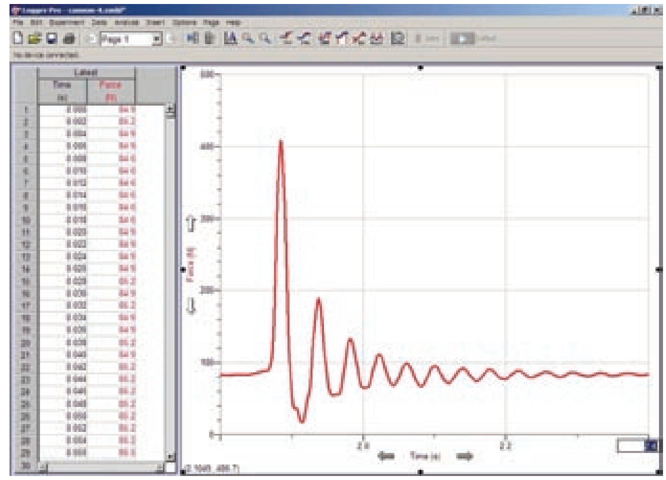

Fig. 3. Force plate output showing a firing of the cannon, the first large peak, and the damped resonance of the force plate after firing.

further simplified because the projectile was initially at rest.

$$F_{avg}\, t = mv_f - mv_i = mv_f \qquad (1)$$

It was hoped that the students would be able to use the data they obtained and work out a method, using Eq. (1), to determine the muzzle velocity. A typical set of data from a firing can be seen in Fig. 1.

All of the students followed the same procedure to use the cannon. The students zeroed the force plate, placed the cannon on the force plate, pressurized it, and then fired the cannon. The cannon was typically pressurized to 60–65 psi. The students would then use the data from the force plate to calculate the impulse. A number of common mistakes were found to occur. First, most groups failed to subtract the effect of the weight force of the cannon. As can be seen in Fig. 1, the contribution of the area due to the weight of the cannon is significant. Those groups that forgot to account for this calculated an impulse that was too large. A second common error was to use the peak force as measured by the plate rather than to average over the width of the peak (time). Typical muzzle speeds for groups with these errors were approximately 150 m/s. The software can be used to determine the area under the curve to give an accurate measure of the impulse, but as mentioned above, the integral form of the impulse momentum was not known by these students. Using the computed area under the curve and subtracting off the area due to the weight of the cannon yielded typical muzzle speeds for the projectile of approximately 90 m/s from Eq. (1). Students in this class did not consider the friction between the projectile or the wadding and the cannon wall. Any air resistance in the cannon was also ignored because these are students in an algebra-based class and are mathematically ill-equipped to calculate this.

Other Uses of Apparatus

There are additional activities that can be done with this apparatus. Students could determine the maximum height of the projectile by measuring the angle above the horizontal and knowing their horizontal distance from the apogee point. The horizontal distance can be estimated if the projectile is shot nearly straight up. After determining the maximum height and knowing the muzzle speed, the students could determine the work done by air resistance on the projectile. Additionally, students could compare their calculated muzzle velocity using the method discussed in this paper and compare that to the value obtained by measuring the range of the projectile fired at a known angle. This unfortunately is impractical on our campus primarily due to student traffic near our building. Another activity would be to determine the density of the air in the pressurized cannon. This is possible because the mass of the air can be measured by the electronic force sensor. In Fig. 2, the force measured by the plate can be seen to have changed due to the pressurization of the cannon. One can see the difference in the force on the plate before pressurizing, the first selected region in Fig. 2, and then after pressurizing, the second selected region. Using this change, students can determine the mass of the air that was added to the cannon and determine the density given the volume of the cannon. Finally, for a more advanced class, the students could determine the damping coefficient and spring constant for the force plate. As seen in Fig. 3, the plate exhibits a damped resonance after the initial recoil.

We were pleasantly surprised by the breadth of topics available from such a simple apparatus. The students enjoyed the activity and were forced to think physically about a situation for which they had already seen several sample textbook-type problems. One word of caution—make sure that you are shooting your projectile into an area free from pedestrians as your projectile will be moving very quickly when it makes its return!

References

1. Richard W. Peterson, Benjamin N. Pulford, and Keith R. Stein, "The Ping-Pong cannon: A closer look," *Phys. Teach.* **43**, 22–25 (Jan. 2005).
2. John Cockman, "Improved vacuum bazooka," *Phys. Teach.* **41**, 246–247 (April 2003).
3. Eric Ayars and Louis Bucholtz, "Analysis of the vacuum cannon," *Am. J. Phys*. **72**, 961–963 (July 2004).
4. A short movie of the air cannon in use can be seen at http://peloton.radford.edu/brett/tpt/air-cannon.mov; Quicktime is needed to see this clip.

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