Revolver Recoil Reduction

A Major Qualifying Project Report
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ABSTRACT

Excessive recoil causes many individuals to avoid using large caliber revolvers and those individuals who do fire such revolvers are often met with pain and an inability to fire repeatedly. This project takes aim at reducing both of these issues for owners, potential owners, and casual shooters of large caliber revolvers through the creation of a newly designed grip with the intention of reducing perceived recoil for the user. To quantify and market the effectiveness of the grip recoil data needed to be verified in order to reach out intended goal of 20-30% reduction of perceived recoil for the user.

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CHAPTER 1: INTRODUCTION

The Revolver Recoil Reduction MQP's goal primarily lies in reducing the perceived and overall recoil when firing by twenty to thirty percent. Large frame revolvers were chosen due to their high-power shots and the high amount of recoil experienced when fired. In order to get the intended recoil reduction percentage a baseline needed to be establish to work with in creating a new grip designed to reduce the recoil. This baseline was created through force data being collected during live firing of the large frame revolvers. As there are no easily accessible mechanisms to test and record recoil force data the project's initial task became to create this setup. Strain gauges were used to read out voltages created from the gunshots that were then converted into force values. The force was plotted in the y-axis and time was plotted in the x-axis. This setup allowed for a full coverage and understanding of how the force is displaced through a wrist and arm when fired by an individual outside of the rig.

Using the collected data from this mechanism, a grip will be designed and created to reach a perceived recoil reduction for the individual firing the gun. The grip will be created specifically for the Ruger Super Blackhawk as it proved to be the firearm most accessible to the team due to being owned by a member of the team, while also being on the upper end of recoil patterns proving difficult to control without extensive experience and training. The new grip would have various advantages to the user in terms of legality, cost, and effectiveness. The use of a grip on a handgun avoids all legal issues with the modification limitations most states have in place on firearms. The grip is very cost efficient and effective overall due to the low cost compared with the expected results that should be attained through the use of the grip. The quick attachment of this grip should improve the user's experience in terms of their overall accuracy, their ability to fire for long without injury, and their general usability of the firearm should increase. Whether it be someone shooting this firearm for enjoyment or for self defense the grip would cater to all audiences.

The resources available to the project provided by Worcester Polytechnic Institute allow for the team to go forward with the patenting process for the force data collection rig and grip being designed. The intellectual property department at WPI has allowed us to learn about the patenting requirements, limitations, and possibilities in depth. After speaking with the IP department, the team will be more forwarding with the patenting process with the financial backing of WPI. Knowing this the team will have to start speaking with potential buyers in order to gain feedback and an understanding of the market that these products will be entering.

The project's major focuses lie with recoil data collection across a multitude of large frame revolvers, showing the need for a grip, and patenting our designs and deliverables. All of these aspects exhibit major and important qualities of the mechanical engineering curriculum.

CHAPTER 2: BACKGROUND

Before designing a device to reduce recoil, background research was needed to guide the scope of the MQP. Various aspects of recoil were investigated, focusing on individuals' perception of recoil, and potential injuries due to recoil, as well as how to calculate, measure, and reduce recoil.

2.1 - Perceived Recoil

Although recoil is a physical quantity that can be measured and calculated, perception of recoil includes multiple factors, and varies from individual to individual. For example, men typically have larger and stronger hands, wrists, arms and shoulders than women, causing them to perceive recoil as less severe. (Grenier, 1991) Individuals may also be wary of recoil due to others' accounts of recoil as well as reports of injuries.

2.1.1 - Flash and Noise Produced by Firearms

One widely overlooked aspect of perceived recoil is the accompanying muzzle flash and noise. One shot from a .38 Special revolver with a barrel under 2 inches in length produces over 140 dB of sound, which is loud enough to cause immediate permanent hearing damage. (Luz, 1983) Because of the impracticality of carrying ear protection while hunting, or concealed carrying, many firearm owners may be subject to dangerous noise levels. Shooters who are not accustomed to large caliber firearms often flinch from the noise produced when firing. This leads to a negative perception of the gun, and the energy that the shooter will have to combat while firing. (Blankenship, et. al., 2004)

Excessive muzzle flash also startles shooters. Muzzle flash is the sudden and instantaneous bright light produced when firing a gun. When the primer ignites the propellant in a cartridge, the propellant rapidly heats up, expanding the surrounding gases and launching the bullet. The propellant often does not completely burn while inside the barrel, resulting in the ejected propellant burning outside of the barrel. This sudden "fire ball", as shown in Figure 1 below, increases as the barrel length of a firearm decreases, because there is less time and distance for the propellants to burn before escaping the barrel. Because of the short length of handgun barrels, their muzzle flash is generally greater than that of rifles in the same caliber. Additionally, larger calibers produce more muzzle flash due to the presence of more propellants. Muzzle flash can temporarily cause sight impairment, especially when firing in poorly lit areas. (Klingenberg, Heimeri, 1992) Because of muzzle flash and excessive noise, many individuals avoid firing handguns, especially those with large calibers and short barrels.

Figure 1. An Image of the Muzzle Flash Produced by a Smith & Wesson 460.

2.1.2 - Muzzle Climb and Rearward Motion

The majority of the negative perception surrounding recoil is due to the impulse recoil exerts on the shooter's body. Handguns with high recoil energies create large rearward forces on the shooter's hands and arms, and large moments about the shooter's wrists.

When the bullet is accelerated by the ignited gunpowder, it creates an impulse in the opposite direction that is equal and opposite to the product of the bullet's mass and acceleration, acting over a small period of time. The reactionary force causes the handgun to move backwards, requiring the user to apply a forward force to stabilize the firearm. Impulses vary from caliber to caliber because of the energy and pressure differences between different rounds. Impulses also vary from firearm to firearm. Handguns with longer barrels allow the bullet to accelerate for longer periods of time, producing larger terminal velocities, and therefore momentums. If two handguns have the same caliber and barrel length, the heavier handgun will have less recoil velocity due to its increased mass.

Because most handguns don't have their center of gravity aligned with the barrel, or the shooter's grip, recoil also manifests as an upward moment, with the handgun rotating in the shooter's hand so that the muzzle rises towards the shooter's face. The rearward force and upward moment act over a period of time long enough that the handgun's motion can be seen by the naked eye. Shooters have a natural instinct to protect their faces, so the rapid motion of the firearm towards the shooter's body can be worrisome. The shooter must apply a moment using their wrist and/or arms to prevent muzzle climb. Because of the large impulse, it's difficult for many shooters to prevent high muzzle climb without applying large forces, which can sometimes result in injury.

2.1.3 - Potential Injuries Due to Excessive Recoil

Another reason some shooters avoid large caliber weapons is the potential for injury. Internet searches of first-time shooters handling large-caliber weapons shows how individuals can get injured. An improper gripping technique, a weak grip, and relaxed arms can all lead to injuries. Grip technique and strength are important to combat the moment produced when firing and therefore muzzle climb. A tight or strong arm is needed to combat the rearward component of the recoil. Although recoil-related injuries are rarely fatal, many injuries still result in hospital visits. From January 1, 1993, to December 31, 1996, a majority of firearm-related non-fatal non-gunshot wounds were self-inflicted, with 43% of these injuries due to recoil. (Hootman et al., 2000)

2.2 - Free Recoil

Free Recoil is the energy the user will absorb from the handgun, based on the calculated kinetic energy imparted on the handgun by each shot. The calculated free recoil is found by using the Law of Conservation of Energy, and the classical mechanics equation for the kinetic energy of a rigid body.

2.2.1 - Conservation of Momentum

The first step in calculating recoil energy is to find the velocity of the revolver using the Law of Conservation of Momentum. Because this project focuses on revolvers, the motion of the slide on semi-automatic handguns does appear in our calculations. To find the revolver's velocity, one must know the bullet's mass, the bullet's muzzle velocity, and the revolver's mass.

Using the equation for the Law of Conservation of Momentum, as shown below in Figure 2 below, we can rearrange the equation to solve directly for the velocity of the revolver.

$$m_{bullet}v_{bullet} = m_{gun}v_{gun} \quad \rightarrow \quad v_{gun} = (m_{bullet}v_{bullet})/m_{gun}$$

Figure 2. The Equation to Calculate the Revolver's Velocity.

2.2.2 - Kinetic Energy

The Law of Conservation of Energy cannot be used to find the velocity or kinetic energy of the revolver. Energy losses to to heat and sound make it unrealistic to simply set the summation of the bodies' kinetic energies to zero. Instead, we can use the velocity of the revolver we found using the Law of Conservation of Momentum to calculate the kinetic energy of the revolver, provided we know the its mass. This process is shown below in Figure 3.

$$E_{gun} = ½m_{gun}v_{gun}^2$$

Figure 3. Calculating the Revolver's Kinetic Energy.

2.3 - Measuring Recoil

Although measured recoil data exists for many firearms, the measurement devices used, and the methods used to obtain the data are not explicitly stated. Before designing a recoil reduction device, we further researched methods and devices to measure recoil data so that we could measure the recoil of a revolver before and after our recoil reduction device is installed.

2.3.1 - Recoil Measurement Devices

Despite the abundance of free recoil data, there is a shortage of data on measured recoil. Only two recoil measurement methods were found through an extensive internet search. One device was designed for rifles and shotguns, and was shaped in a manner that we could not use it for measuring recoil in revolvers. The other method was to measure the muzzle climb of handguns when they are attached to a Ransom Rest. (Miller, 2014) By measuring the muzzle climb, this device was taking relative recoil measurements between handguns. Although this method seemed useful, quantifiable force and time data are more pertinent to our project. Additionally, Ransom Rests cost upwards of $400, which would have expended two thirds of our project budget.

Because few recoil measurement devices exist, we decided to construct our own so that we could still obtain measurements but not exceed our project budget. By creating our own device, we could tailor its design to suit the shape and forces related to large caliber revolvers.

2.3.2 - Force-Time

The most important information to obtain for recoil measurements are force and time data. Perceived recoil can be reduced by expanding the time over which the recoil force acts, thus reducing the amplitude of the force. Because the force acts over a timespan in hundredths of seconds, any measurement device would require a high enough sampling rate to catch the shape of the force-time curve. The measurement device would also have to be durable enough to withstand the recoil forces of large caliber revolvers, which peak upwards of 50 pounds of force. Devices such as strain gages are used to record resistance (voltage) changes, which can be calibrated and converted to quantities such as force and pressure. WPI has electrical measurement devices that students can use for projects, such as Data Acquisition (DAQ) Boxes, Strain Gage Amplifiers (SGAs), and laptops. Using strain gages, an SGA, a DAQ box, and a laptop one could measure forces in various materials, change sampling rates and excitation voltages, and save the data for later analysis.

2.3.3 - Moments

Once the force and time data have been gathered, the upward force components would have to be calculated into a moment about a fixed point. This moment corresponds to the moment about the shooter's wrist that creates the muzzle rise of the revolver. The angles of the revolver, device, and their union would be necessary to calculate moments. Additionally, the center of mass of the revolver (and distances to and from the center of mass) are needed to account for the revolver's weight when calculating the moment produced.

2.4 - Reducing Perceived Recoil

Although recoil is a problematic by-product of shooting, many products exist to help reduce recoil and muzzle climb. From handguns meant for pocket-carry to large caliber rifles and shotguns, different methods and materials are employed to mitigate recoil.

2.4.1 - Current Products

One of the most common methods to reduce recoil is by adding a stock. Rifle and shotgun stocks redirect the recoil forces of firearms away from the shooter's hands and into the shooter's shoulder, as shown in Figure 4 below. By placing the barrel and stock in close alignment, the muzzle climb in firearms with stocks is significantly less than those without.

Stocks also increase the weight of firearms, reducing the velocity imparted on them by the impulse of each shot. In addition to reducing recoil, stocks help improve aimed accuracy by adding a more stable point to hold a firearm up than using one's hands.

Figure 4. Shouldering a Stock, with the Direction of the Recoil Force Shown in Red.

Another common device is the muzzle brake. As shown in Figure 5 below, a muzzle brake is a device that is attached to the front of a firearm's barrel which redirects the gases ejected from the barrel. Muzzle brakes usually redirect the gases rearward or upward. These gases produce forces when ejected from the barrel. By changing the direction gases are ejected, muzzle brakes can produce forward or downward forces, which help combat recoil and muzzle rise.

Figure 5. M11 Severe-Duty Muzzle Brake by Precision Armament.

A common method for reducing recoil in handguns is to add a textured, or rubber grip. Adding texture to grips produces more surface friction so that the shooter can get a tighter grip on the handgun, preventing the handgun from rolling out of the shooter's hand due to a high recoil moment. Some companies have been making revolver grips out of different types of elastomers, as shown in Figure 6 below. Elastomers absorb shock, expand the time over which the shooter endures the recoil energy, and supply more friction for an even tighter grip.

Figure 6. The Hogue Monogrip - A Textured Revolver Grip Made from an Elastomer.

2.4.2 - Selecting a Grip as the Means to Reduce Recoil

Although these various products that can reduce recoil exist, many of them cannot be used for our project because of laws, costs, and the timespan we have to complete our project.

Adding a stock would be the easiest way to reduce recoil. However, adding a stock to a handgun would constitute the creation of a Short-Barreled Rifle (SBR). SBRs fall under the National Firearms Act (NFA) of 1934, which requires the individual who created the SBR to fill out and submit a Form 1, and $200 tax fee, to the Bureau of Alcohol, Tobacco, Firearms, and Explosives for approval (ATF, 2017). Because of our timespan and budget, building an SBR is impractical.

Muzzle brakes are extremely useful in reducing recoil, but may require modification to the revolver. Most firearms that use muzzle brakes are large caliber rifles and some revolvers. Because we are working with a revolver that is not already threaded at the muzzle, adding a muzzle brake would require permanent modification to the revolver. We would like to create a product that doesn't require permanent modification, so we chose not to design a muzzle brake.

For the above reasons, we chose to design a new grip for our revolver. Grips come in multiple materials, shapes, and styles, so creating a grip that reduces recoil while still maintaining appropriate dimensions and weight should be an achievable task.

CHAPTER 3: METHODOLOGY

Our project goal was to reduce the perceived recoil of a large-caliber revolver by 30%. To accomplish this goal, we developed the following five objectives:

1. Construct measurement devices to gather recoil data for various revolvers.
2. Receive permission from a firing range to test our measurement devices.
3. Gather baseline recoil data, and analyze the results.
4. Design a grip to reduce the perceived recoil of a revolver.
5. Measure the recoil of a revolver with the new grip attached.

Objective 1: Construct measurement devices to gather recoil data for various revolvers.

In order to accomplish our project goal, we first had to design a device to measure recoil in a consist and repeatable way. Because we determined revolver recoil has two basic components, an upward torque and a rearward force, we developed a measurement device that holds and acts on the revolver like a human hand and arm would. We used a two bar linkage connected to a bike brake handle and cable to act as a trigger finger so we could fire revolvers without having to put any external forces on the system. A pivot and spring were used in place of the wrist and a spring and slider in place of the elbow and shoulder. We placed strain gauges on the linkages in each of these two systems so that we were able to electronically measure the force acting on the springs. Each system, one being the pivot and the other being the slider, contained a 1/16”x1/2” cross-section piece of aluminum flat bar for placement of the strain gages. The gages were placed in full bridge configuration to avoid measuring any effects due to bending or temperature changes in the aluminum. Using the properties of the aluminum, the strain gage manufacturer’s stated gage factor and resistance, and known forces, we calculated and verified through experimentation that for every pound of force, we would read 45 millivolts of output voltage. For our calculation, see Appendix A. By calibrating our set-up, we know how much force we are reading based on the voltage we record. Our measurement device, and its exploded view, are shown in Figures 7 and 8 below.

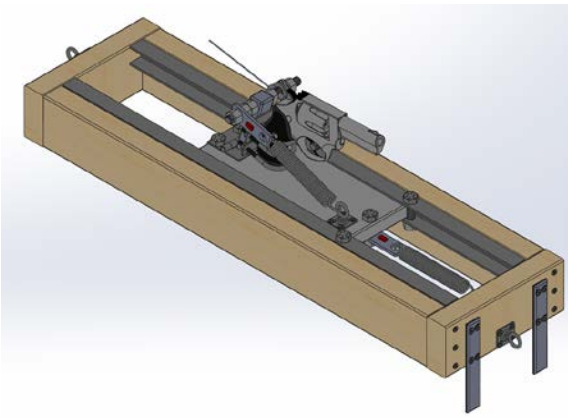

Figure 7. Recoil Measurement Device.

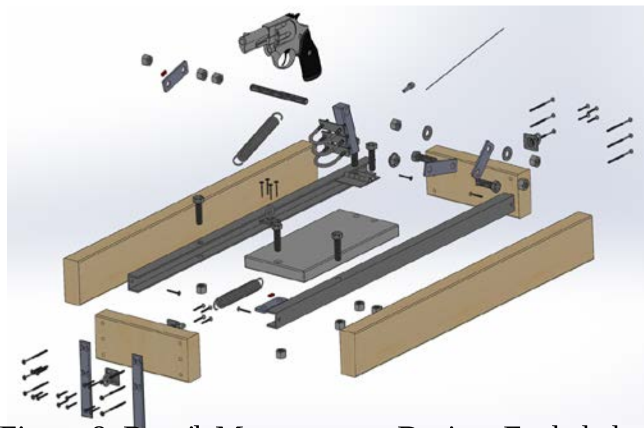

Figure 8. Recoil Measurement Device, Exploded.

We added a gridded background board to our device and filmed the displacement of each revolver as it fired, as shown on the following page in Figure 9. With two exceptions, our device was created using materials and parts available in local hardware stores and household tools. The first exception was that we had to weld the pivot bar to its hinge, and the second exception was that we had to order a piece of Delrin for the sliding plate. We chose Delrin for its low friction properties when it contacts aluminum. We created the complete firing mechanism without the electronics for around two hundred and fifty dollars.

Figure 9. The Muzzle Rise of the Ruger Super Blackhawk after Firing a .44 Magnum Round.

To power and read our strain gauges we used 2 strain gauge amplifiers which connected to a Data Acquisition Box (DAQ Box). We then connected the DAQ box to a computer equipped with the software LabView, which sampled the voltage across the strain gauges ten thousand times per second and exported the data to an Excel file where our team could then convert the data from voltage to force for analysis. For pictures of our equipment, please see Appendix B.

Objective 2: Receive permission from a firing range to test our measurement devices.

Because firearms are not allowed on campus, we had to find a firing range where we could test our equipment. Most ranges surrounding Worcester require membership, and limit the number of guests each member may bring. Additionally, we needed to find a range that would give us permission to test our set-up, use their electricity for our devices, and film our shots. To seek permission, we compiled and photographed a comprehensive list of all of all our equipment and our setup. We attached the list to a letter containing an explanation of the project, the tasks we need to complete at the range, and any resources we might need from the range. The letter and its supplements were sent to two ranges that met all of our requirements. To view the Range Letter and Supplemental Information, see Appendix C. Ultimately, Jacob attended a Board of Directors meeting at the range he is a member of, the North Leominster Rod & Gun Club (NLRG). The NLRG Board of Directors voted unanimously to allow us range access, electricity, and to operate our measurement equipment.

Objective 3: Gather baseline recoil data, and analyze the results.

Rather than starting measurements with the powerful .44 Magnum, we opted to take measurements with lesser calibers first. The first revolver tested was a Ruger SP101 with a 3 inch barrel, chambered in .357 Magnum. The SP101 was chosen for its small size, and for the ability to also safely chamber and fire .38 Special ammunition. To gather force data, we fired 5 shots of .38 Special with both the pivot and slider able to move. We then fixed the slider so the pivot would take all of the recoil energy for the next 5 shots of .38 Special. Finally, we fixed the pivot so the slider would take all of the recoil energy for the final 5 shots of .38 Special. We then repeated this process with the SP101 shooting .357 Magnum ammunition. We fixed the 2 different systems to determine if locking one's elbows would significantly increase the moment about their wrist, and if locking one's wrist would drastically increase the rearward recoil. After testing the .357 Magnum, we set-up our large caliber revolver that we would attempt to reduce recoil with, the Ruger Super Blackhawk (SBH).

The SBH we tested has a 7.5 inch barrel, and is chambered in .44 Magnum. The reason the SBH was chosen was because of its availability (Jacob owns it), and because the project group is displeased with how its standard grip feels in the hand. Testing for the SBH was conducted in the same manner as the SP101: .44 Special, the weaker cartridge, was tested first, then the .44 Magnum. Similar to the SP101 tests, 5 shots were recorded with just the slider free to move, then 5 shots with just the pivot free to move, and finally 5 shots with both the pivot and slider free to move. Between each shot, we rebalanced the wheatstone bridges in our strain gage amplifiers so that we had proper zero readings after firing the revolver.

Throughout testing, every shot was video recorded at 960 frames per second using a Sony DSC RX100 M4. We recorded slow-motion video of each shot so that we could see the actual path the revolver moves in. By looking at the video, we can determine the spring displacement, vertical muzzle rise, the motion arc the muzzle rises in, and any necessary angle and lengths we need to calculate the forces and moments about the revolver.

Once the four calibers were recorded, we sorted the Excel data, by caliber,into folders. We then converted the measured voltages into forces, and found the maximum force, minimum force, and the baseline force before and after firing. We also graphed the forces against time so that we could see the Force-Time curve for each shot. With the shots sorted out we could analyze our data to note any trends or relationships between calibers, weight, and revolver shapes.

Objective 4: Design a grip to reduce the perceived recoil of a revolver.

To design a grip, we analyzed grips that already exist on the market. The major two manufacturers of grips that shooters use for large caliber revolvers are Pachmayr and Hogue. Both companies use grips comprised of a thick layer of an elastomer. While elastomers are useful for absorbing the impulse due to recoil, some of the elasticity is lost due to the shooter's tight grip. We decided to implement a two-layer design, shown in Figure 10 below, with an outer layer (blue) comprised of a stiff rubber and an inner layer (red) made of a softer, more elastic material. This design would act in the same manner as two springs in series, with the stiffer spring (outer layer) absorbing less energy while the softer spring (the inner layer) absorbs more energy. By adding more elastic padding, the force will act over a longer period of time, reducing the amplitude of the force the shooter endures. The grip features a "beavertail" towards the top of the grip that will rest on the outside of the shooter's hand between the shooter's thumb and index finger. The beavertail helps prevent the revolver from rotating in the shooter's hand, adding stability. To make sure the shooter could keep a stable grip on the revolver, the front and back straps of the grip have been textured with horizontal indents. This texture will help stabilize the weapon by reducing the potential for the weapon to slip out of the shooter's hand.

Figure 10. Side View of the 3D-Printed Prototype of the Grip Design

Objective 5: Measure the recoil of a revolver with the new grip attached.

To be completed during in C term.

CHAPTER 4: FINDINGS/RESULTS

We collected 50,000 data sample per shot, for 15 shots in each of the following calibers: .38 special, .357 Magnum, 44 Special, and .44 Magnum. This data was collected in sets of 5 shots for each scenario of both the pivot and slider being free to move, only the pivot being free to move, and only the slider being free to move. The analysis for this data will be based off the averages obtained from the shots in order to minimize noise affecting data on a per shot basis.

4.1 - 38 Special Data and Analysis

The first firearm tested was the Ruger SP101 loaded with 38 Special with both gages active. The slider experienced an average force of -1.39lb before the shot and -1.44lb after the shot with an overall average of -1.42lb. The maximum force was 8.98lb with an average maximum force of 8.59lb and an average force increase of 10.00lb. Within the pivot gage the average force before the shot was -0.07lb and -0.17lb after the shot with an average difference of -0.12lb. The maximum force was 20.85lb with an average maximum force of 19.22lb with an average force increase of 19.34lb. These data points act as the baseline measurements as they are the most “realistic” test environment.

With the fixed pivot gage the slider gage experienced a preload force averaging -1.55lb and -1.53lb before and after the shot respectively with an average difference of -1.54lb. The maximum force was 16.50lb with an average max force of 12.87lb and an average force increase of 14.41lb. The fixed pivot gage experienced an average preload of -8.69lb before the shot and -8.65lb after the shot with an average preload of -8.7lb. This large increase in preload is due to more constant force being applied on the metal bar the gage is mounted on due to no dampening from the spring. The maximum force was -8.67lb with an average maximum force of -8.52lb and an average pivot force increase of -0.14lb.

Finally, for the 38 Special the slider was fixed. The slider gage experienced an average preload before the shot of -1.79lb and -1.74lb after the shot with an average preload of -1.77lb. The maximum force experienced was 3.07lb with an average max force of 2.82lb and an average force increase of 4.59lb. The pivot had a before shot preload of -4.55lb and an after shot preload of -4.54lb with an average preload of -4.55lb. The maximum force experienced was 22.25lb with an average max force of 20.95lb and an average force increase of 25.50lb.

4.2 - 357 Special Data and Analysis

The second round tested was the 357 Magnum with both gages active, there was an average force of -1.68lb found in the pivot gage before the firearm was fired due to a preload from the springs within the system. This preload was dependent on the dimensions of the firearm and the ammunition used within the system due to differing weights and lengths. The average force registered after the shot was recorded was -1.58lb and the average of these two forces is -1.63lb. The difference can best be accounted by the springs being slightly more preloaded due to the firearm moving further back in the system after each shot. The max force experienced by the slider gage with both gages active was 11.75lb with the average force increase, the difference between the preload force and the maximum force experienced during the shot, being 13.29lb. For the pivot gage the average force before the shot came to be -5.42lb and the average force after the shot was -5.65lb with an average difference of -5.54lb for the preload. The maximum force experienced was 51.27lb with the average force increase being 55.39lb.

Next, the 357 Magnum was fired with the pivot gage fixed. From the slider gage we found the average force before the shot to be -1.28lb and the average force after the shot to be -1.26lb with the average preload to be -1.27lb. The maximum force experienced from the slider was 19.19lb with the average max force being 16.88lb and the average force difference being 18.15lb. This increase is due to more strain being applied to the strain gage as a result of no force being absorbed from the pivot spring. The pivot gage had an average preload force of -8.49lb before the shot and -8.45lb after the shot. The maximum force in the pivot was -4.48N and the average maximum force was -7.02lb with an average difference of -1.44lb.

Finally, the 357 Magnum was fired with slider gage fixed. The average force before the shot was -0.503lb and the average force after the shot was -0.507lb in the slider gage. The maximum force in the slider was 5.67lb with an average max force of 1.20lb. The average force increase was 1.70lb for the fixed slider. For the pivot the average force before the shot was 1.25lb and the average force after the shot was 0.44lb with an average of 0.85lb. The maximum force was 56.72lb with an average max force of 55.44lb and an average force increase of 54.60lb. The shot time for all testing for the 357 Magnum was 0.065 seconds and the increase and decreases in forces reacted as expected from the different gages being active and fixed respectively.

4.3 - 44 Special Data and Analysis

The 44 in both Magnum and Special was the most valuable data for the project due to the specialty of the grip being designed around this revolver. The data analysis begins with the 44 Special with both gages active. The 44 Special with both gages active had the slider read an average before shot force of -0.17lb and an average after force shot of -0.23lb and an average of -

0.20lb. The maximum force experienced was 12.87lb with an average maximum force of 12.56lb and an average force increase of 12.76lb. The pivot averaged a before shot force of -0.08lb and an after shot average of 0.21lb with an average of these forces coming to 0.06lb. The maximum force experienced was 23.26lb with an average max force of 22.81lb and an average force increase of 22.75lb.

The fixed pivot and slider data had an average before shot force of -0.06lb and an after shot force average of -0.06lb with an average force of -0.058lb. This consistent force readout is due to the stable base the firearm was mounted against not pivoting allowing for the gun to stay in position much better despite its powerful shot. The maximum force recorded was 13.87lb with an average max force of 13.60lb and an average force increase of 13.66lb. The pivot read an average force of -0.08lb before the shot and -0.09lb after the shot with the average being -0.082lb. The maximum force recorded at 0.73lb with an average max force of 0.39lb and an average force increase of 0.47lb.

The fixed slider gage recorded an average force before the shot of -0.32lb and average force after the shot of -0.29lb with an average of -0.30lb for both force readouts. The maximum force experienced was 9.61lb with an average max force of 5.89lb and an average force increase of 6.20lb. The pivot gage experienced a before shot force of -0.11lb on average with an average after shot readout of 0.23lb with the average of before and after being 0.06lb. The maximum force readout was 21.22lb with an average max force of 20.68lb and an average for increase of 20.62lb. The average time of each test shot was 0.095 seconds for all testing.

4.4 - 44 Magnum Data and Analysis

The data analysis begins with the 44 Magnum with both gages active. The slider experienced an average preload before the shot was 0.03lb and 0.07lb after the shot with an average overall preload of 0.05lb. The maximum force was 17.74lb with an average max force of 17.26lb and an average force increase of 17.21lb. The pivot gage had an average force of -0.10lb before the shot and -1.37lb after the shot with an average preload of -0.74lb. The large difference in the preload is mainly due to the shape of the handle of the Ruger Super Blackhawk not fitting very well with the system therefore causing a lot of change in position of the firearm within the system. The maximum force experienced by the pivot gage was 55.19lb with the average max force of 50.91lb and an average increase of force of 51.65lb.

With the pivot gage fixed the slider had an average force of -0.11lb before the shot and -0.20lb after the shot with an average preload of -0.16lb. The maximum force was 21.07lb with an average max force of 20.79lb and an increase of 20.94lb. The pivot gage had an average preload of -0.121lb with an average preload of -0.118lb before the shot and -0.123lb after the shot. This was the most consistent preload within testing. The maximum force experienced was 3.15lb with an average max force of 1.44lb and an average force increase of 1.56lb.

The fixed slider had an average preload of -0.16lb with an average before shot preload of -0.18lb and an average after shot preload of -0.15lb. The maximum force experienced was 14.81lb with an average max force of 12.99lb and an average force increase of 13.16lb. The pivot gage had a before shot force of -0.14lb and an after shot force of -1.18lb with an average preload of -0.66lb. The maximum force recorded was 57.89lb with an average max force of

53.29lb and an average force increase of 53.94lb. The average time was 0.1 seconds for all test shots.

4.5 - Data Analysis Conclusion

The data proved to be insightful and intuitive as it was recorded as expected in increasing value from small to large caliber. There were testing discrepancies that arose in testing due to several factors such as the mounting and securing of the firearm in the case of the 44 Magnum testing, the connections of the strain gages to the strain gage amplifiers not being completely tight, and preloads that changed dramatically. As an overall collection of data these discrepancies can be ignored as they are absorbed through the averaging process, but in addition to numerical data there was visual data collected through the high fps camera on every shot during testing. This video footage could be used in order to verify certain values by calculating the displacement of the gun barrel throughout the test shot. There are also small adjustments that can be made to the system in order to reduce variance and increase overall accuracy that will be mentioned in the next section upon completion of the final report. The data collected for the 44 Magnum and Special were especially important due to the 44 being the target of the grip design for the project. Appendix D along with supplemental data summary sheets and raw data provide an entirely encompassed numerical report of all testing processed.

CHAPTER 5: RECOMMENDATIONS

To be completed at a later time.

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APPENDICES:

Appendix A: Force-to-Voltage Calculation

Force, F = 10 lb

<u>Our Aluminum Bar's Properties:</u>

Cross Sectional Area, A_{xs} = 1/16" x ½''

Young's Modulus of Elasticity, $E = 10^7$ psi

Poisson's Ratio, v = 0.3

<u>Our Strain Gage Properties:</u>

Resistance, R = 120 Ω

Gage Factor, $G_f = 2.14$

<u>Our Amplifier Set-up:</u>

Excitation Voltage, V_{ex} = 10 V

Our Gain = 1000

$\sigma = F/ = 320$ psi → $\varepsilon = \sigma/E = 3.2\text{x}10^{-5}$.

For one strain gage in tension, which is ¼ of the full bridge:

$V_{out,1} = [(V_{ex})(G_f)(\varepsilon)(Gain)]/4 = 0.1712$ V

The, accounting for Poisson's Ratio and the parallel strain gage:

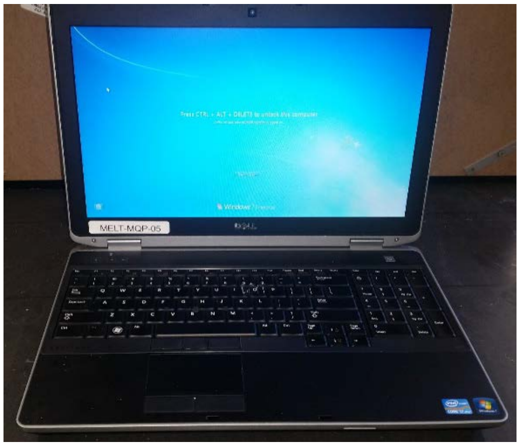
$V_{out} = V_{measured} = (V_{out,1})(2)(1+v) = 0.44512$ V = ~ 445 mV

Since we have 445 mV for 10 lbf, our Calibration Factor, C_f, is:

C_f = 445 mV/10 lbf = 44.5 mV/lbf, or

C_f = 45 mV/lbf

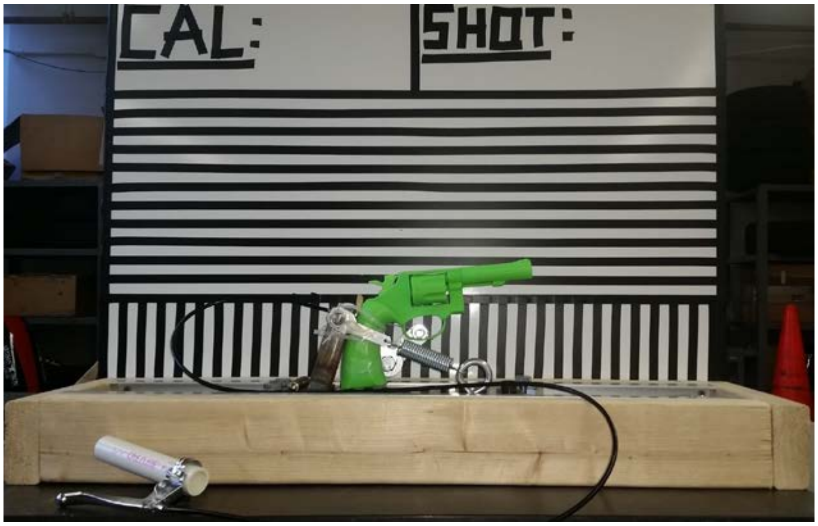
Appendix B: Images of the Measurement Equipment



Laptop

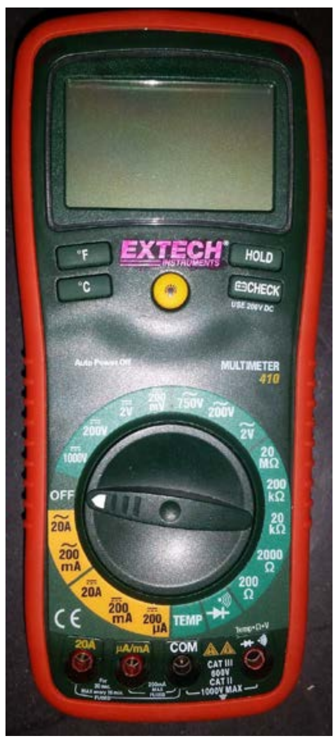
Data Acquisition Box

Strain Gauge Amplifier



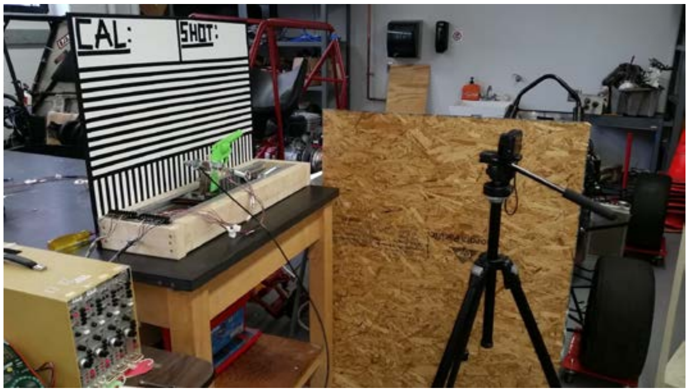
Firing Mechanism

Rotational Inertia Measurement Device



Multimeter

Sony Cyber-shot DSC-RX100 IV Camera on Tripod



Range Setup

Support Table Set Up

Appendix C: Range Letter and Supplemental Information

Dear Sir or Madam,

We are contacting you to seek permission to use your range for academic purposes. We are a group of three seniors majoring in Mechanical Engineering at Worcester Polytechnic Institute (WPI). Our Major Qualifying Project is to design a device for a large caliber revolver to reduce the revolvers' recoil. We created a device to measure recoil of revolvers of various calibers and sizes. We intend to record video on our building process for the measurement device, as well as video of the device being tested.

We seek access to your range, as well as permission to film and fire revolvers secured to our device. The calibers we wish to test are .38 Special, .357 Magnum, .410 Shotshell, .44 Special, .44 Magnum, .45 ACP, .45 Colt, .454 Casull, and 500 S&W. If you have revolvers in these calibers we would be grateful if we could rent them.

We would require 3-4 hours per day for a few days at the range during the month of November. Spatially, we would need a booth at least 36 inches wide, and a few shelves to place our Laptop, Data Acquisition Box, Strain Gauge Amplifier and Camera on. We would need access to an electrical outlet to power our devices, or permission to use our own generator. We are willing to pay for a range safety officer's supervision.

Our Professors will advise on and oversee the construction of the device, ensuring all safety precautions are taken. We will not receive any profit for videos we create, or for our measurement device, as they will be published publicly for educational purposes.

Jacob Grealis has an unrestricted License to Carry (Class A) in Massachusetts, Michael Griffin has a Firearms License in the State of New Jersey, and has passed the NRA's Basic Firearms Safety Course, and Carlos Ordonez has been taught the Four Basic Rules of gun safety but has not attended any certified firearms safety course. Professor David Planchard also has an unrestricted License to Carry in the State of Massachusetts.

If you grant us the aforementioned permission, we will acknowledge you in our videos, as well as our formal report. On the following pages we have attached pictures and descriptions of our devices. We thank you for your consideration.

Sincerely,

Jacob Grealis
Carlos Ordonez
Michael Griffin
Professor David Planchard
Professor John Hall

Objectives and Tasks

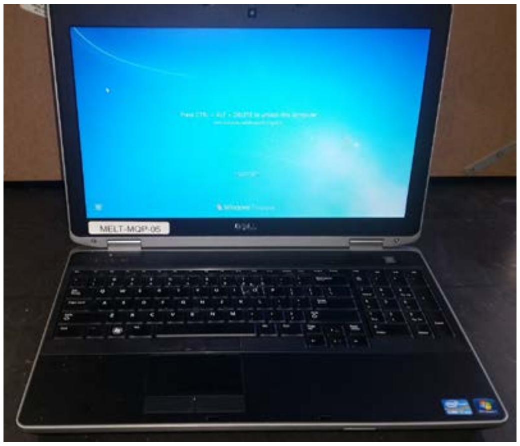
Our goal is to reduce perceived recoil in a large caliber revolver. To accomplish our goal, we need to achieve the following objectives by completing the accompanying tasks. Tasks we must complete at the range are shaded in grey.

- Get permission to test our firing mechanism at the range. (1 range visit)
  - Explain our project, equipment, and tests.
  - Fire at least 1 revolver, possibly 2, to test measurement equipment.
  - Leave on a good note with the range officer/whomever we meet.
- Reflect on our first range visit.
  - Ensure our data makes sense.
  - Make any necessary fixes to our equipment and programs
- Return to the range and gather baseline data on recoil. (2-3 range visits)
  - Gather data for various calibers and revolvers.
- Analyze our data and create a device to reduce recoil in one revolver.
  - Gather all of our data, notice any trends or relationships.
  - Choose a revolver that has considerable recoil to base the device on.
  - Construct the recoil reduction device.
- Return to the range to test the recoil reduction device. (1 range visit)
  - Test the revolver without the device to ensure the setup is working properly.
  - Test the revolver with the device to gather data on the effects of our device.
- Analyze our data.
  - Gather all of our data on the revolver, before and after the device is attached.
  - Make any necessary adjustments to our device, and if necessary,
- (Potential) Make one final trip to the range to gather any necessary data.

Logistics

What	● Gather baseline recoil data on revolvers of different shapes, sizes, and calibers. ○ Measurements include recoil force, revolver oscillation frequency, revolver centroid, loaded revolver weight, revolver dimensions
Why	● Create a device to reduce perceived recoil in a revolver. ○ i.e. a grip
Who	● Prof. David Planchard, Prof. John Hall, Jacob Grealis, Michael Griffin, Carlos Ordonez
When	● Early-to-Mid November ○ Friday Morning ○ Range's Business Hours
How	● Set up our laptop and high speed camera. ● Place revolvers in our frequency measurement device, and let the revolvers spin for 10 cycles, recording the time with a stopwatch. ● Hang each revolver in two different configurations to find each revolver's centroid. ● Place each *unloaded* revolver in our firing mechanism and secure it. ● Measure necessary angles and distances between the mechanism and each revolver. ● Load each revolver. Once the camera and program begin recording, fire each revolver. ● After each shot (15 shots each caliber/revolver), remove the empty cartridge and place another live round in the chamber to compensate for the lost weight of each fired round. ● Repeat this process for all available revolvers and calibers.

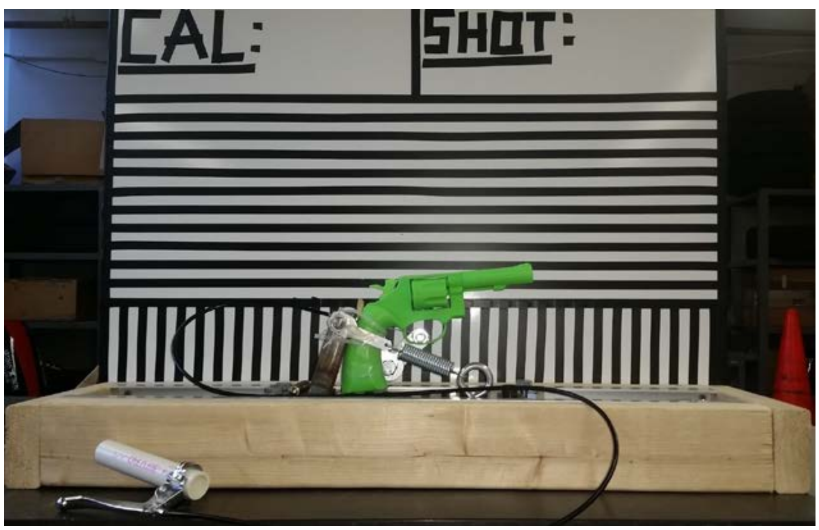
Equipment Size and Specifications



Laptop: 15in x 10in x 11 in, 7.5 LBS, 2.5 Amps at 120 VAC

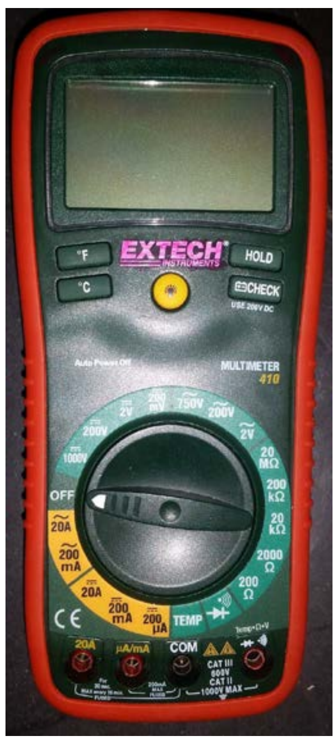
Data Acquisition Box (DAQ): 7in x 12in x 3in, 6 LBS, 0.8 Amps at 120 VAC

Strain Gauge Amplifier: 9in x 19in x 7in, 30 LBS, 0.35 Amps at 120 VAC



Firing Mechanism: 10in x 35in x 24in, 19 LBS

Rotational Inertia Measurement Device: 43in x 26in x 20in, 19 LBS

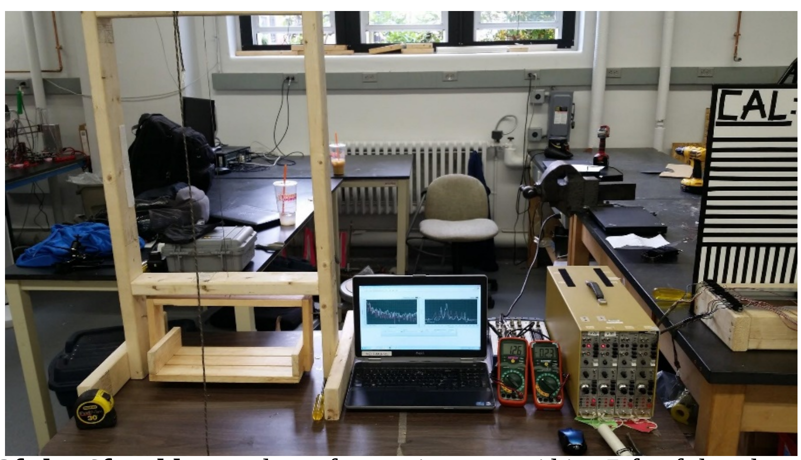


Multimeter x 2: 2in x 4in x 8 in, 0.7 LBS

Sony DSC-RX100 IV Camera on Tripod: 24in x 24in x 48in, 7.6 LBS .2 Amps at 120 VAC

<u>Total Space and Power Requirements:</u>

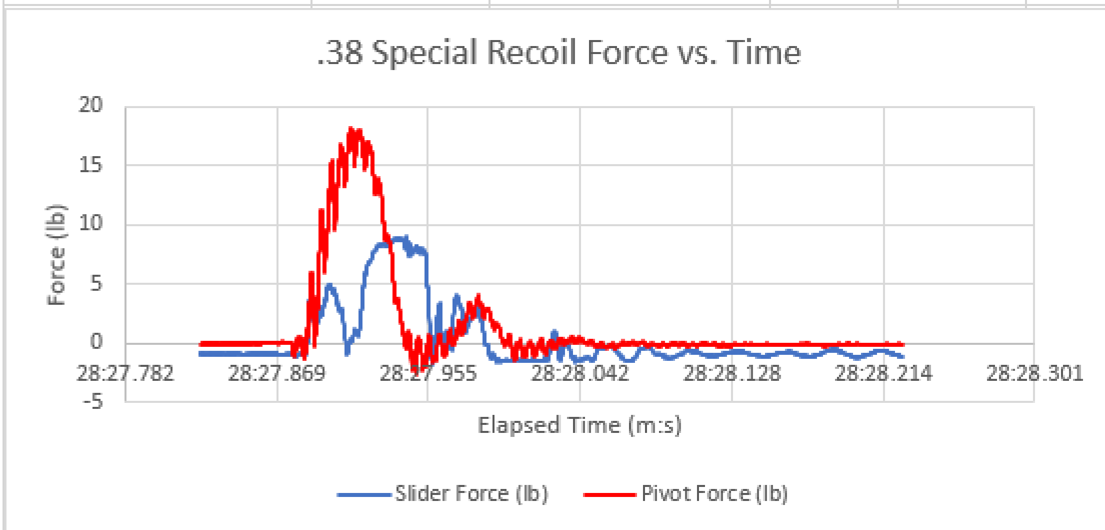
1 to 2 Shooting Lanes (lane width and range style dependant): One for our firing device and one for our camera and team.



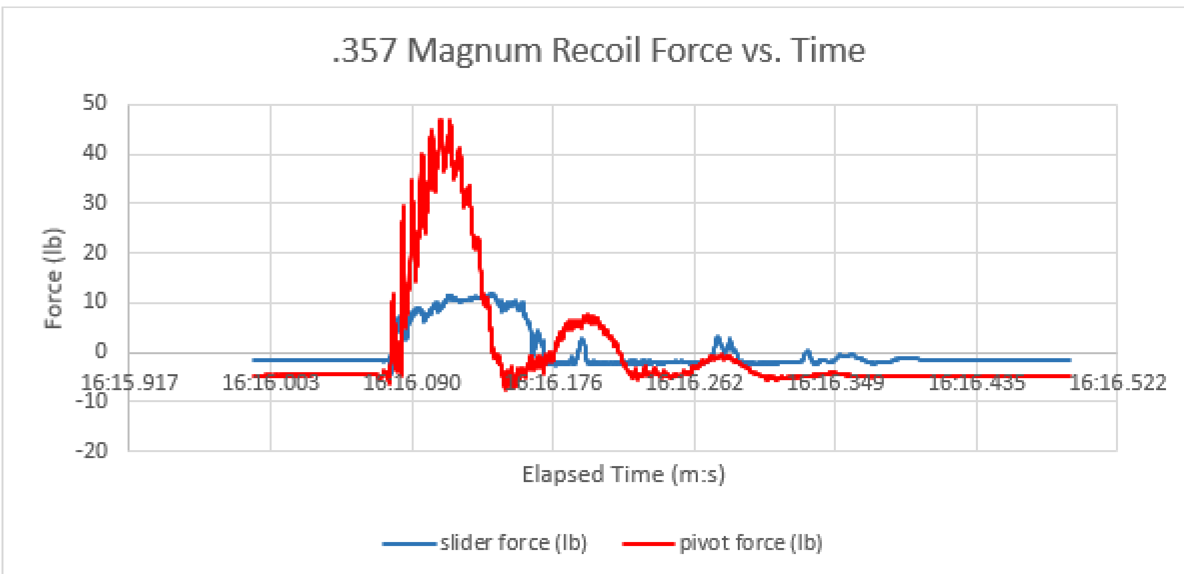
Space for a 2ft by 6ft table: as show for equipment within 5 ft of the shooting lane and preferably near an outlet.

One 120 Volt AC electrical outlet: that can supply up to 4 AMPS.

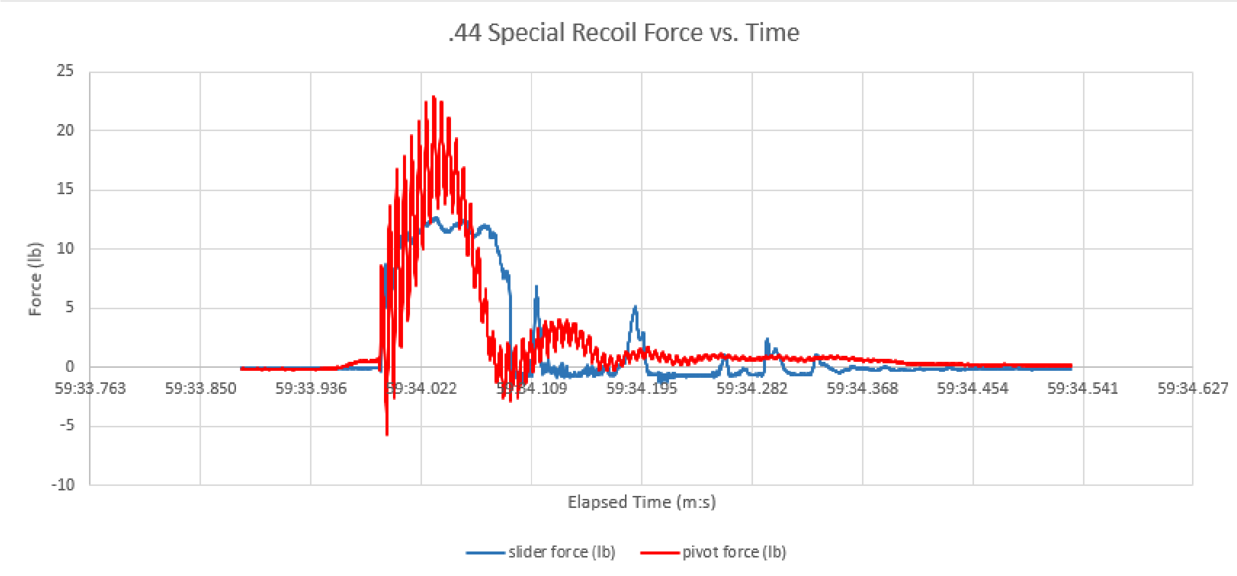
Appendix D: Firing Data Graphs, Both Gages Active



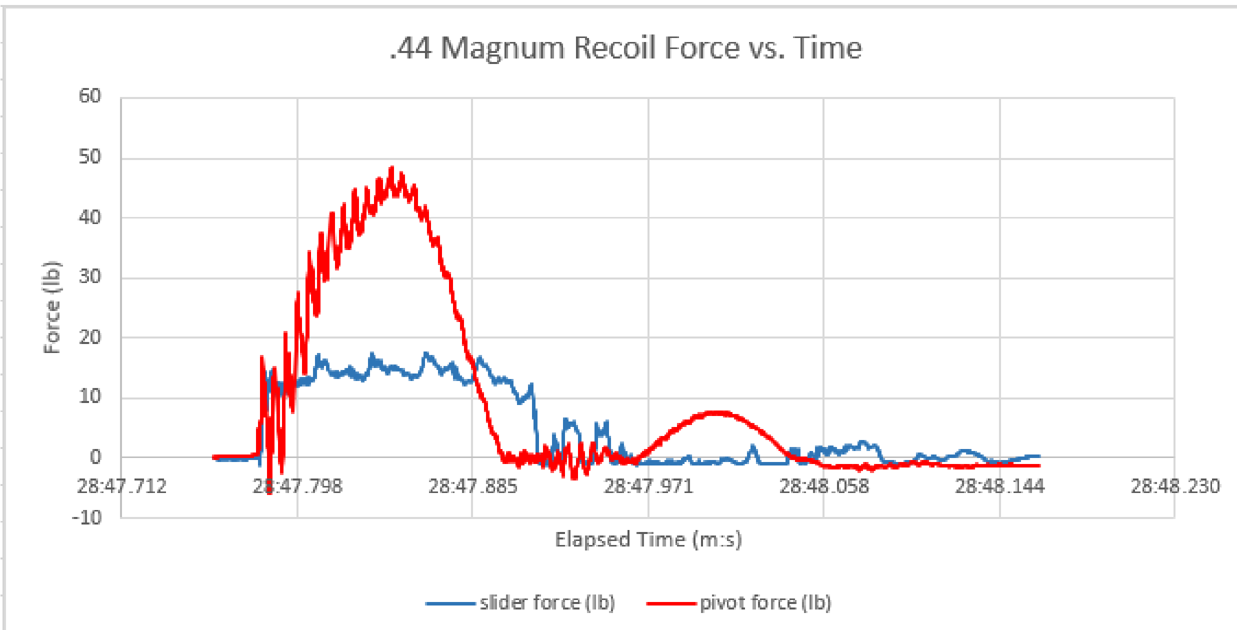
38 Special Test Shot Data



357 Magnum Test Shot Data



44 Special Test Shot Data



44 Magnum Test Shot Data