BULLET IQ
BY ADVANCED PRECISION DEVICES

USER GUIDE AND EXAMPLE USES

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Warning: Follow proper firearm safety when using this product. Advanced Precision Devices LLC accepts zero liability resulting from the use of this product, use of a firearm, or improper firearm or ammunition configuration or assembly with our without this product. Installing Advanced Precision Devices software constitutes an acceptance of these terms.

Introduction

Congratulations on your purchase of the Bullet-IQ by Advanced Precision Devices. The Bullet-IQ is a scientific instrument. By mounting strain sensors on the barrel itself, and by measuring strain of the barrel, the theoretical pressure inside the barrel can be calculated via the laws of solid mechanics in accordance with elastic theory. The Bullet-IQ has two channels and thus offers the ability to measure pressure at two locations on the barrel. This valuable quality allows the user to directly measure bullet lead time (BLT).

Bullet-IQ Operating Principle, Specifications, and User Requirements

WARNING: NEVER PERFORM ANY STRAIN GAGE INSTALLATION, OR CONFIGURATION ON YOUR FIREARM WITH A LOADED FIREARM, MAGAZINE, OR CHAMBER.

The Bullet-IQ Is a high performance laboratory-grade pressure measurement system. It is a complete package seamlessly integrating two channels of pressure data, a data acquisition system with proprietary firmware, and a software interface working together to provide data thus far available only to large organizations. Until now, multi-channel barrel pressure measurement has only been available to organizations with dedicated engineers and technicians, and the means to develop and invest tens of thousands of dollars into instrumentation, and expensive commercial signal conditioning data acquisition systems generating mountains of data to filter, postprocess, and evaluate manually. The Bullet-IQ automatically detect the pressure events on channel A, records both channel A and channel B wherever they are on the barrel, and plots the pressure data from both channels out to 0.0025 seconds (2.5 milliseconds).

Warning: Follow proper firearm safety when using this product. Advanced Precision Devices LLC accepts zero liability resulting from the use of this product, use of a firearm, or improper firearm or ammunition configuration or assembly with our without this product. Installing Advanced Precision Devices software and/or hardware constitutes an acceptance of these terms. This instrument is designed to estimate pressure inside a barrel and chamber based on geometry and properties entered by the user. This process, like any other, is susceptible to error and cannot be controlled by Advanced Precision Devices LLC. Because the pressure values are calculated based on user inputs and assumptions, we cannot guarantee they are an accurate representation of pressure inside the firearm. That can only be done with a full system calibration, which still will not guarantee against failure or rupture in a given firearm. We caution the user to never exceed SAAMI standards for pressure, powder weight/type, bullet weight/type, seating depth, or any other parameter related to reloading rounds. Bullet-IQ is not intended to and does not replace SAAMI or CIP test methods and is not a replacement for SAAMI/CIP safety tests. Bullet-IQ can help evaluate ammunition performance but should not be used to determine the safety of ammunition. APD may change Bullet-IQ specifications or performance metrics at any time.

Specifications and System Requirements

Table 1: Bullet-IQ operating specifications. (Specifications are liable to change at any time with updates to Bullet-IQ, or new Bullet-IQ models)

Bullet-IQ Specification	Value
Sensor Type	Strain (both ¼ and ½ bridge)
Minimum Full Scale Measured Pressure (psi)	Ch A=150,000, Ch B=300,000
Typ. Strain Measurement Accuracy Typ. (% of FS)	+/-1.25%
Gas Pressure Resolution (psi)	50 or better
Sampling Rate (samples/second)	200,000 per channel
Samples Per Shot	500
Shot Detection Duration Window (seconds)	0.0025
Approximate System Weight (lbf)	1.0
Sensor Cable(s) Length (ft)	5.0
USB Cable Length (ft)	5.0

To use the Bullet-IQ the user must simply install the software from the APD website (www.recoiliq.com) on their computer that has a windows 10 (or newer) operating system equipped with the specifications shown below (Table 2).

Table 2: User PC System Requirements (system requirements are subject to change)

User PC System Requirement	Value
Operating System	Windows 10 or newer
RAM	8+ GB
CPU	Dual Core or Better
USB	2.0+
Mac OS Support	None. Future Versions Will Support OS
Firearms Included	None
SKU	APD-BK-0002

Component Overview

The Bullet-IQ consists of a high performance Sensor Control Module (SCM), and User Interface Software (Figure 1). The system uses strain gages that are carefully bonded to the barrel by the user using adhesive. The barrel dimensions (ID/OD) must be carefully determined at the location of bonding to ensure highest possible pressure measurement accuracy.

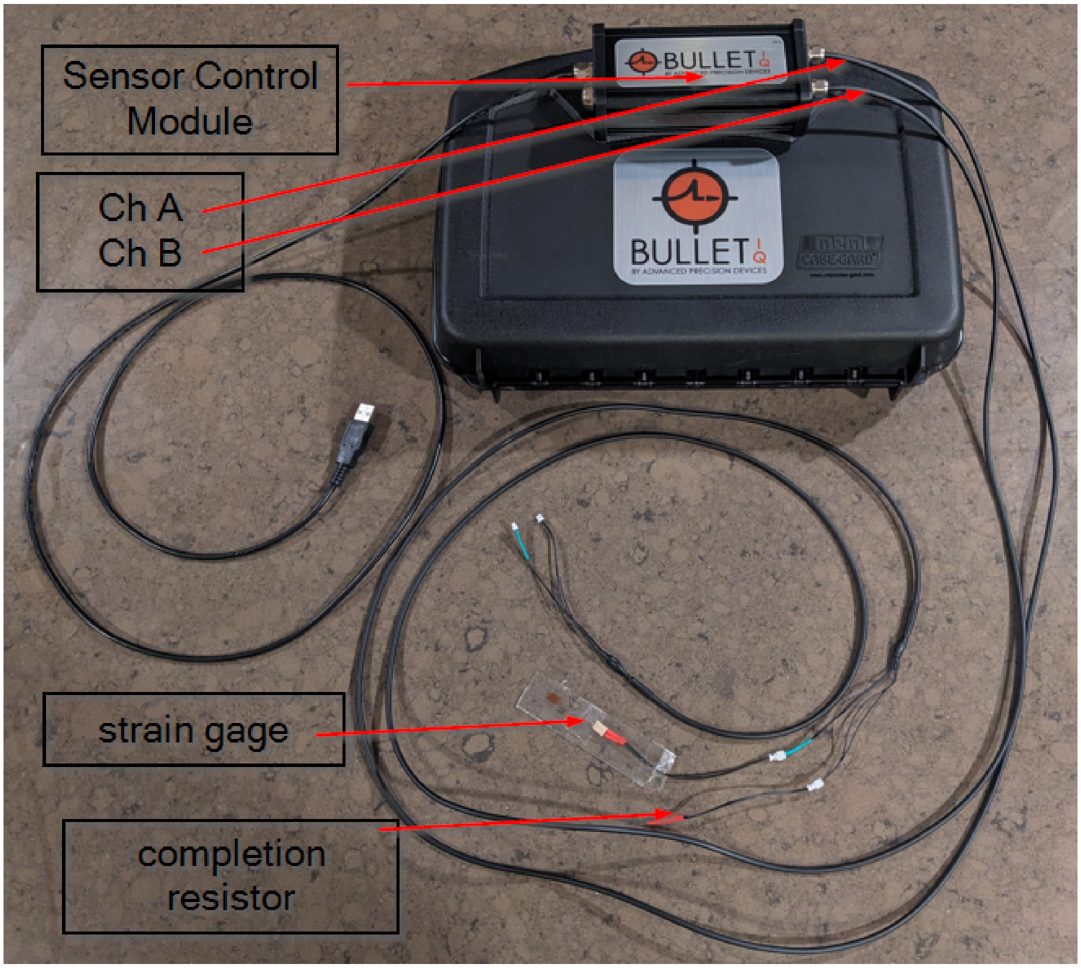

Figure 1: Component Overview

Use Modes

Single-Channel

In Single Channel Mode, the user bonds one strain gage to the barrel. The strain gage, as properly installed, measures the diametral expansion of the barrel during the shot. As such it must be oriented tangentially to the cylindrical barrel surface, and not longitudinally to the barrel axis. The gage can be mounted over the chamber, or further down the barrel. Also enter the elastic modulus of the barrel. A very common alloy for barrels is AISI 4140, commonly known as Chromoly, and has an elastic modulus of 29,500,000 +/- 1%. If you know the particular alloy, and modulus of your barrel material, enter it below. For composite barrels, the effective modulus is difficult to know without manufacturer data or calibration. In the image below, the entry fields are configured for a 6.5 Creedmoor with strain gages installed at the start of the rifling near the chamber, and at the muzzle, for channels A and B, respectively (Figure 3).

Dual Channel Mode

In dual channel mode, the user can install both channels A and B. By installing two channels, the user can measure pressure at two locations. If channel A is installed near the chamber, and channel B is installed at the muzzle, the user can measure the duration that the projectile is in motion from ignition to muzzle exit. This is referred to bullet lead time (BLT). Bullet-IQ defines BLT as the time from when chamber pressure at channel A reaches 10% of its peak pressure immediately following ignition, to the time when channel B reaches 20% of its peak pressure. Channel B will only register pressure once it is exposed to pressur once the bullet has passed by it. The Channel B strain gage can be placed anywhere on the barrel, including mid-length on the barrel on the barrel. For several reasons, it is important to note that the pressure in the barrel does not reach zero at the moment the bullet exits the muzzle because there is still a large mass of pressurized burned and burning powder still exiting the barrel. This is evident to anyone who has used a muzzle brake or observed muzzle flash in low light conditions. If it is desired to use dual channel mode, the user must complete the fields for both channels, and then during the setup menu, the toggle switch for Dual Channel mode must be selected. If the test goal is to most accurately measure BLT, then channel A must be placed at the chamber or the case mouth, and channel B as close to the muzzle as possible. Note that neither channel has to be installed exactly at the chamber or the muzzle. Different measurement locations can be used, and will deliver pressure data at that location, but the correct diameter data must be entered for those locations. Also note that if the strain gage is mounted at a location where there is no brass present, for instance an inch beyond the bullet, the cartridge wall thickness should be entered as zero. For channel B, the program will always assume that the cartridge wall thickness is zero.

Software Installation

Visit the website for Advanced Precision Devices (https://www.RecoiIQ.com/) and download the software. Install the software.

Software Setup Guide

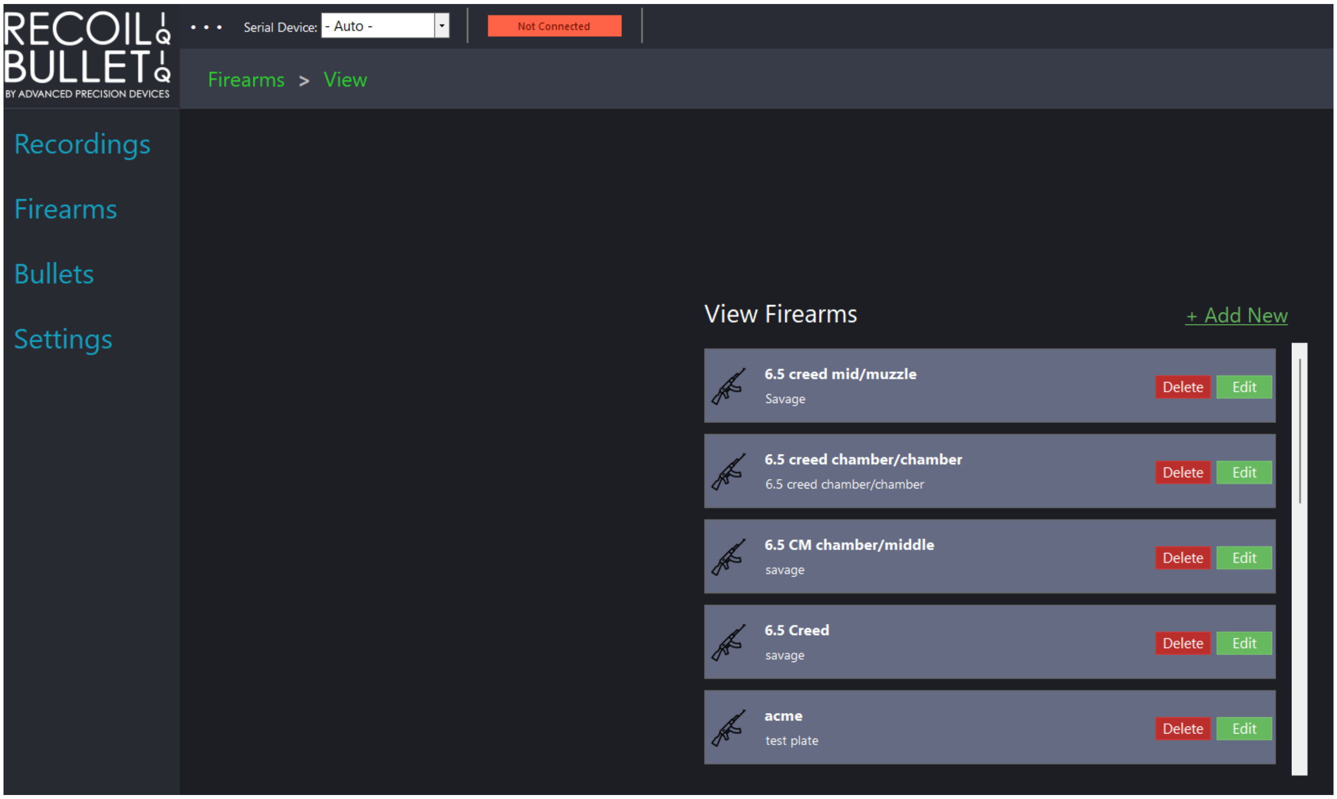

Figure 2: Bullet-IQ Software Firearm Configuration

Firearm Configuration

Open the software and connect your Bullet-IQ. To use the software you must read and agree to the Bullet-IQ safety agreement. Once connected click on the Firearms Tab and click +Add New (Figure 2).To properly calculated internal pressure, the dimensions and properties of the barrel must be known and entered in the firearm edit menu. For a given firearm, the user may need to use and maintain multiple firearm configurations. The reason for this is because the firearm configurations include information on barrel metrics such as inner and outer diameter. A user could place dozens of strain gages on their barrel in different locations, with each gage having different barrel metrics at that location. It is important for the user to configure and select the right firearm configuration based on the location of the strain gages that the Bullet-IQ is connected to at the time of testing.

Correction Factor

Because the Bullet-IQ uses the laws of solid mechanics in accordance with elastic theory to determine pressure in the absense of a calibration, there may be errors associated with the measurement. These errors can be due to many factors known and unknown, including but not limited to errors in entered diameter, nonconcentricity of barrel bore, errors in elastic modulus assumption, cracks or material flaws in the barrel material, errors in gage factor value, calibration drift, human error, etc. These errors may cause the Bullet-IQ to underreport, or overreport measured pressure. In order to allow the user to correct their measurement, we offer the Correction Factor. The user should use a round with a known peak pressure as a reference. This could be a round measured and verified in a SAAMI laboratory using CUP, Strain gage,or Piezo methods on a calibrated barrel. If the user knows that the peak pressure of the round should be 55000 psi, but only registers 50000 psi with the Bullet-IQ in an uncorrected state, then the user can enter those values into the correction fields below. In the trusted round peak pressure field, the user would enter 55000, and in the uncorrected observed field, the user would enter 50000 (Figure 3) below shows both values equal, as no correction is being used). *Warning: this correction cannot be considered a calibration. As always, caution is required.* The user is responsible for determining and entering the proper diameters, elastic modulus, gage factor, and Correction Factor information in order to achieve best accuracy in pressure measurement.

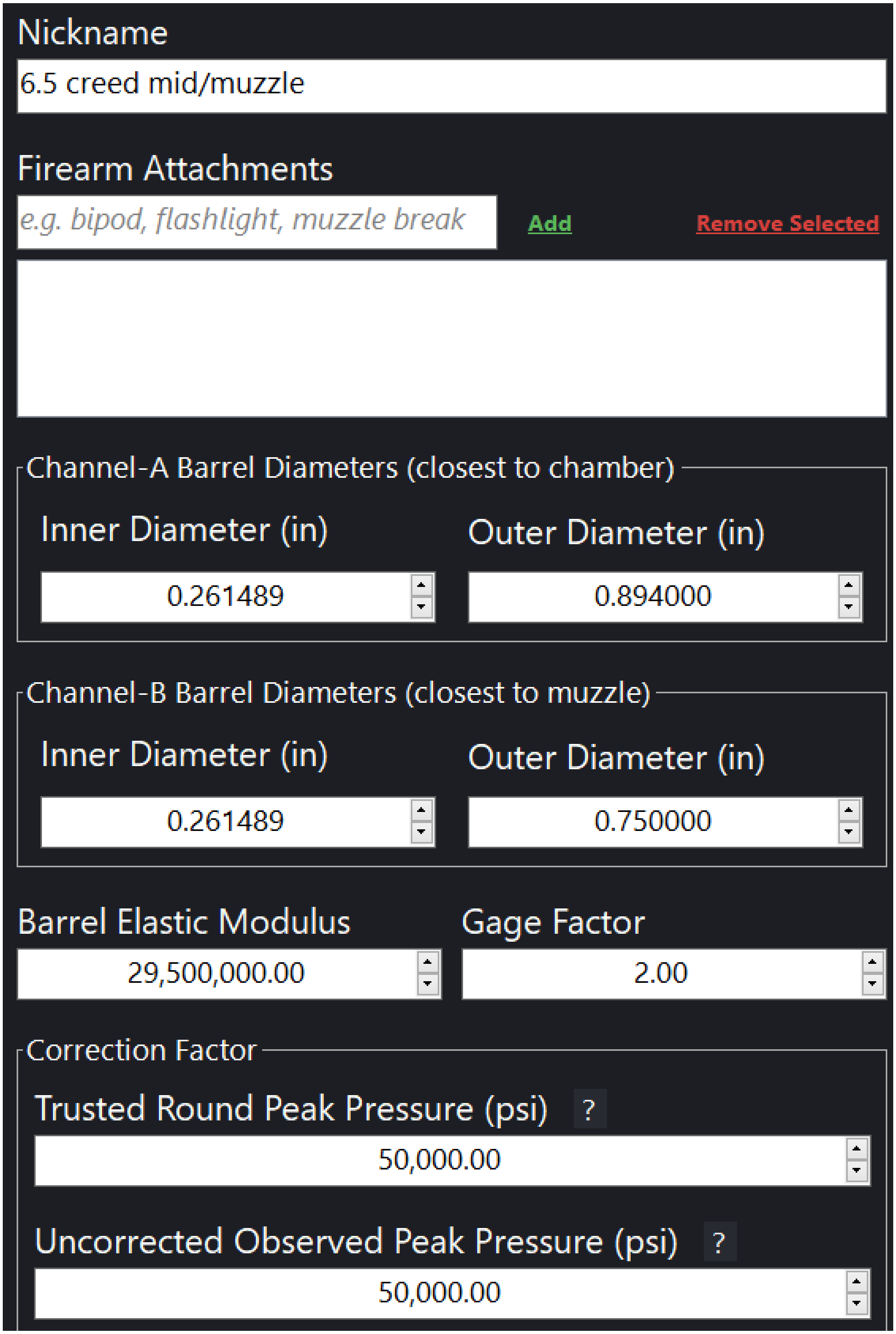

Figure 3: Barrel Configuration Fields for a 6.5 Creedmoor Rifle and gage Config.

Defining Inner Diameter

Inner diameter must be defined carefully. If the user is measuring pressure on top of the cartridge, it is reasonable to measure the diameter of a cartridge *that has been fired (and thus expanded)* at the location of the strain gage, and add approximately .002″. If the strain gage is located on a rifled area of the barrel, then a reasonable value for Effective ID can be defined as follow: Effective Inner ID=(%groove)*(Bullet Diameter)+(%land)*(caliber). For a reference 6.5 Creedmoor used by APD, this is calculated as (.69)*(.264″)+(.31)*(.2559″)=.261489″. We have found that this calculation approximation is very accurate (within 0.04%) in the worst case compared to an FEA model and an analytical model of a rifled barrel geometry. Note that for optimally accurate diameter measurement, castings must be made as barrel manufacturing tolerances and wear can have an effect on this measurement. To measure the Outer Diameter of the barrel, use a calibrated caliper or micrometer at the gage location.

Defining Ammo

The user will also define their ammunition in the bullet setup field (Figure 4). Please select the proper cartridge material field. Different cartridge materials (steel, brass, aluminum, plastic) have different properties. Also carefully measure the cartridge wall thickness. You may need to saw a used cartridge in two in order to measure the thickness properly with a caliper. Wall thickness may range from as little as .01″ to as much as .03″. If the strain gage is not placed over the cartridge, then the cartridge wall thickness should be entered in as zero.

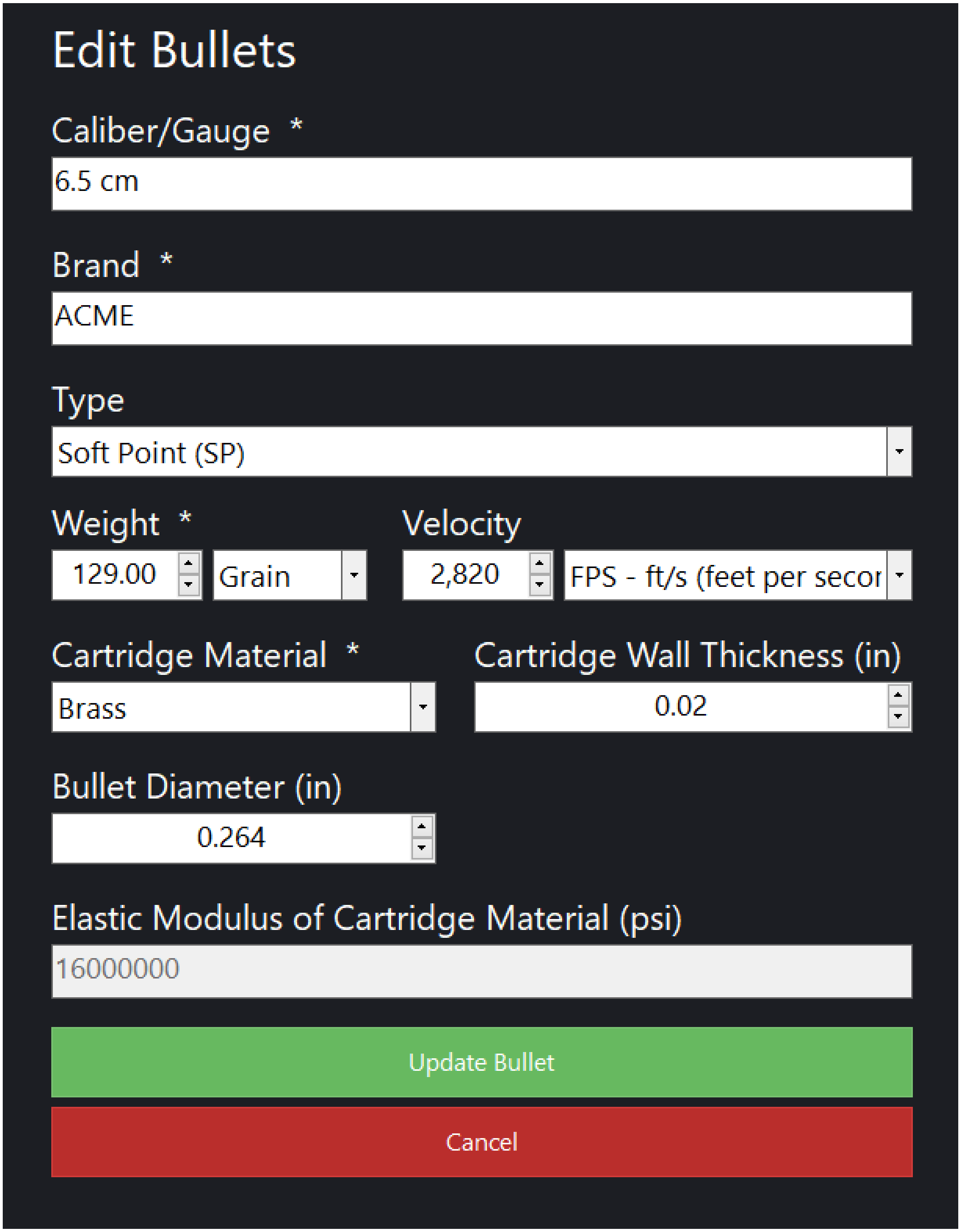

Figure 4: Bullet Configuration Example of 6.5 Creedmoor

Preparing for Data Collection

Bonding Strain gages

Your Bullet-IQ will come with two strain gages. We recommend the purchase of extra strain gages since bonds fail and strain gages can be difficult to handle. They must be considered as a consumable item and cannot be reused. Strain gages are bonded to the barrel with adhesive. Cyanoacrylate adhesives (super glue) such as Visha Mbond 200 are an effective way to temporarily bond your strain gage. Acetone is helpful to dissolve and remove Cyanoacrylate. Alternatively, two part expoxies such as JB Weld or A12 are more tenacious than Cyanoacrylate for a longer-term bond, though they are harder to apply, and cleanup and removal can be much more difficult.

Surface Preparation

Surface preparation is critical for a reliable bond. For best results the surface should be cleaned repeatedly with a solvent. A 50/50 mixture of reagent grade acetone and isoproyl alcohol has been shown to APD to be very effective. A large supply of cotton swabs should be used for this process. The cotton swabs should be dipped in the solvent and rubbed on the barrel location of interest, being careful to prepare a region plenty large enough for the strain gage. The cotton swab will come off of the barrel discolored for many swipes, especially on blued barrels. This treatment will likely discolor the surface of the barrel as an unavoidable consequence. Once the surface is clean, the strain gage can be applied. If mounted to a surface prepared in this way, using cyanoacrylate, this strain gage may last for dozens or even hundreds or more measurements. If a more durable mount is required, then the surface can be prepped by very lightly sanding with 800 grit silicon carbide paper, and cleaning deeply as per the above after sanding. A more complete guide to this process can be seen at the following Vishay surface prep video (https://rb.gy/pe40xu).

Strain gage Bonding

To bond the strain gage to the surface, a very clean glass surface should be prepared as a work area. The glass surface should be cleaned with solvent using the process outlined in the prior section for the gage area. Having cleaned the surface, a gage can be removed from the packaging. Never touch the backside of the strain gage. Any contaminants will make bonding more difficult. Place the strain gage backside down on the clean glass surface. Take a small piece of polyester tape such as 3M 8911, and adhere the tape to the top of the gage, to use it as a lifting and placement mechanism. Other types of tape can be used, but they are more difficult to remove from the gage once the gage has been bonded. Move the tape/gage assembly to the barrel, positioning the gage in the prepared spot. The gage should be oriented circumferentially around the barrel, not lengthwise. Anchor the tape in place so that the gage is in the correct spot, then lift one end of the tape until the gage is fully pulled off, but one end is still nearly touching the surface. Then apply your cyanoacrylate to the gage and the underlying barrel. Having done this, push the gage down flat, applying strong thumb pressure for approximately two minutes. For a more complete guide to this process, visit this helpful video link by Vishay (https://rb.gy/tr4nbr). Having bonded the gage, allow it to cure for 24 hours before using. Tape the gage leads responsibly to the side (Figure 5).

Figure 5: Applied gage and Completion Resistor (gage connected to green-indicated connector, and Completion Resistor on second connector)

Hardware Connections

Having prepared the ammo configuration, firearm configuration, and bonded the strain gages, the electrical setup needs to be complete before data can be collected. Connect the ChA cable to the ChA strain gage. The green-indicated connector goes to the strain gage (remember "gage=green"). The connector with no green indication receives a completion resistor which should be connected at this point. Two completion resistors are provided with your Bullet-IQ system, one for each channel. The completion resistors provided by APD match the gages provided by APD. If gages or resistors are used outside of those provided by APD, they must match each other in impedance. Recall that ChA and ChB gages should be configured so that ChA is exposed to pressure before ChB. ChA is the shot detect channel and this ensures that the event timing is flagged properly by the Sensor Control Unit.

Collecting Data

Notice: The Bullet-IQ is an extremely sensitive sensor equipped with signal amplification and conditioning to measure and record tiny electrical signals from the strain sensor. The presence of phones, electric motors, current sources, and other sources of electrical noise must be removed from the proximity of the Bullet-IQ to avoid signal contamination. Turn off phones or place at least 5 feet from Bullet-IQ. Turn off running vehicles and other electrical devices except the computer used for testing – make use of the usb cable and sensor cable to maintain a few feet of distance from the test computer.

Having configured the ammo and barrel, and bonded and connected the gages, data collection can begin. Click the recordings tab on the left side, and click “New Recording” (Figure 6). Connect the Bullet-IQ to an open USB port. Click Connect. The connection process could take 1-30 seconds. If no connection is established, press the reset button and try again. If still no connection is established, disconnect the usb cable, reconnect it, restart the app, and try again.

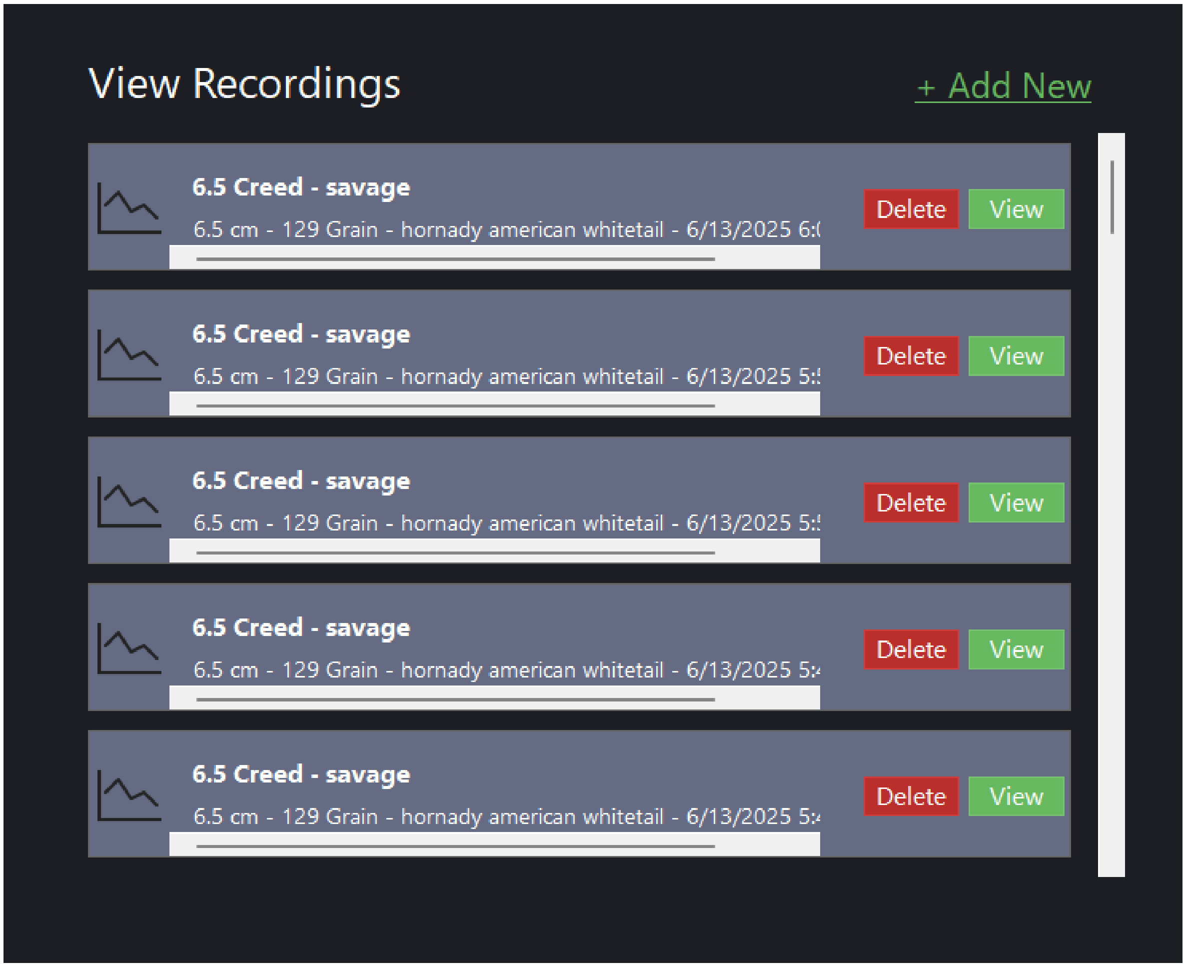

Figure 6: Add New Recording

Having successfully connected (Figure 7), click Next, and select your configured firearm, ammo, and the number of channels(Figure 8), click Finish and Start Recording. In the image show in Figure 7, it can be seen that Channel A has a green flag and Channel B has a gray flag for “Last Zero Status”. That is because in this example only channel A was connected and properly zeroed. If the user plans to use both channels, they must both be connected to their gages and completion resistors so that they can auto-zero properly and their indicators show green.

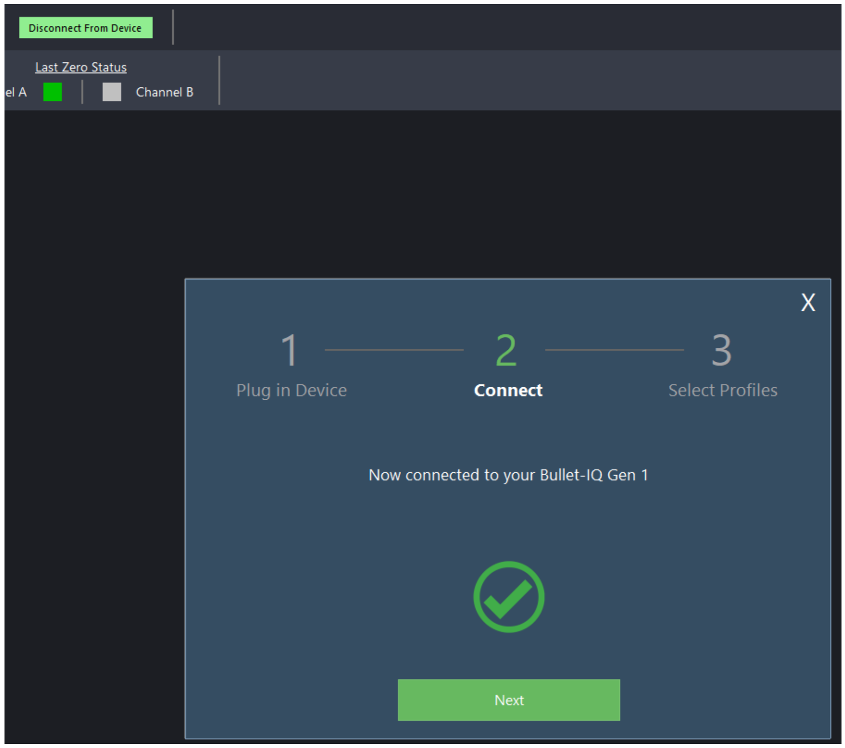

Figure 7: Successful Connect

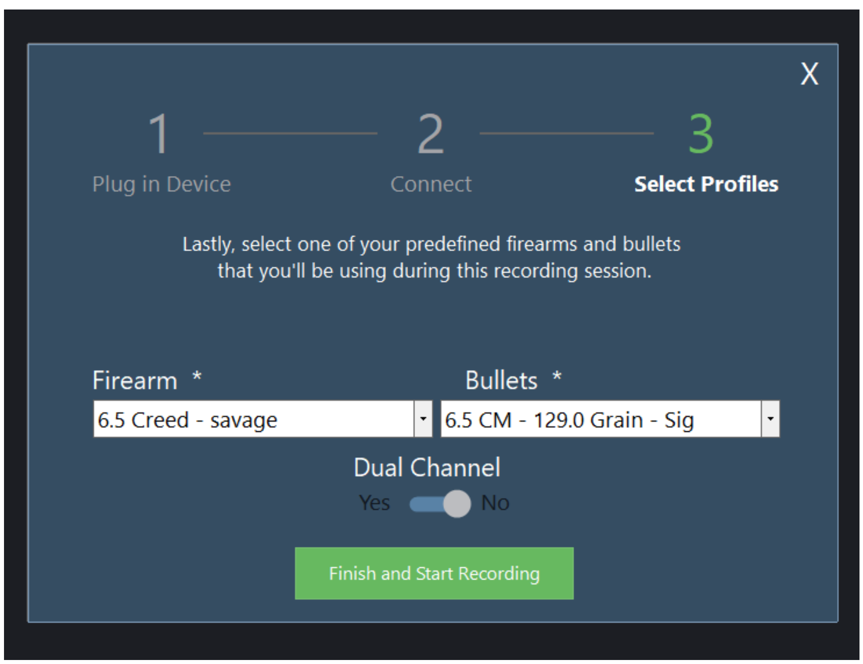

Figure 8: Firearm and Ammo Select

Having done this, you are ready to start collecting data. **<u>Observing all firearm safety practices according to but not limited to the Advanced Precision Devices safety agreement, local laws, and common sense, you may proceed.</u>** Now you can collect data automatically. The Bullet-IQ will automatically detect shots and plot them. You must wait approximately three seconds between shots for the detection, calculation, and plotting to finish. If you shoot another shot too early, it may not be detected and plotted properly. Having completed the data collection, click “Finish and View Results”. Having done that, peak pressure on both channels will be tabulated and can either be saved or discarded. Note that BLT will only be recorded if dual channels are used. Further, BLT should only be considered as a proper measurement of BLT if ChA is located on or very near the chamber, and ChB is used as close as possible to the muzzle. Note that if the ChB gage is located 0.20″ from the muzzle, and the muzzle velocity is 2950 fps then the BLT as calculated by the Bullet-IQ will be approximately .0055 millisecond shorter than actual. This is approximately equal to one sampling interval on the Bullet-IQ and is thus a very small error, especially considering a typical high powered rifle BLT ranges from .60-.95 milliseconds. Thus, the BLT measurement will be very accurate and underrported by less than 1% if you can mount the gage closely to the muzzle.

Example Data

Chamber/Muzzle Data

As an example, Figure 9 is data from a bolt action 6.5 Creedmoor. For this dataset, the ChA is mounted at the case mouth, and ChB is mounted approximately 0.20″ from muzzle. This setup will give a very reliable BLT and chamber pressure. The display table shows peak pressures in excess of 180,000 psi on ChA for both shots. This occurs the bullet has left the muzzle. ChA Peak pressure while the bullet is in the barrel is approximately 53000 psi for both shot 1 and shot 2. BLTs of .80 ms and .805 ms are also calculated and displayed.

Bullet Event	Channel 1 Peak Pressure (psi)	Channel 2 Peak Pressure (psi)	Bullet Lead Time (ms)
1	198329.613	91725.19	0.805
2	189344.413	74580.311	0.81

Figure 9: 6.5 Creedmoor Pressure Curves (case mouth, and muzzle)

The ammunition used was 129 grain soft point ammo, at a muzzle velocity of 2820 fps. If this example was evaluated with an internal ballistic analysis tool, a user would find that the pressure curves measured and shown above will deliver very similar velocity. This very strongly supports our experience that the data delivered by the Bullet-IQ, though based on first principles and not a calibration, can be quite accurate when used properly. The pressure taken while the round is still in the barrel is also less than the 63000 psi SAAMI maximum pressure for the 6.5 Creedmoor. Unfortunately, there is very conspicuous secondary pressure event that occurs after the bullet leaves the muzzle. This pressure event is present at both the chamber and the muzzle, giving a chamber pressure of almost 200000 psi (the data is actually saturated, meaning it exceeded the maximum value for channel A, indicating the pressure is likely even higher than measured), and muzzle pressure of between 72000 psi and 100000 psi. This type of event has been observed in the past with other chamber pressure measurement devices. It is a very concerning phenomenon. It is very conspicuously present, and occurring at approximately the same moment on both channels, and two consecutive shots for this particular ammunition. More research is necessary to study this phenomenon.

Chamber/Mid-Length Data

To evaluate pressure mid-length instead of at the muzzle, the Channel B strain gage was applied approximately 10 inches from the Channel A gage at the case mouth. Using the same rifle and ammunition used in the section above, the results are shown below in Figure 10. The data shows very clearly when the bullet arrives at the mid-length strain gage, and from this BLT is still calculated and shown in the results table (though in this case BLT is perhaps not as interesting since the bullet hasn't left the muzzle). Still concerning is the presence of the large secondary pressure event, which is present both at the case mouth, and mid-length. Compared to Figure 9, where the secondary pressure event at the muzzle is much smaller than at the chamber, at mid-length the pressure from this event is as severe or worse than at the chamber. Again this is a concerning observation and our testing strongly suggests that the pressure event is occurring throughout most of the barrel. The two channels of data provided by the Bullet-IQ makes this difficult measurement possible, and provides conclusions in place of guesses. Additional Research is necessary on this topic.

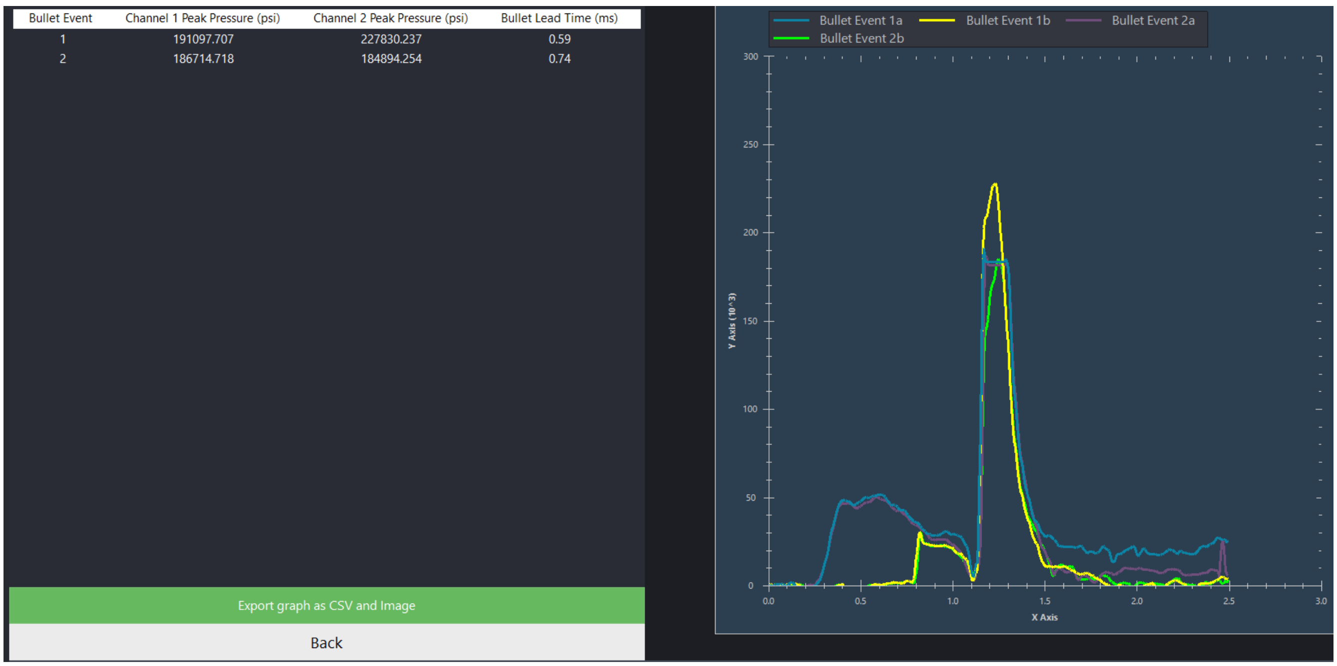

Figure 10: 6.5 Creedmoor Pressure Curves (case mouth, and mid-length)