# Method for Non-Destructive Characterization of Projectiles and Cartridge Cases

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## Abstract:

A proof of concept non-destructive test system has been designed and tested that is capable of characterizing both Cartridge Cases and projectiles, both intact as well as those discharged from a weapon.

The technique utilizes a device equipped with a proprietary and patented sensor which detects energy reflected off the unit under test. This detected signal undergoes Fourier Transformation which creates a signature which can them be used for comparison with other existing samples for matching purposes.

This system has been shown to be able to match Cartridge Cases as well as projectiles to a degree that could potentially allow matching of samples to a degree sufficient to determine like production lot members, and other linked criteria.

This system is projected to be much more cost effective than current systems and the hope is to have units installed in Forensic vehicles and laboratories nationwide, and globally for government and law enforcement applications.

By standardizing the measurement system, data can be stored in a repository similar to current repositories, for remote access to stored data as well as to be able to upload measured signatures directly to the data base.

The system has shown good results in early tests and is ready to progress through further testing to a preproduction stage, once funding has been secured to enable this.

Keywords: Bullet, Projectile, Cartridge Case, Forensic ballistics, Firearms,

## Introduction:

Physical ballistic evidence recovered from a crime scene can be characterized by rifling markings impressed upon the projectile as it is fired.

Cartridge Cases retrieved at the crime scene can also be examined.

Tool mark identification is the established prime method of identifying ballistic evidence and tracing it to a given weapon.

Comparative bullet-lead analysis is another method of characterization that was first used after the Kennedy assassination in 1963 which used chemistry to link crime-scene bullets to ones possessed by suspects.[1] This method would be very powerful in helping law enforcement trace the evidence back to a given cache of ammunition.

The method presented here is an alternative to bullet-lead analysis, and complementary to other methods.

Preliminary results show promise that a relatively inexpensive technique exists that is capable of detecting a “signature” from a piece of ballistic evidence and comparing it to another sample.

## Methods:

The proof of concept test setup block diagram is shown in Figure 1 where the Unit Under Test (UUT) is placed on the fixture.

An external Operator initiated trigger starts the initial data capture process. Both the measured signal and the pulse which drives the LED are detected by the PicoScope which digitizes and forwards the signals to the Computer for display and processing.

The quenching of the LED initiates the refractory period which is the period of interest for the measurement.

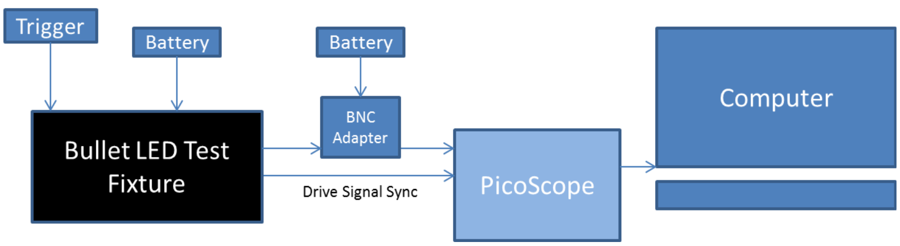



*Figure 1 System Block Diagram*

The onset of LED quenching, or turn-off, is used as a trigger to initiate data capture of the refractory period. Figure 2 shows the trigger signal, shown in red. The detected refractory signal is shown in blue.

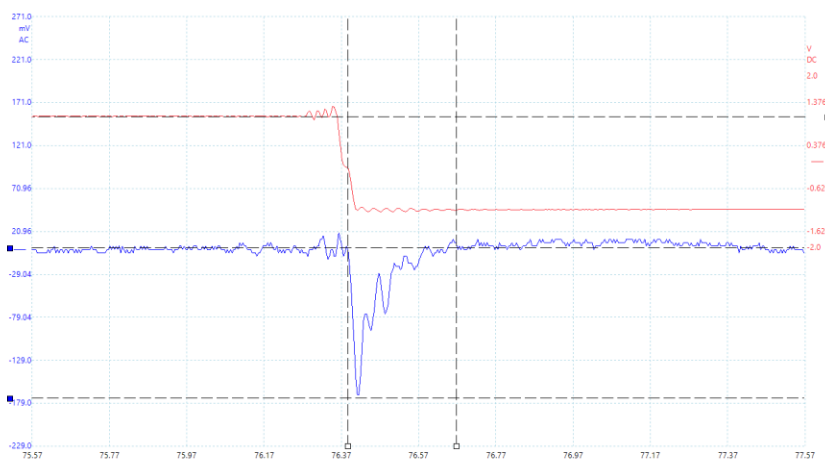


*Figure 2 Representative Captured Waveform*

The refractory period data, which covers a period on the order of 100's of nanoseconds, is then operated on by a Fourier Transform. The resultant spectral Fourier representation, a sample of which is shown in Figure 3, can then be compared with a different sample UUT and differences between the two representations can then be readily compared.

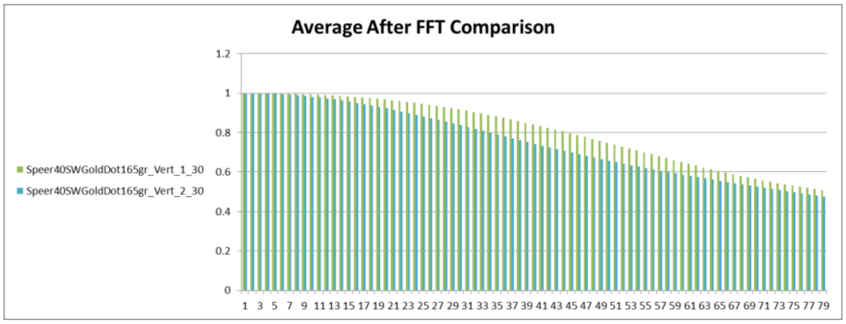



*Figure 3 Representative Fourier Output*

## Sensor Configuration

The placement of the key measurement components is represented in Figure 4. The Unit Under Test (UUT) could be a projectile, a Cartridge Case or an intact bullet. The LED is pulsed and the UUT is illuminated by the pulsed LED light. The sensor is patent pending Intellectual Property of Tichauer Technical Laboratories. The key take away is that the actual light ,generated by the LED, does not impinge on the sensor directly. The light source is used solely to excite the UUT.

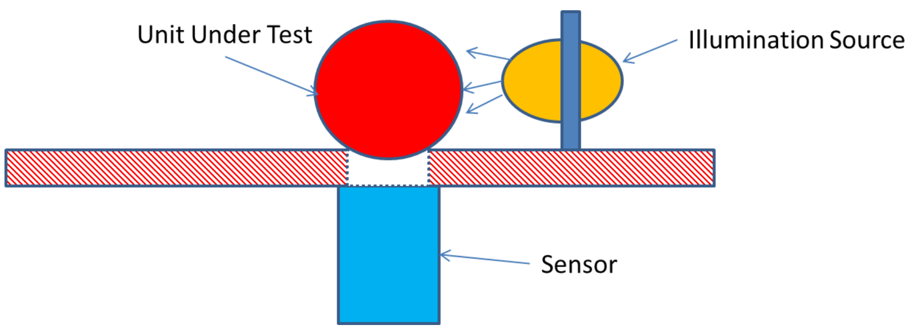



*Figure 4 Relative Placement of Key Elements*

Figure 3 shows the comparison between two projectiles. Both samples were vertical relative to the platform shown in Figure 4.

Initially all measurements were made in the horizontal rather than the vertical position. However with a deformed fired projectile it is very difficult to make reliable and repeatable contact with the platform. By placing the projectile vertically it is possible get repeatable measurements because, of the samples tested, the rearward portion of the projectiles are intact.

It is true that the rear of the projectile is not always planar since this is a function of the number of grains associated with the projectile.  However, good results were achieved with both 124 grain and 165 grain 9mm projectiles.

Cartridge Cases were tested in the horizontal position since there was no deformity present in the samples tested.  However, if a Cartridge Case was damaged and the Cartridge Case was placed vertically the effect of the primer on the reading may vary.  The variability with respect to reloads for the Cartridge Cases may also add additional uncertainty.  For these reasons it is clear that best practices will always include both vertical and horizontal testing when possible.

The Fourier analysis allows a spectral signature to be generated.  Because there are approximately 80 or so points it is only possible to get a preliminary result from these samples.  A greater degree of accuracy will be  achieved as the number of samples is able to increase from the current 80 or so to any power of 2 greater than the original number of samples by padding the data with zeros.  This allows the accuracy and discernibility of the UUT's to rise dramatically.  In addition the capability exists to overlay successive samples to allow for averaging of trace data such that any external variability could be averaged out.  Even though there are 4096 available signature points only 80 or so were used in the graphics for this presentation since it appeared sufficient to discern between samples considering the present system's prototype limitations.

## Tests & Results

The samples presented for measurement were not individually marked, neither was any information such as to whether the samples came from the same box of ammunition or not.

Each sample was marked with an indelible marker in an area close to the tip of the sample. The marking of the data on the graphs allowed for traceability of the data back to the PicoScope captured trace from which the data was derived.

Orientation was also recorded since both horizontal as well as vertical measurements were made where possible.

The question arises as to whether the measurement is orientation dependent.  There is a difference between a horizontal vs. a vertical measurement but it appears, from the data measured to date, that rotationally there is no difference as far as tracking between samples is concerned.  However, the difference between the same sample whether oriented either vertically or horizontally  the measurements concerned track relatively well.  This can be seen by examining two Winchester 9mm projectiles and their comparisons as shown in Figure 5 through Figure 7.  Any discrepancy could be attributed to the relative placement of the sample to the LED light source.  As previously stated, best practice will be to combine horizontal and vertical tests when the device is eventually deployed.

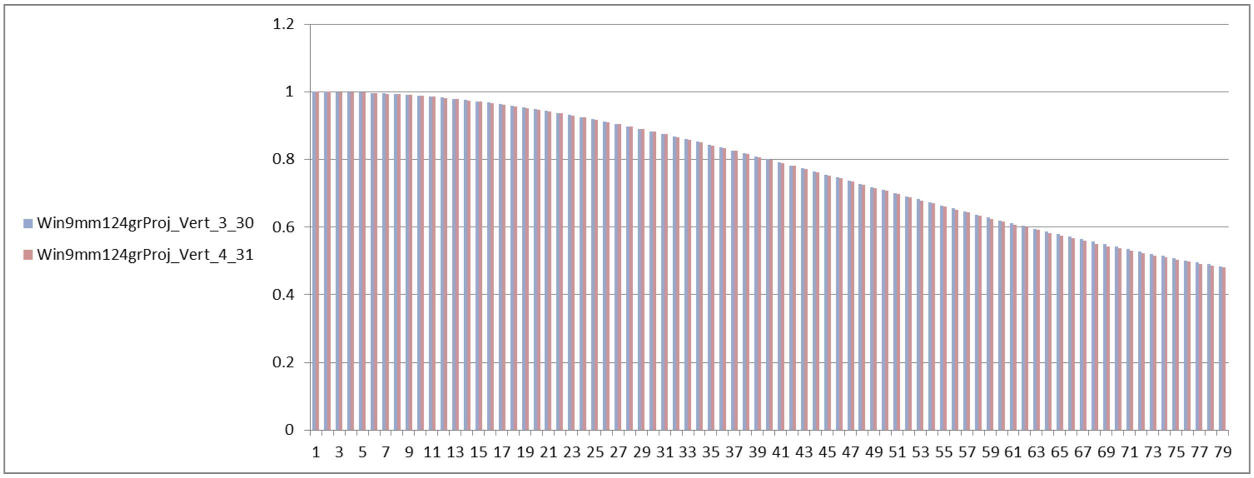



*Figure 5 Close correlation with Samples Vertical*

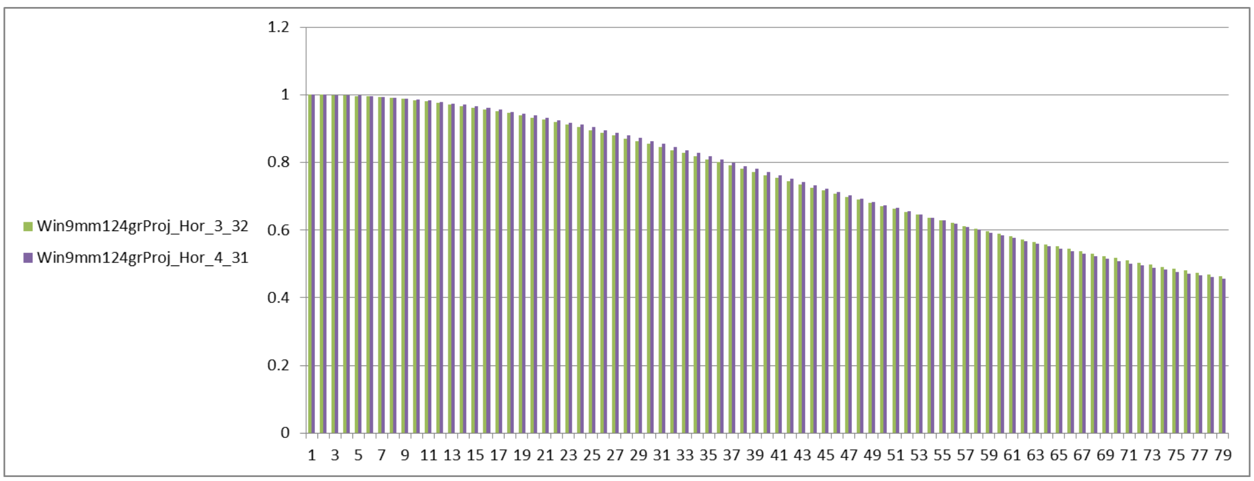



*Figure 6 Close Correlation with Samples Horizontal*

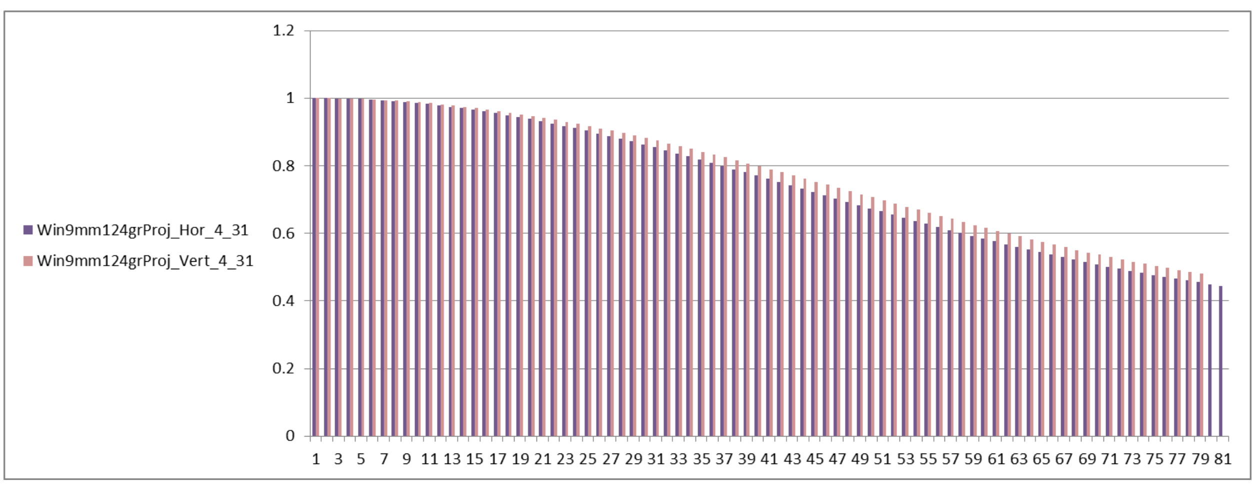



*Figure 7 Difference between Horizontal and Vertical Measurements*

For samples which do not correlate well but are from the same manufacturer Figure 8 is a good representative example. This most likely due to variations in the metallurgy of the samples since the system detects the molecular signature of the sample.

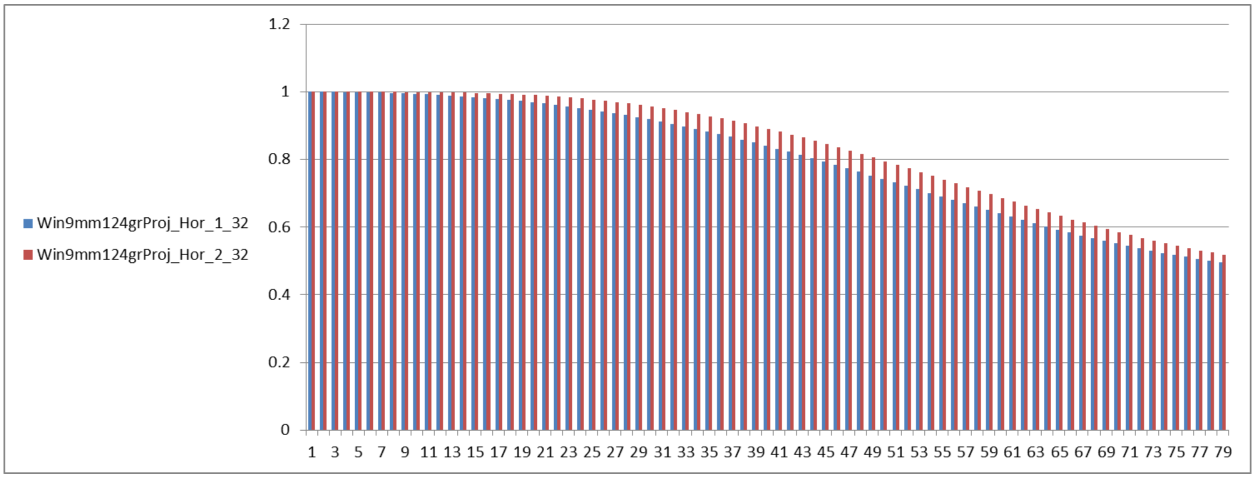



*Figure 8 Example of Poor Correlation between Samples*

*Figure 9* demonstrates the case where two 9mm projectiles, of different gram weight, from two different manufacturers are compared to each other.

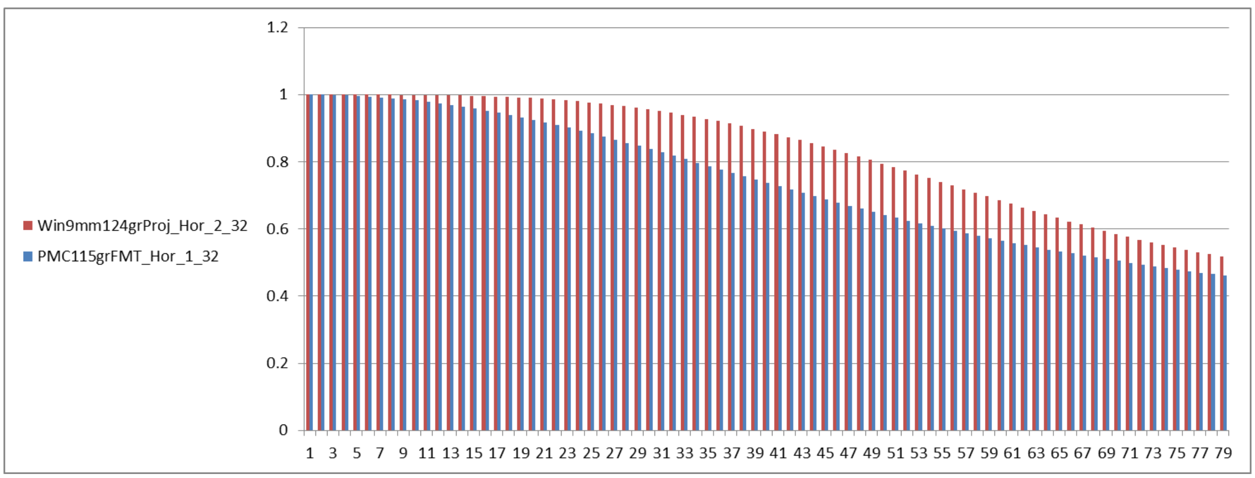



*Figure 9 Comparison of Same Caliber Projectile from different manufacturers*

Figure 10 shows the comparison of 3 different samples of various calibers as well as manufacturer. It is evident that the signatures can have enough variability to allow comparison of two samples and potentially be able to tell whether there is a real match or not.

The degree of variation allowed between the samples to allow for the confidence level to be able to declare a match has yet to be determined. This can be rectified by the establishment of a sample database with sufficient comparative data and samples for effective correlation. Some of these correlations could include:

- Manufacturer

- Lot Code
- Gram weight
- Condition of sample

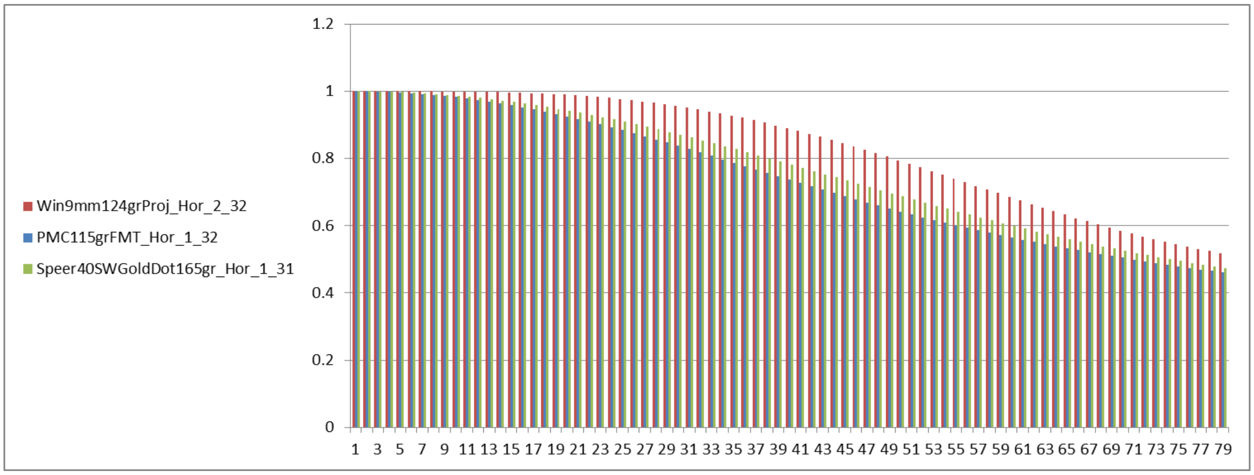



*Figure 10 Two 9mm Samples and One 40 Caliber Sample*

## Projectile Test Results:

*Figure 11* shows a compilation of vertically oriented 9mm PMC 115gr projectiles. As can be observed from the graph there seems to be a wide variation among the four samples measured. *Figure 12* shows the same samples but measured in the Horizontal orientation. There appears to be more sensitivity in the vertical direction based on the observation of these two figures.

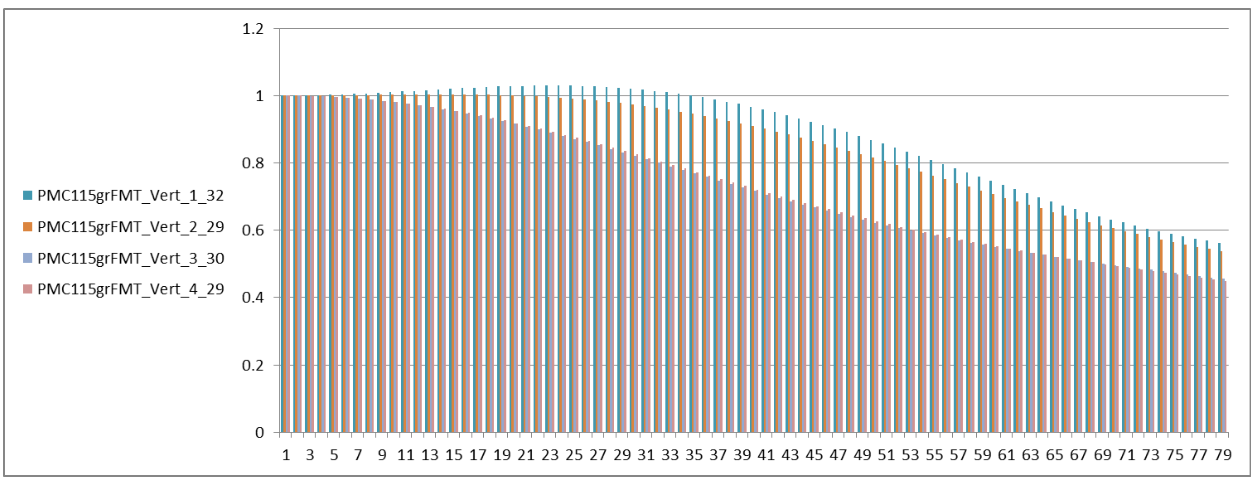



*Figure 11 9mm PMC115gr Projectile Vertical Compilation*

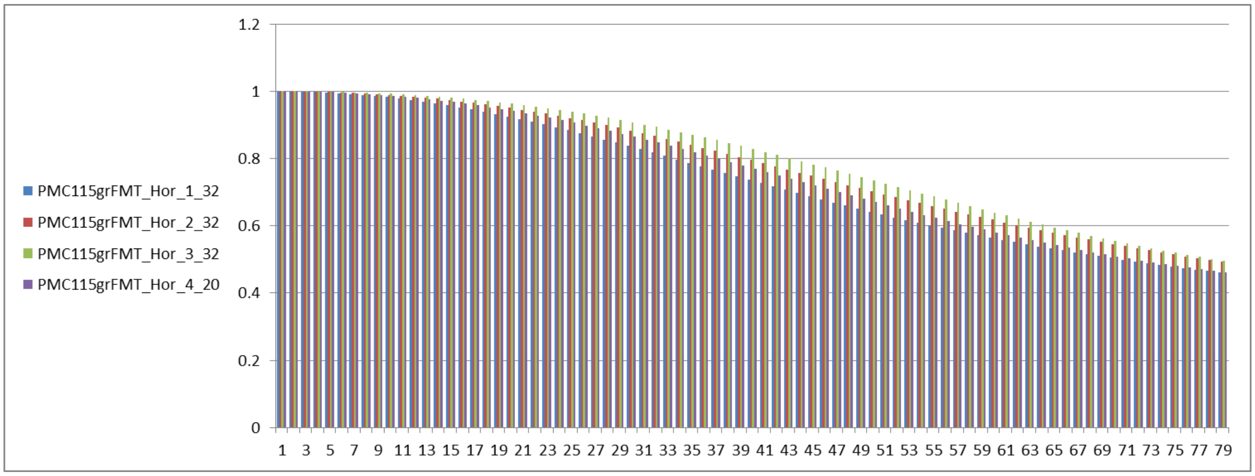



*Figure 12 9mm PMC115gr Projectile Horizontal Compilation*

This observation is reinforced when comparing the results of projectiles 3 and 4 in both the horizontal as well as the vertical orientations as depicted in *Figure 13* and *Figure 14*.

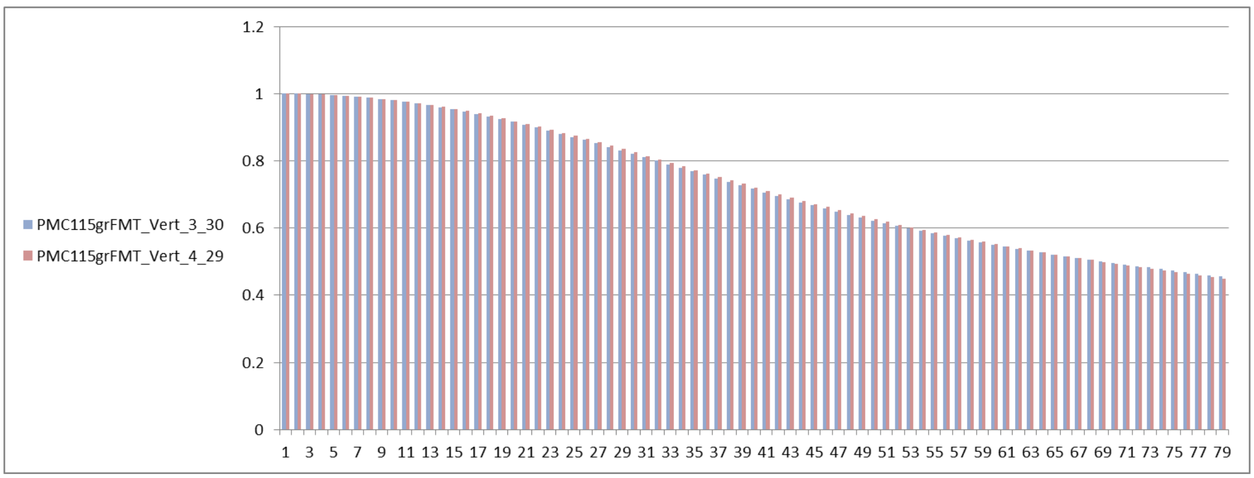



*Figure 13 9mm PMC115gr Projectiles 3 & 4 Vertical*

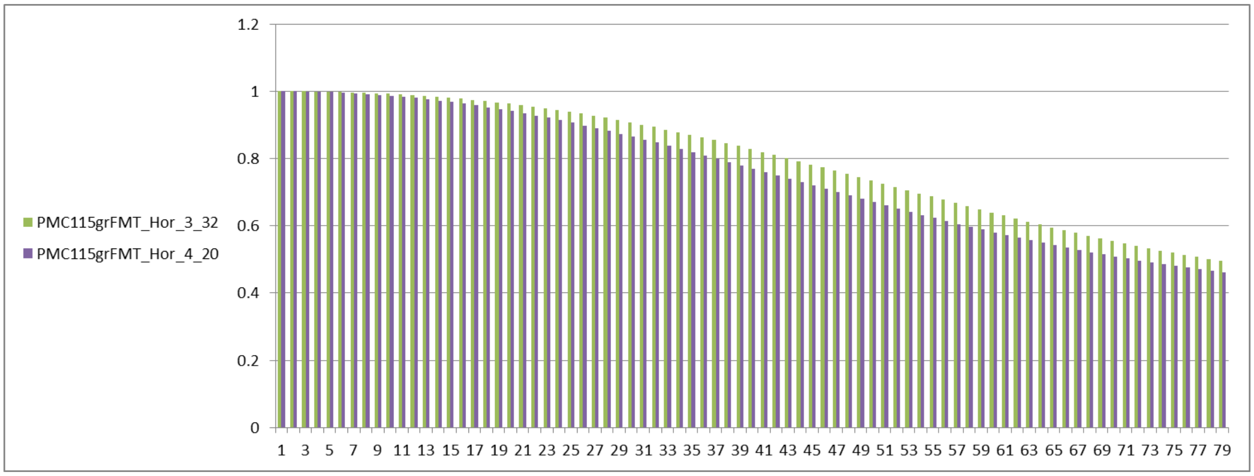
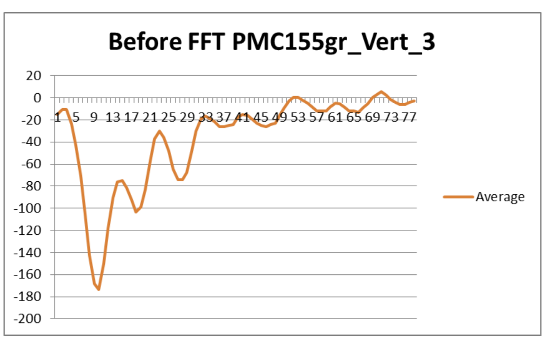
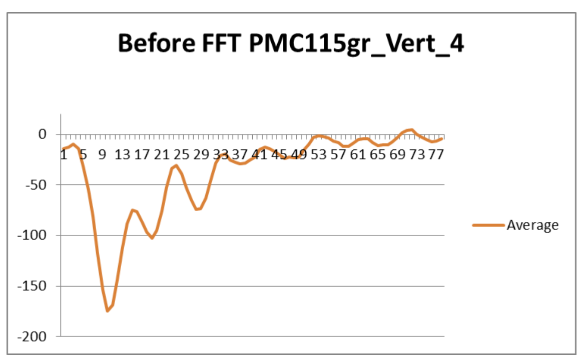


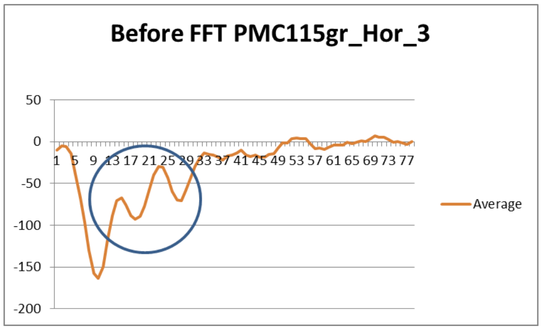

*Figure 14 9mm PMC115gr Projectiles 3 & 4 Horizontal*

One explanation for this can be found in the following 4 graphics which depict the actual analog waveform captured over five samples and then averaged. There appears to be much less variation between the Vertical measurements, as previously discussed, when compared to the waveforms for the Horizontal orientation.

The key areas of discrepancy in the horizontal orientation are circled in the respective graphics. The 9mm samples are the smallest diameter of the sample types measured in this experiment. The distance from the light source and the orientation of the sample are critical for a successful measurement. The fixture was designed to accommodate 45 caliber and smaller samples in the horizontal orientation. However, the vertical portion of the fixture was optimized for 9mm samples since these samples would have the smallest diameter and therefore the pedestal, required for sample repeatable placement, was designed accordingly. For that reason the placement of the vertical samples are more repeatable than for horizontal samples for the smaller caliber type samples. This discrepancy will be narrowed in future physical device models by allowing for compensation according to projectile or casing size.





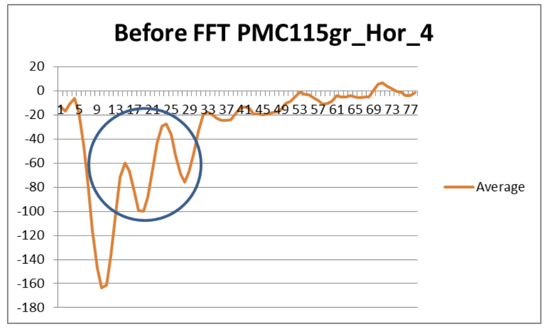




*Figure 15* and *Figure 16* are further evidence of the disparity that may be apparent in the Horizontal orientation. Better fixture design will mitigate this situation by making caliber specific jigs for measurement purposes.

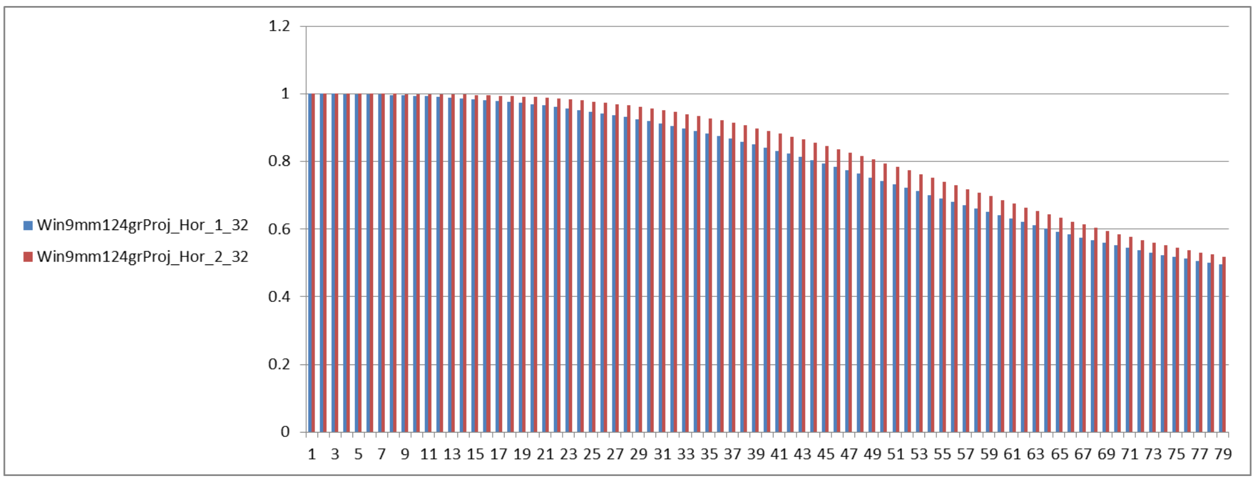



*Figure 15 Win9mm124gr Projectiles 1 and 2 Horizontal*

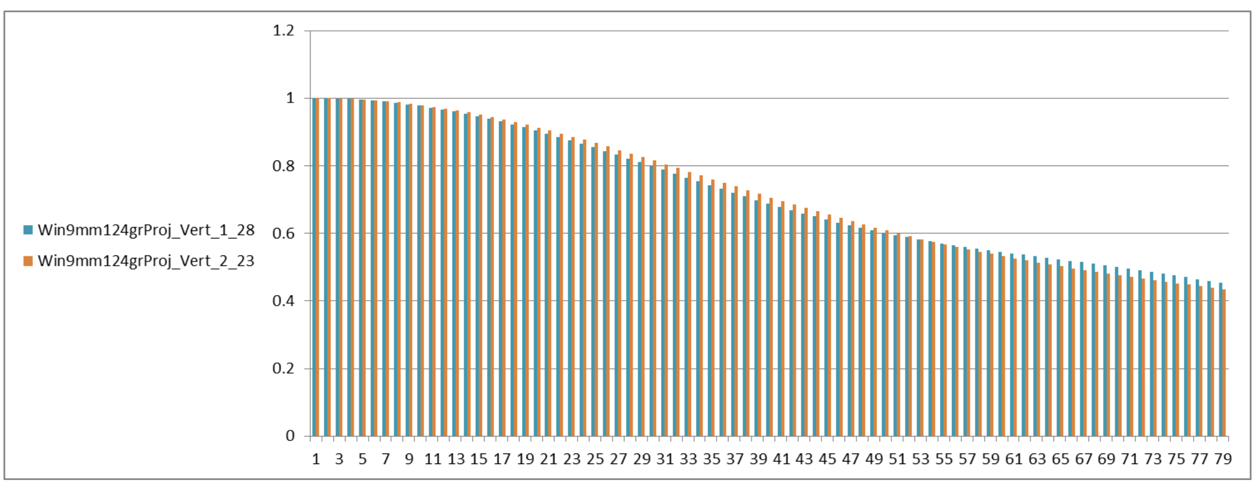



*Figure 16 Win9mm124gr Projectiles 1 and 2 Vertical*

*Figure 17* and *Figure 18* show the apparent agreement that can be achieved between orientations when properly placed on the test jig.

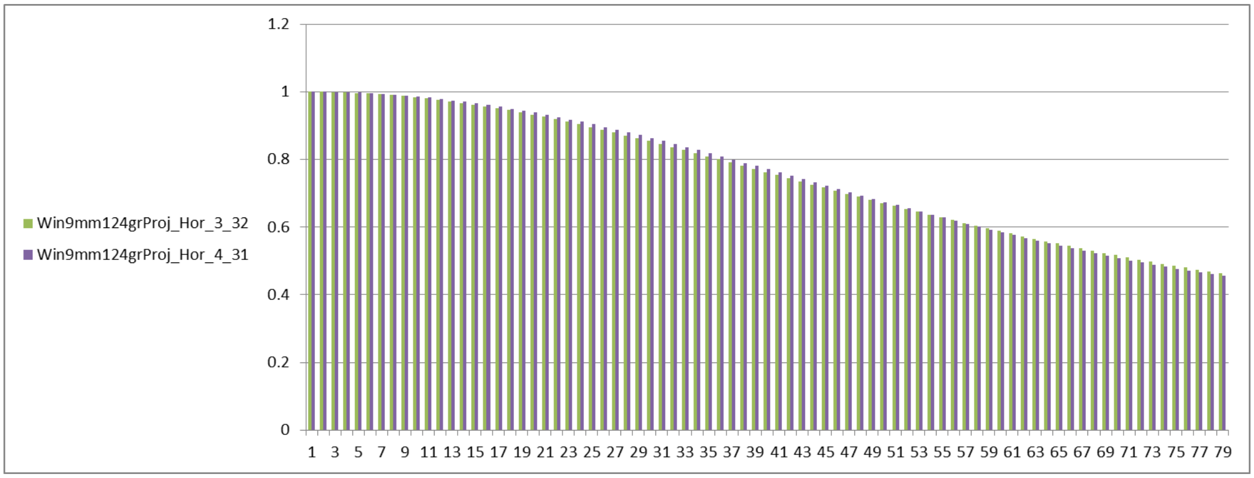



*Figure 17 Win9mm124gr Projectiles 3 and 4 Horizontal*

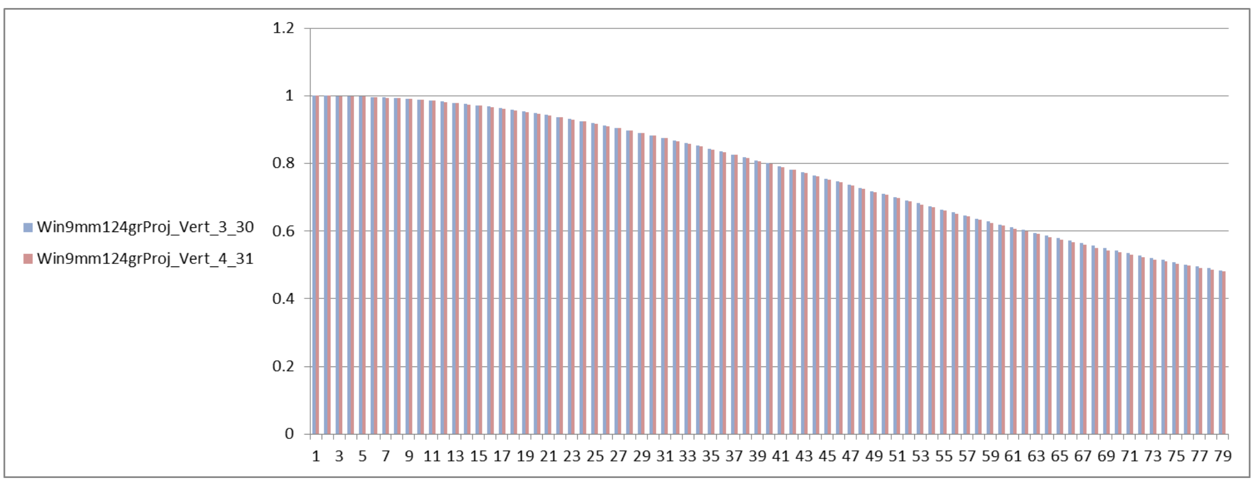



*Figure 18 Win9mm124gr Projectiles 3 and 4 Vertical*

*Figure 19* shows the physical projectile samples tested where the two on the right side are referred to as "Fired". By having the ability to examine only the bottom surface of the projectile, it is much simpler to compare deformed samples to others that are also deformed or not deformed at all.

*Figure 19 Speer Gold Dot 165 gr Samples Tested*

Figure 20 shows two fired hollow point projectiles. It is conjectured that they may have come from the same lot due to the degree to which they track each other.

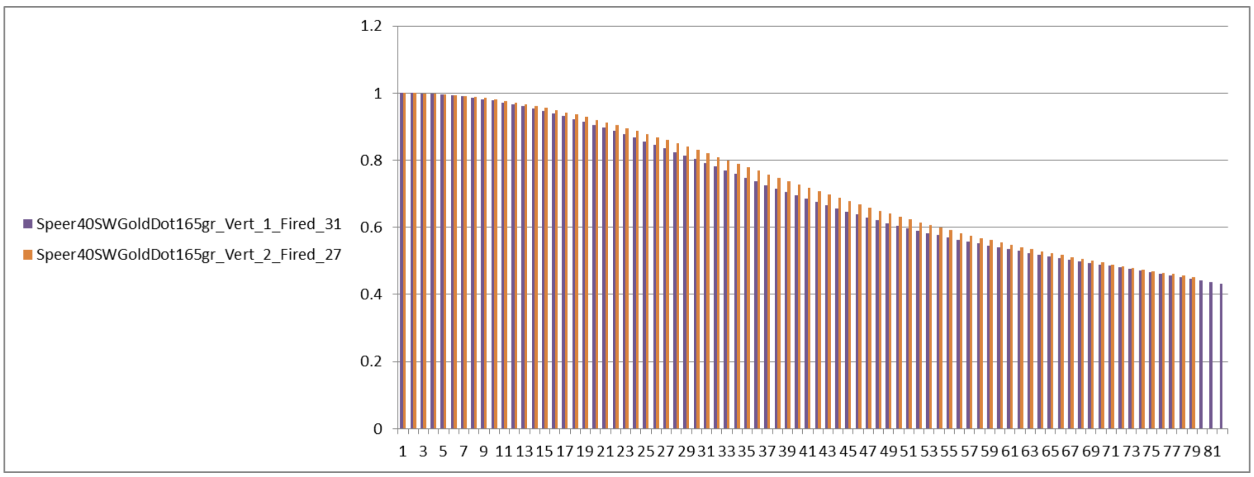



*Figure 20 Comparing Two Fired Samples of Unknown Pedigree*

It is evident that the two unfired samples shown in *Figure 21* are not from the same lot due to the great disparity between the two samples.

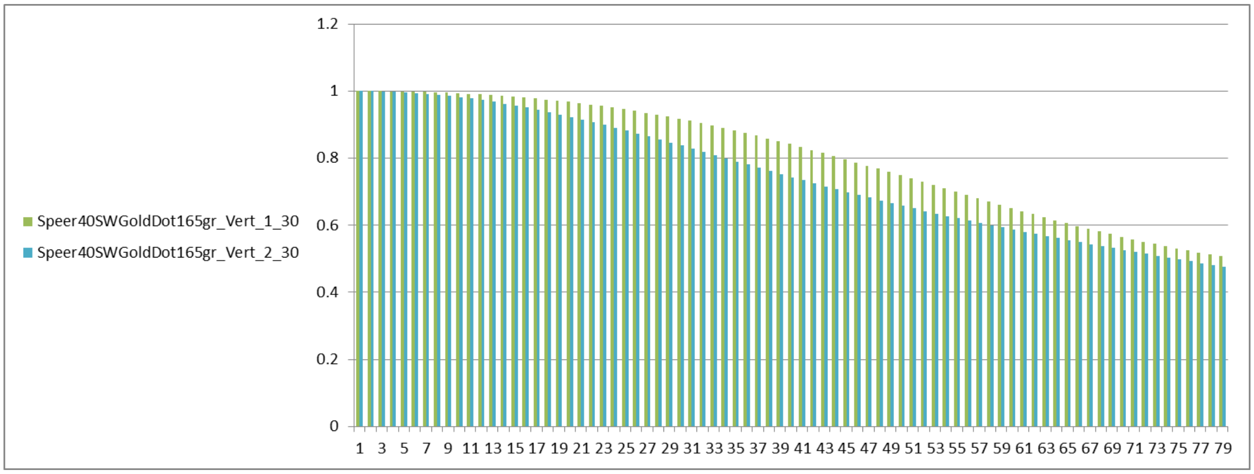



*Figure 21 Comparison of Unfired Samples*

The samples shown in *Figure 22* appear to represent a closer relationship than the two unfired samples. Depending on the criteria for matching these two samples may be declared a match.

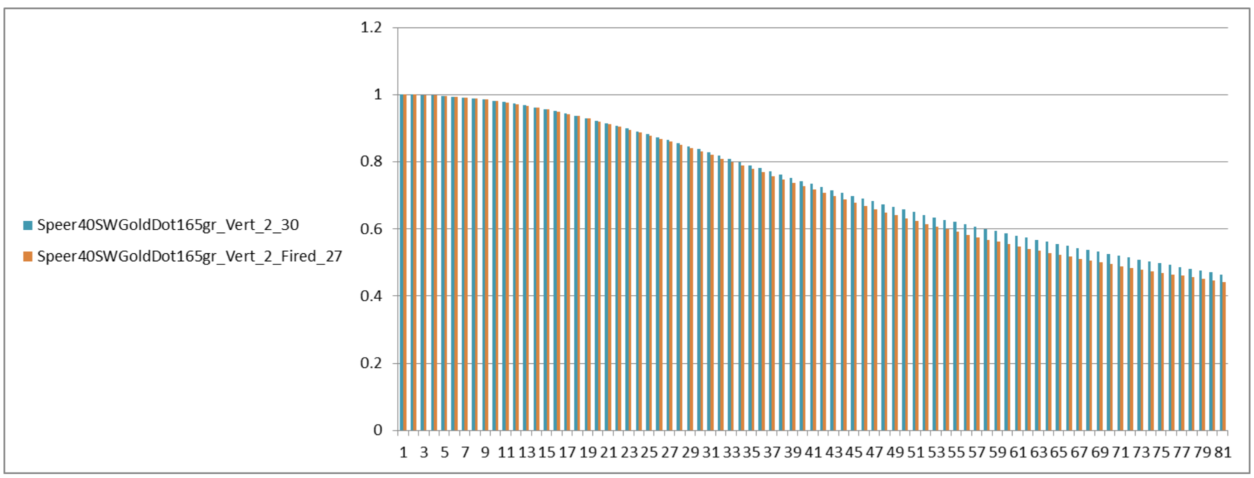



*Figure 22 Two samples where one was fired and one not fired*

Comparing the figures shown above one could surmise that the unfired sample number 2 and the fired sample number 2 are most closely related to each other among the sample space of the 4 samples.

Shown in the following set are Remington 45 ACP 230gr projectiles including 2 intact bullets. The challenge here is to measure the bullet in its assembled form. Since there is a curvature of the nose of the exposed projectile the degree of intimate contact with the sensor area for this particular fixture is limited greatly. Therefore this could introduce a degree of uncertainty in the resultant measurement. In this case, and for this case only, trends will be examined rather than perfect matching.

Since intact bullets are tested, with the existing fixture, the horizontal position only will be used for characterizing intact bullets.  The projectiles will be characterized in both the horizontal as well as the vertical position for completeness and also for comparing the two projectile samples.

*Figure 23* appears exhibit a relatively close match between the two projectiles. However, the vertical measurements in *Figure 24* seem to have less of a correlation so it appears that the two samples are closely related but that is all that can be surmised at this point.

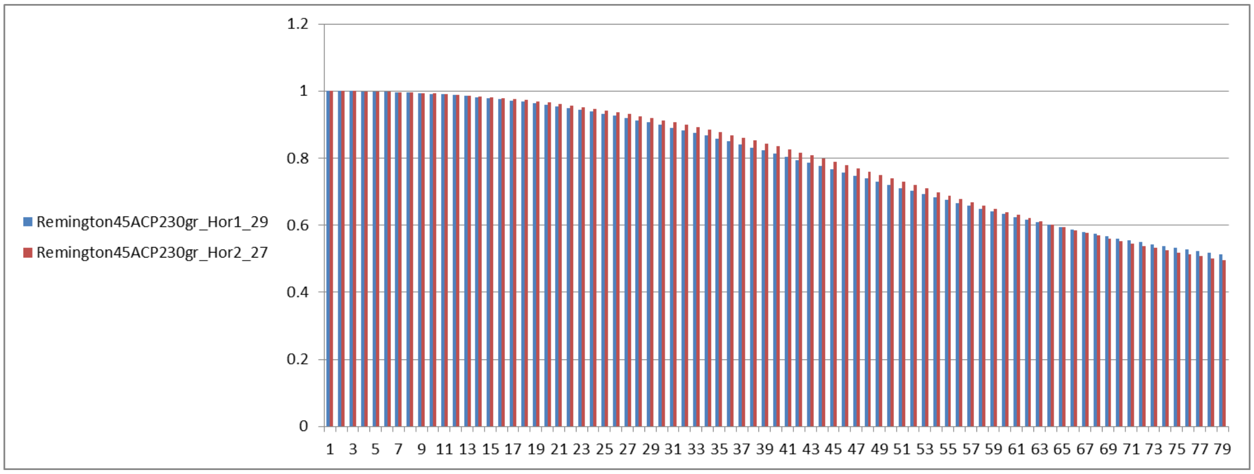



*Figure 23 Remington 45 ACP Projectiles 1 and 2 Horizontal*

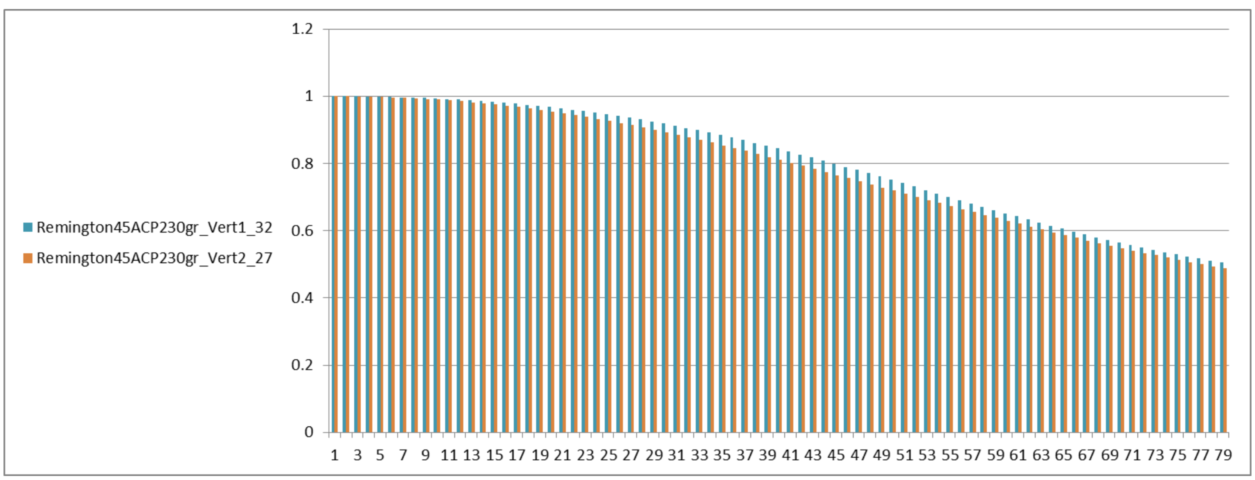



*Figure 24 Remington 45 ACP Projectiles 1&2 Vertical*

Inspecting *Figure 25* it appears that the two bullets are not closely correlated and so it is assumed that they came from different lots.

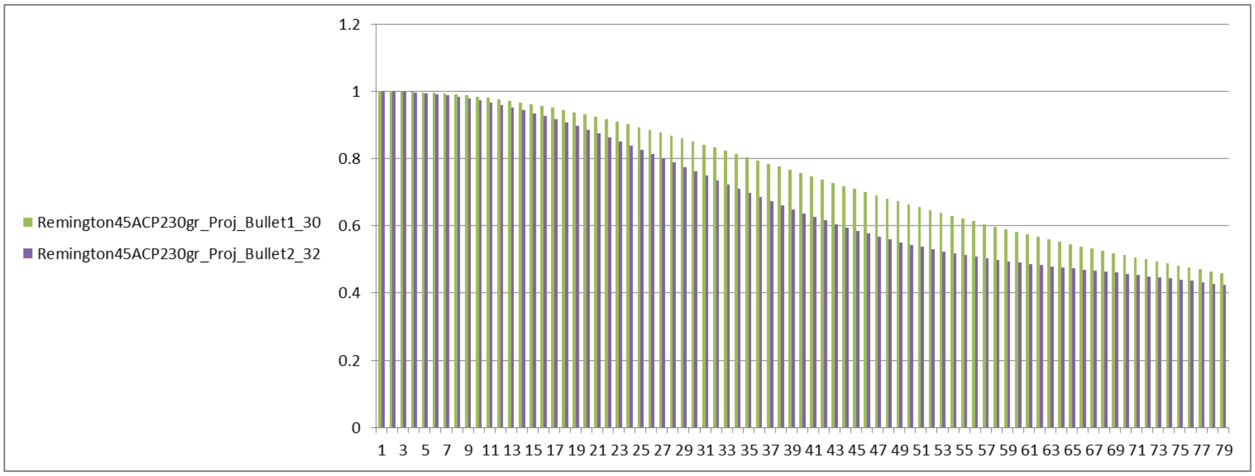



*Figure 25 Remington 45 ACP Bullets 1&2 Horizontal*

Now the task at hand is to determine whether or not there is a match between any of the individual projectiles and either of the intact bullets. Comparing projectile 1 with bullet 1, shown in *Figure 26* seems to show a reasonable trend between the two samples. However, when projectile 1 is compared with bullet 2, as shown in *Figure 27*, it appears that these two samples do not trend well.

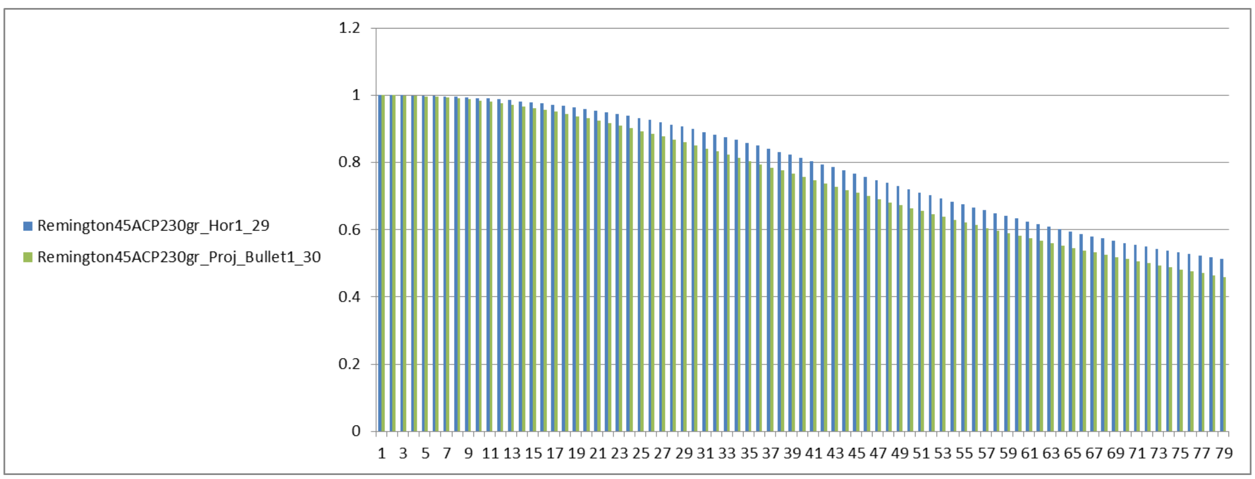



*Figure 26 Remington 45 ACP Bullet 1 & Projectile 1*

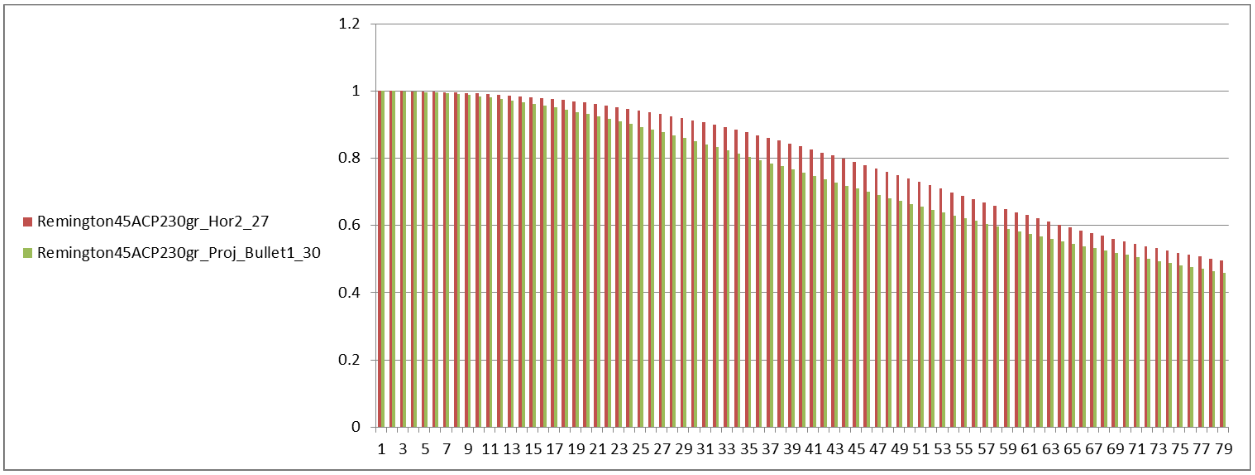



*Figure 27 Remington 45 ACP Bullet 1 & Projectile 2*

*Figure 28* appears to show no trending match between projectile 2 and bullet 2.

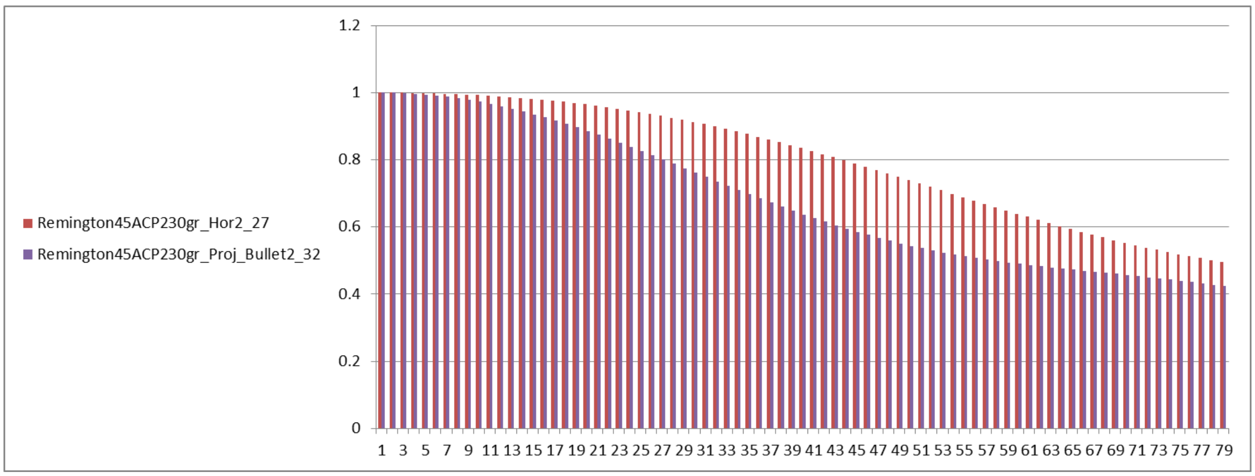



*Figure 28 Remington 45 ACP Bullet 2 & Projectile 2*

Therefore it appears that the only match is between projectile 1 and bullet 1.

## Cartridge Case Test Results:

Cartridge Cases were also compared. There are two sets of 9mm Cartridge Cases which are referred to by their respective projectile gram weights. It is understood that the Cartridge Cases are independent of projectile gram weight but this distinction was made to keep the data sets consistent. As was stated earlier, all samples were measured horizontally.

*Figure 29* and *Figure 30* show both show very close correlation between their representative Cartridge Cases. *Figure 31* is a compilation of all four Cartridge Cases and there appears to be very close correlation when compared to the samples shown in *Figure 32* which have more disparity between their Cartridge Case samples.

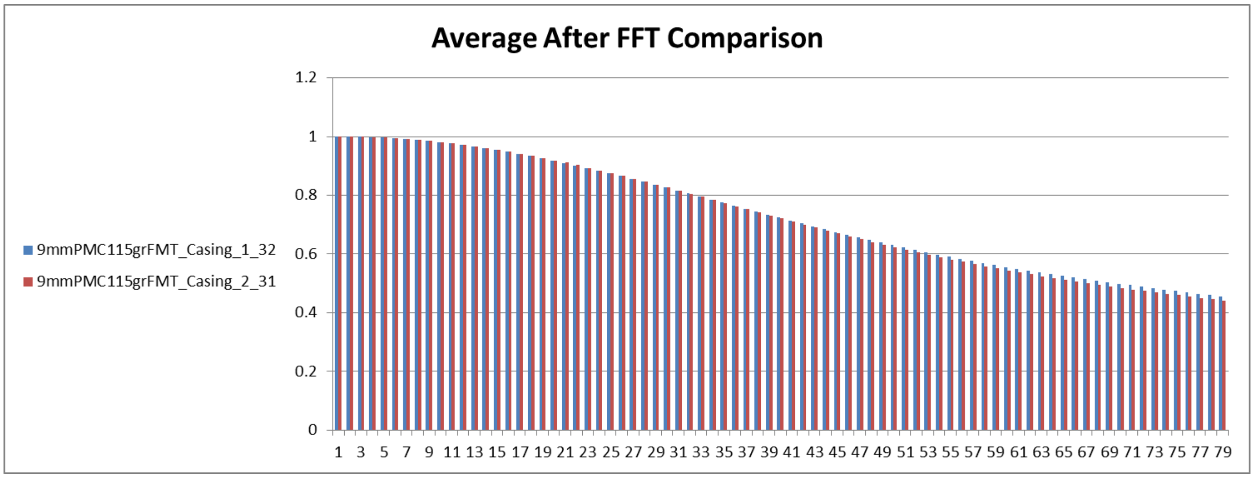



*Figure 29 9mmPMC Cartridge Cases 1 and 2*

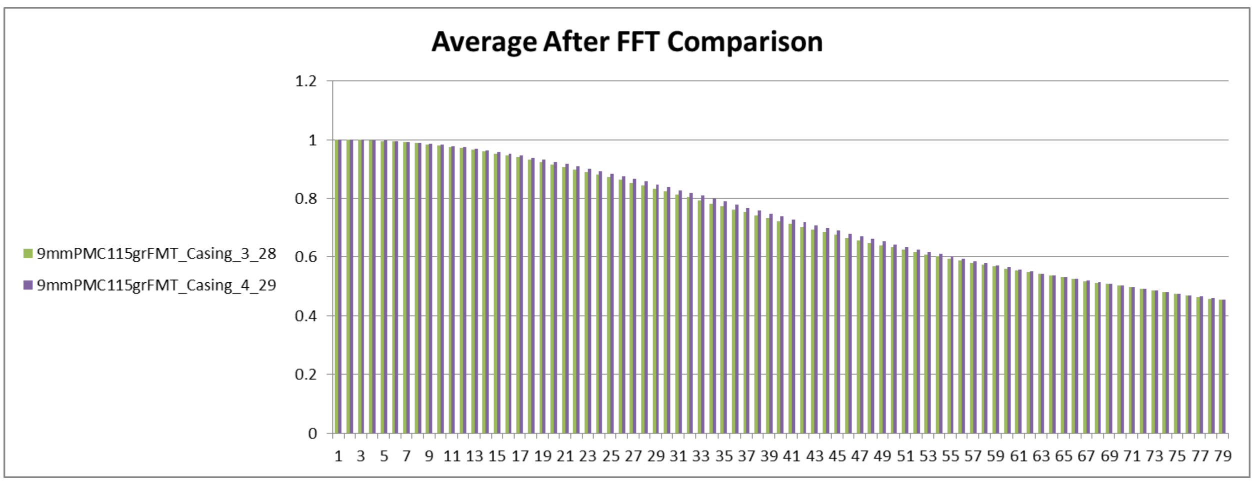



*Figure 30 9mm PMC Cartridge Cases 3 and 4*

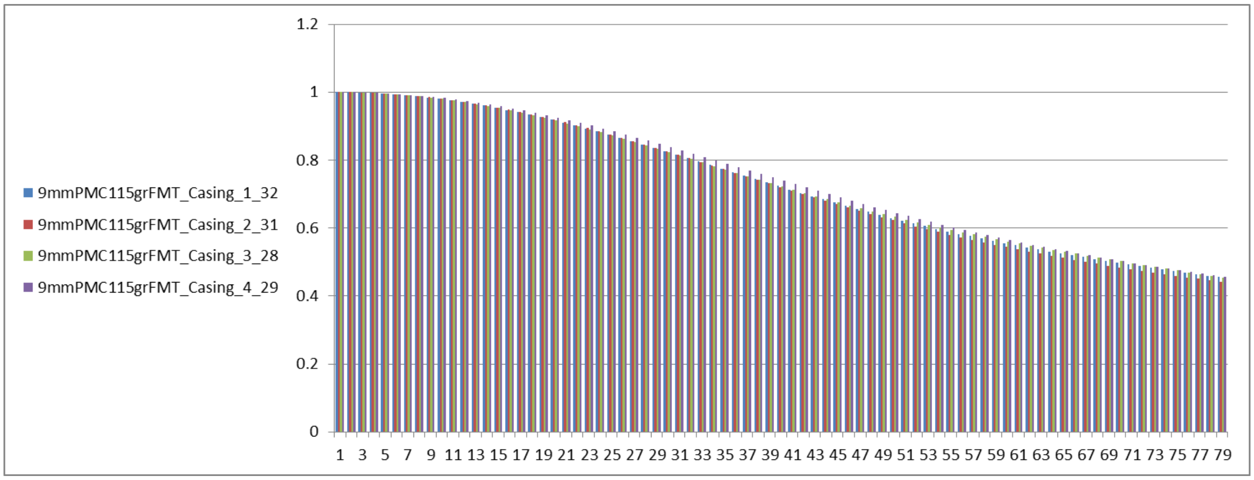



*Figure 31 Compilation of 9mm PMC Cartridge Cases*

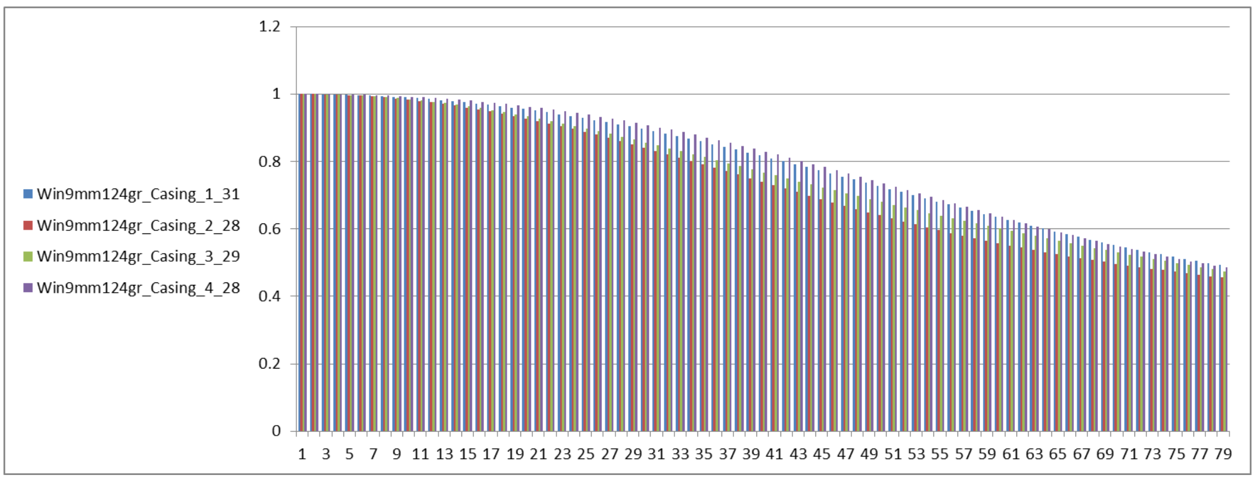



*Figure 32 Compilation of Winchester 9mm Cartridge Cases*

*Figure 33* Shows two Remington 45 ACP Cartridge Cases as well as the Cartridge Cases of two intact bullets. From the figure it is clear that there is a lot of variation in this set of samples. By inspection it appears that Cartridge Cases 1 and 2, shown in *Figure 34*, have a fair degree of agreement as to their characteristics.

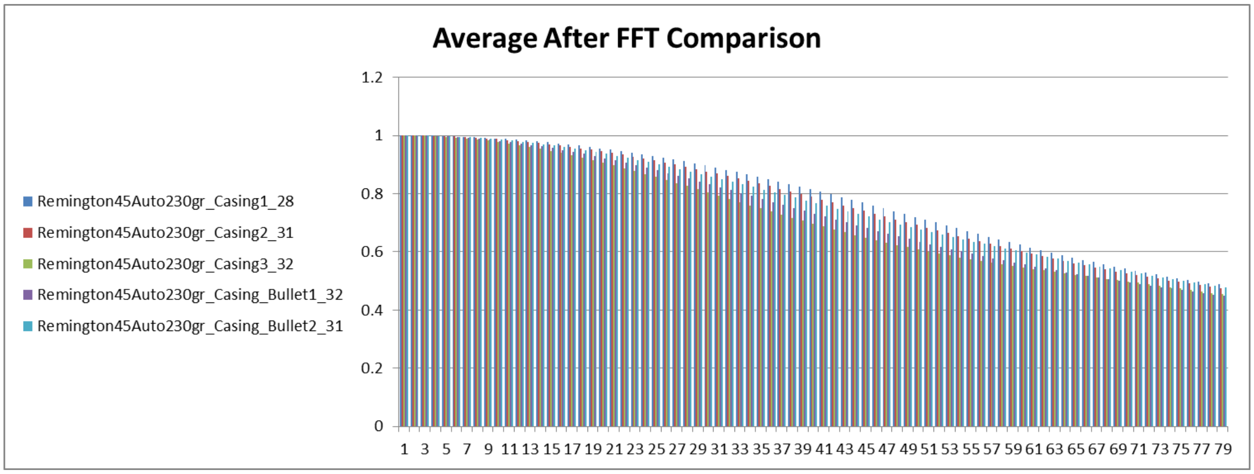



*Figure 33 Remington 45 ACP Cartridge Case Compiliation*

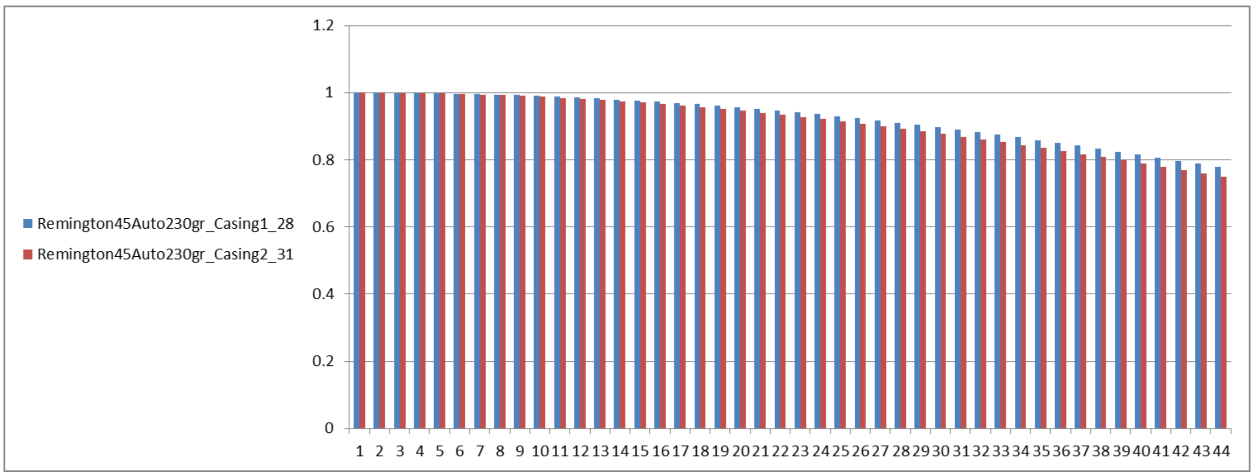



*Figure 34 Remington 45 ACP Cartridge Cases 1 and 2*

The agreement between intact bullet Cartridge Cases 1 and 2, shown in Figure 35, do not have the same degree of agreement between the two Cartridge Case characteristics or signatures.

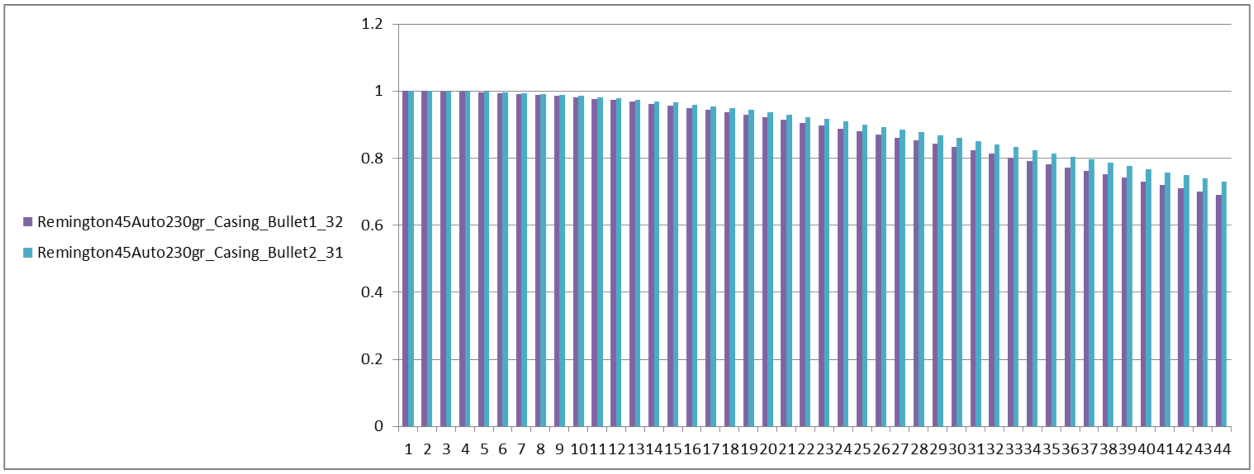



*Figure 35 Remington 45 ACP Bullet Cartridge Cases 1 and 2*

Inspection of *Figure 36* through *Figure 38* indicates that the highest level of correlation appears to be between Cartridge Case 2 and Bullet 2.

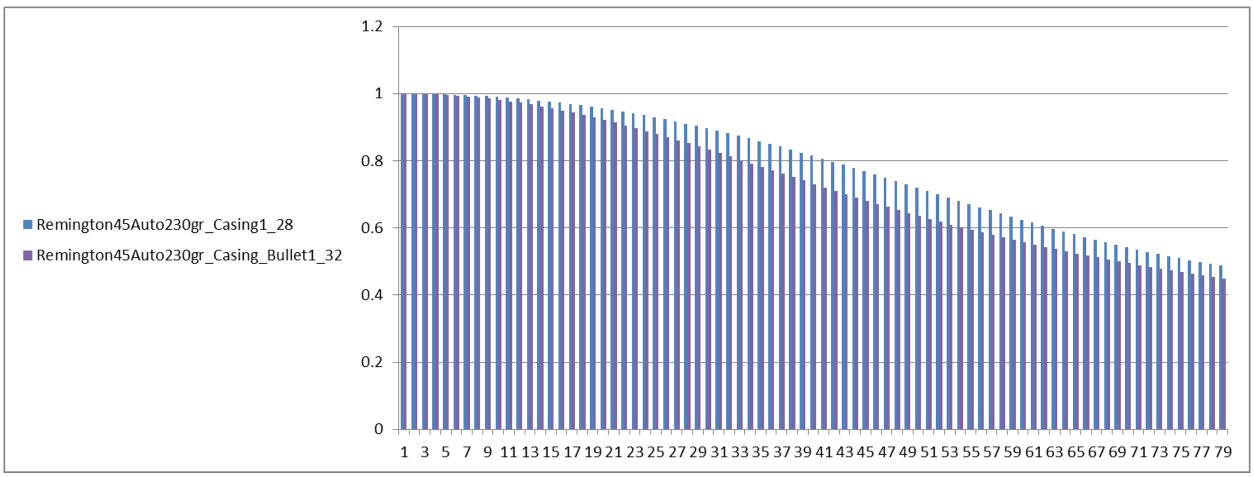



*Figure 36 Remington 45 ACP Cartridge Case 1 and Bullet 1*

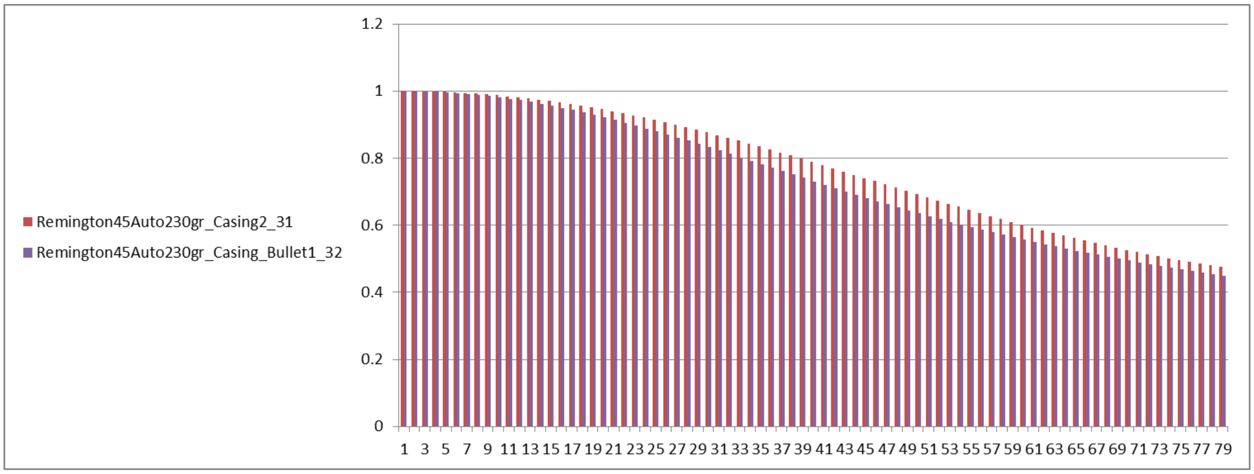



*Figure 37 Remington 45 ACP Cartridge Case 2 and Bullet 1*

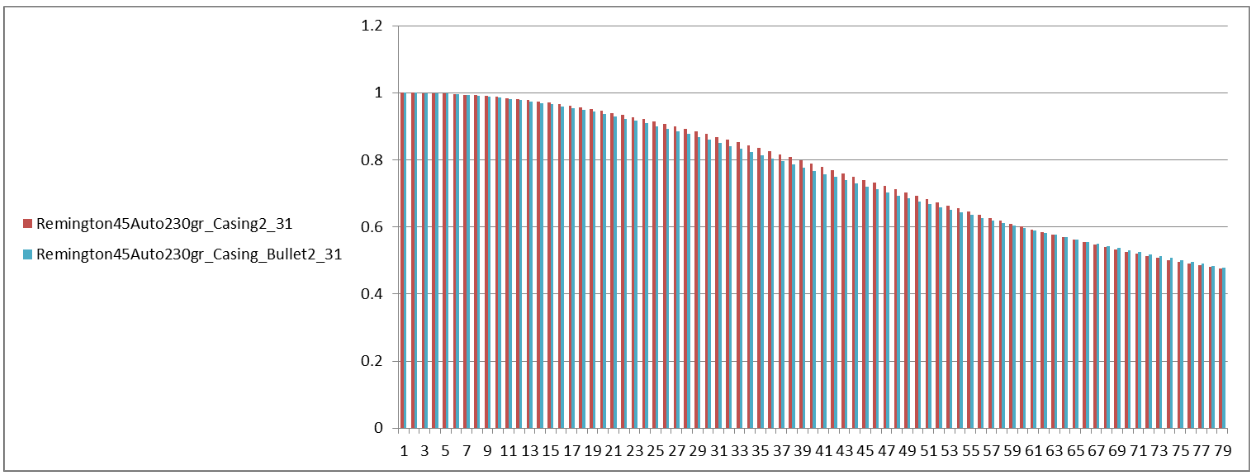



*Figure 38 Remington 45 ACP Cartridge Case 2 and Bullet 2*

Of the Speer 40 Caliber Cartridge Cases represented in Figure 39 and Figure 40 it is clear that there is closer correlation between sample Cartridge Cases 1 and 2 than with samples 3 and 4, shown in Figure 41, though not as close as the Winchester 9mm Cartridge Cases. However the best match of the remaining samples appears to be represented in Figure 40 and Figure 43.

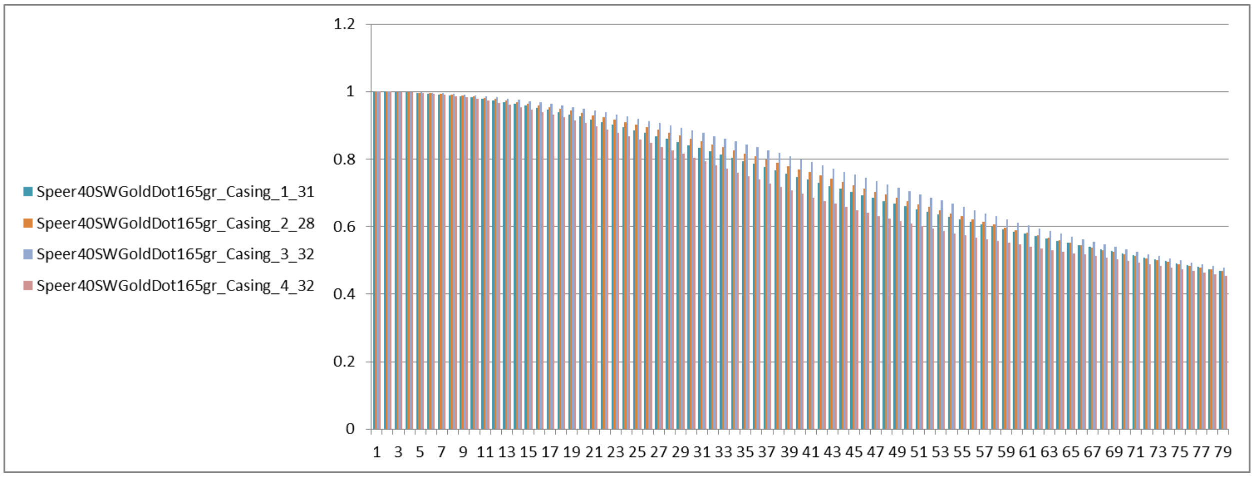



*Figure 39 Compilation of Speer 40 Caliber Cartridge Cases*

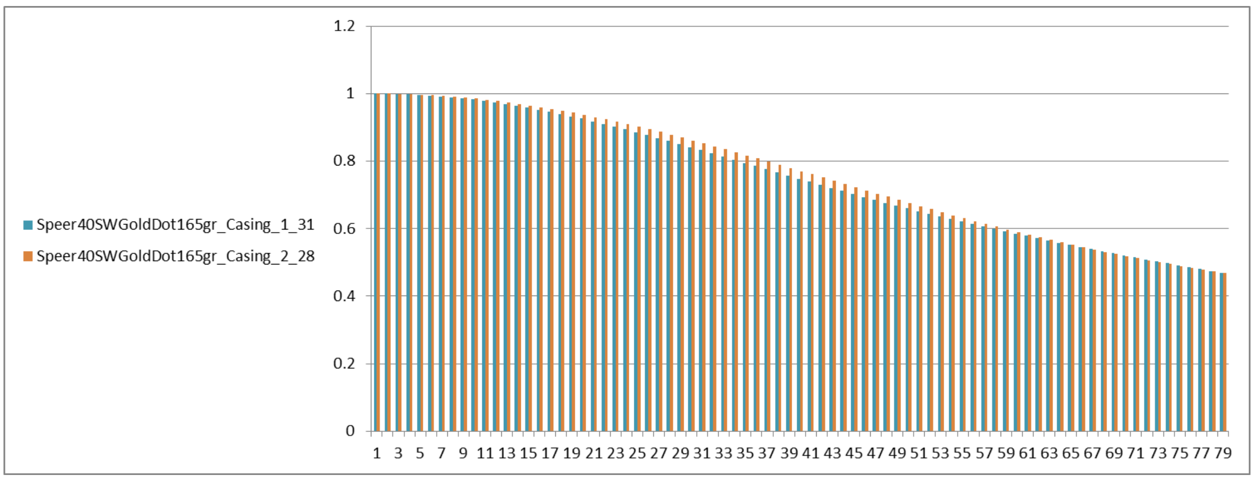



*Figure 40 Speer 40 Caliber Cartridge Cases 1 and 2*

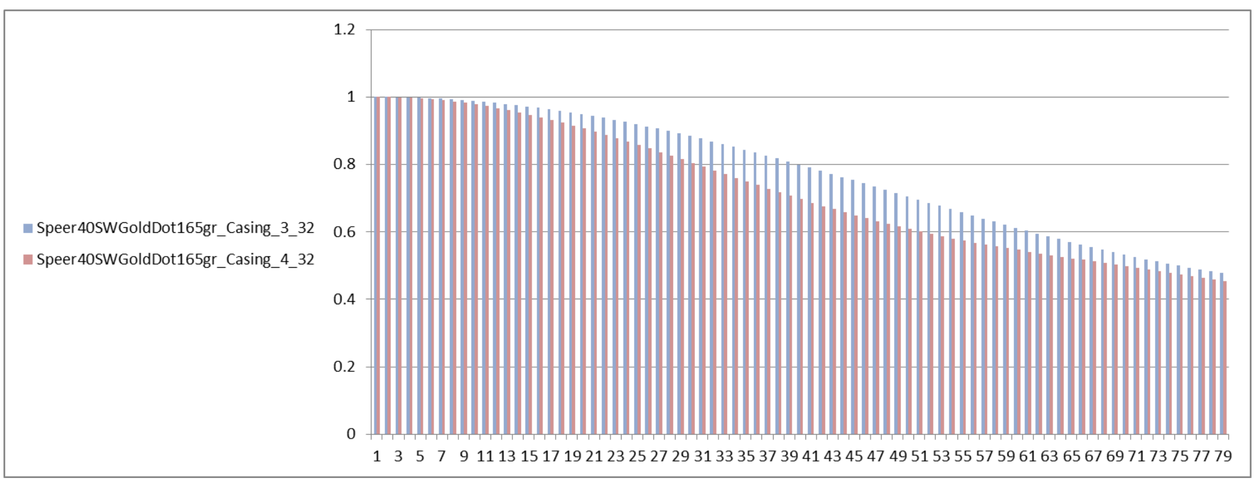



*Figure 41 Speer 40 Caliber Cartridge Cases 3 and 4*

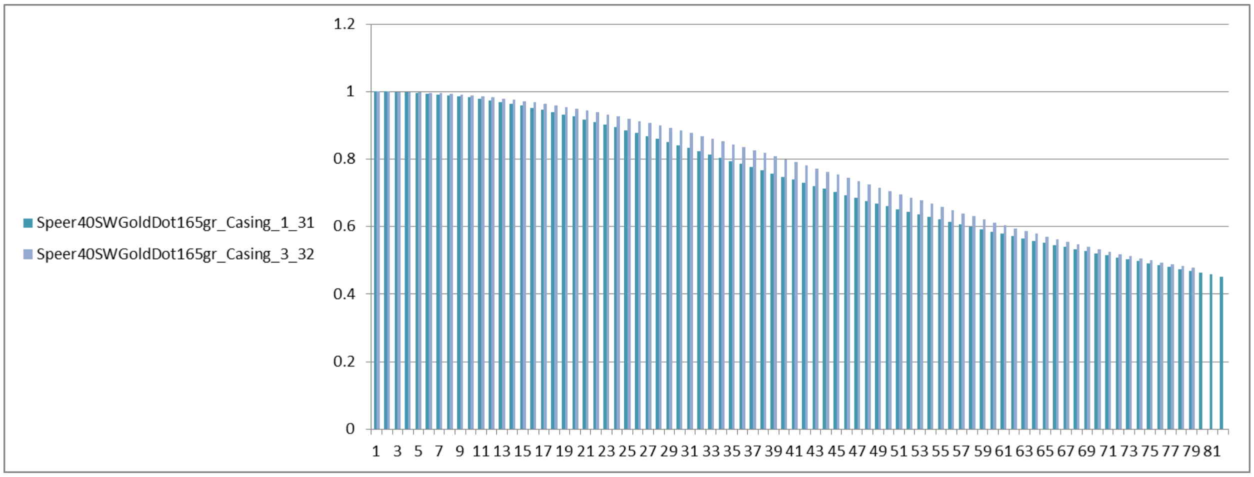



*Figure 42 Speer 40 Caliber Cartridge Cases 1 and 3*

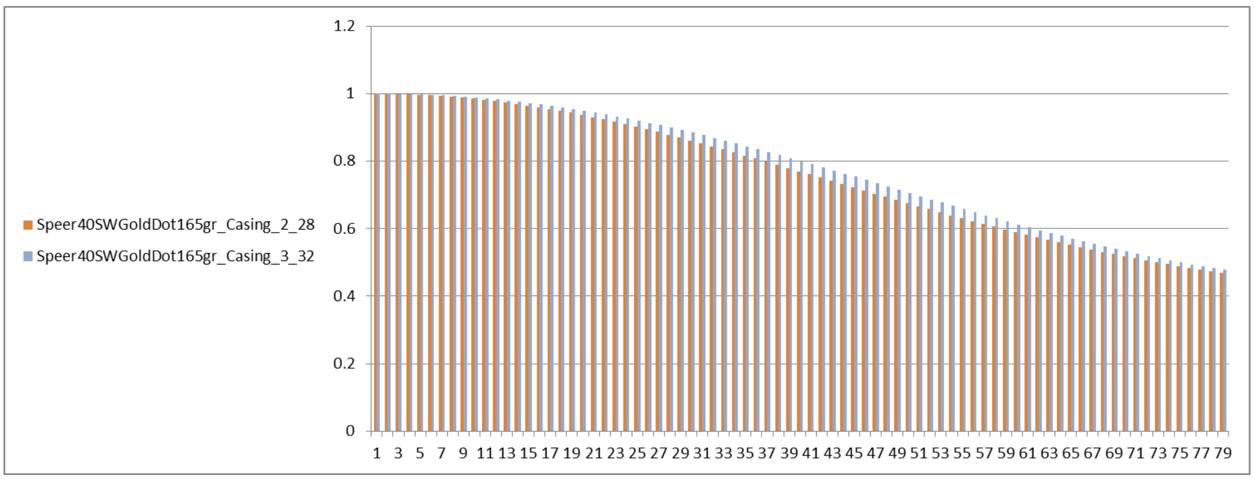



*Figure 43 Speer 40 Caliber Cartridge Cases 2 and 3*

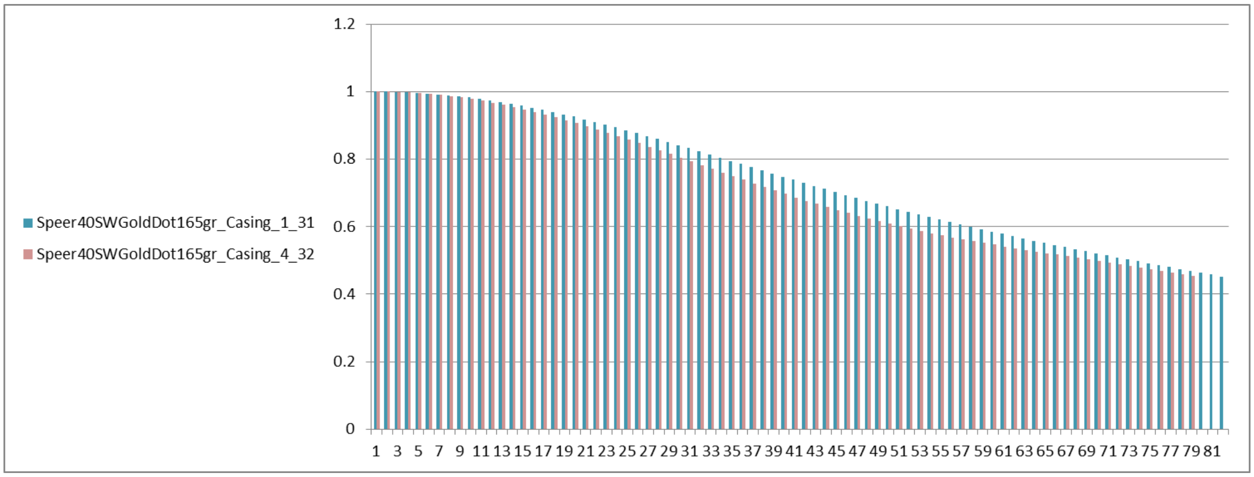



*Figure 44 Speer 40 Caliber Cartridge Cases 1 and 4*

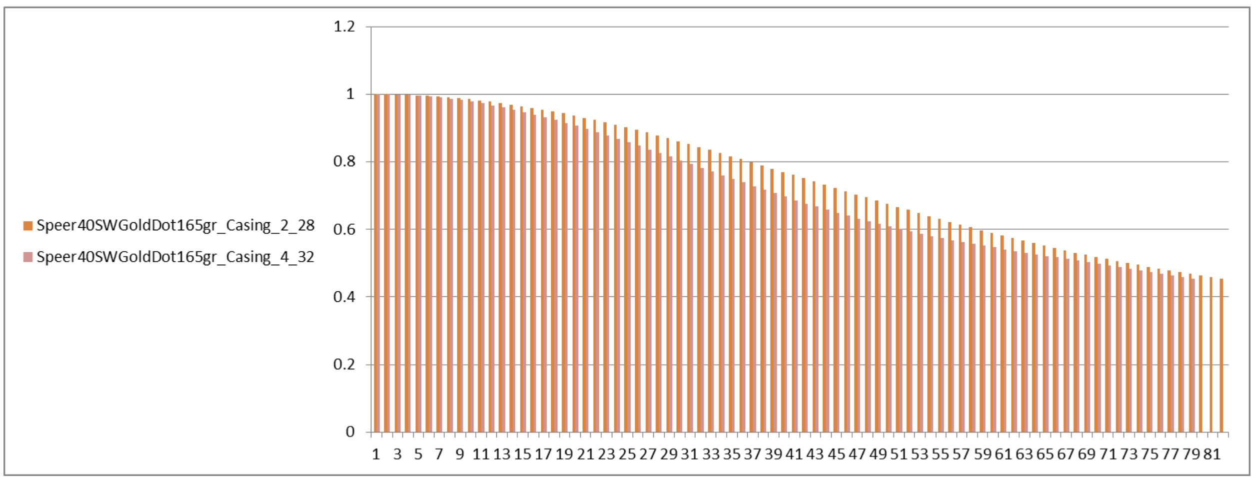



*Figure 45 Speer 40 Caliber Cartridge Cases 2 and 4*

## Conclusion

Based on the measurements presented with a proof of concept measuring system it appears that we are able to develop accost effective bullet characterization system for testing of projectiles and Cartridge Cases.

Comparison to intact bullets would initially, and optimally, entail disassembling the bullet into its component parts and comparing these parts to discrete samples. Where this option is not available then, further development of the jig design will allow optimal results to be readily accomplished.

Repeatability from test fixture to test fixture has preliminarily shown to given the same results as to matching samples. How exactly they match from one fixture measurement to different fixture's measurement has not been critically demonstrated as yet, and is subject to further testing.

It should be noted that only a portion of the data available for analysis has been shown. Only the first 80 or so samples have been presented here while there are a total of 4096 data points available for comparison. The reason that more data points were not presented is mainly due to the fact that an 8 bit

Analog to Digital Converter (ADC) was used for digitizing the captured waveform.  A planned increase in the resolution of the ADC will allow for more confidence in lower amplitude signal components.

The technical risk involved in developing this proof of concept to a deliverable is very low.  The major development expenses will be in hardware refinements, software development so as to allow for an initial User Interface and an API for agencies to develop onto/extract data from, and extensive sample testing.

Tischauer Technical Laboratories is currently seeking partners and agencies to fund and assist in bringing this product to market, through Huckworthy LLC – our commercial partner.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I cannot thank enough my friend the late Alfiero Balzano who introduced me to Rocky Edwards so as to pursue this line of investigation.

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John Poksheva has advised on analytics and provided the FFT resolution suggestion that the data presented here is reliant upon.

I would also like to thank Joshua Tichauer and Douglas Hirsch for developing the code for the automation of the FFT analysis and for keeping the project on track, respectively.

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1. Solomon, John, Washington Post November 18, 2007