Hamline University
Department of Criminal Justice and Forensic Science

CJFS 3450: Forensic Firearm and Toolmarks Examination

Lab Manual

Version 2.0

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HAMLINE
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Table of Contents

Laboratory Rules and Regulations

In this course you will handle firearms, live ammunition, and propellants. When instructed, students will be required to wear provided eye/ear protection. You will only handle these materials under direct supervision of the instructor. If at any point, you are uncertain, please ask the instructor for assistance. Please review the core safety rules for firearm operation below:

Rules and Regulations (adopted from the NRA Gun Safety Rules)

1. **ALWAYS keep any firearms pointed in a safe direction**
   This is the primary rule of gun safety. A safe direction means that the gun is pointed so that even if it were to go off it would not cause injury or damage. The key to this rule is to control where the muzzle or front end of the barrel is pointed at all times. Common sense dictates the safest direction, depending on different circumstances.

2. **ALWAYS keep your finger off the trigger until ready to shoot**
   When holding a gun, rest your finger on the trigger guard or along the side of the gun. Until you are actually ready to fire, do not touch the trigger. Only do so when instructed.

3. **ALWAYS keep the gun unloaded until ready to use**
   Whenever you pick up a gun, immediately engage the safety device if possible, and, if the gun has a magazine, remove it before opening the action and looking into the chamber(s) which should be clear of ammunition. If you do not know how to open the action or inspect the chamber(s), leave the gun alone and get help from someone who does.

4. **ALWAYS know how to use the gun safely**
   Before handling a gun, learn how it operates. Know its basic parts, how to safely open and close the action and remove any ammunition from the gun or magazine. Remember, a gun's mechanical safety device is never foolproof. Nothing can ever replace safe gun handling.

5. **ALL participants are responsible for safety**

Note: Be aware that certain types of guns and many shooting activities require additional safety precautions.

Assignment 1: Firearm Mechanisms

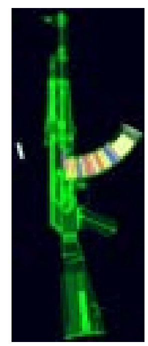
Objective of Assignment

Through the disassembly and reassembly of firearms, an understanding of the interrelationship between the mechanisms within the firearm will be learned. Understanding how the parts work in combination is important to determine how the firearm operates, creates the markings observed during forensic analysis, and whether a firearm has been purposefully altered by a user, or if the wear in the firearm is due to normal use.

Instructions

Using the World of Guns software you will examine, analyze, and describe the assigned firearms. Critical thinking and a desire to apply what is learn to figure out how an unknown firearm works will be the object of this lab exercise.

Manufacturer	Model
Browning Arms Company	Browning Auto-5
Colt's Manufacturing Company	M16 A1
Colt's Manufacturing Company	Colt M1911A1
Glock	Glock 19
Izevsk Machinebuilding Plant	AK-47
Magnum Research, Inc.	Desert Eagle .44
Marlin Firearms Company	Marlin 336 Deluxe
Remington Arms Company	Remington 700



Additionally, you can complete the following firearms for extra credit (2 pts each).

Manufacturer	Model
Colt's Manufacturing Company	Colt Single Action Army
Fabbrica d'Armi Pietro Beretta	Beretta 92FS
Izevsk Machinebuilding Plant	Tokarev pistol
O.F. Mossberg & Sons	Mossberg 500 SPX
Springfield Armory	Springfield XDm
Walther Arms	Walther PP

Report Requirement for the Assignment

Include a screenshot (see Figure 1) of the message at the completion of disassembly. You will also have to include a paragraph description of the firearm and the mechanism by which it operates.

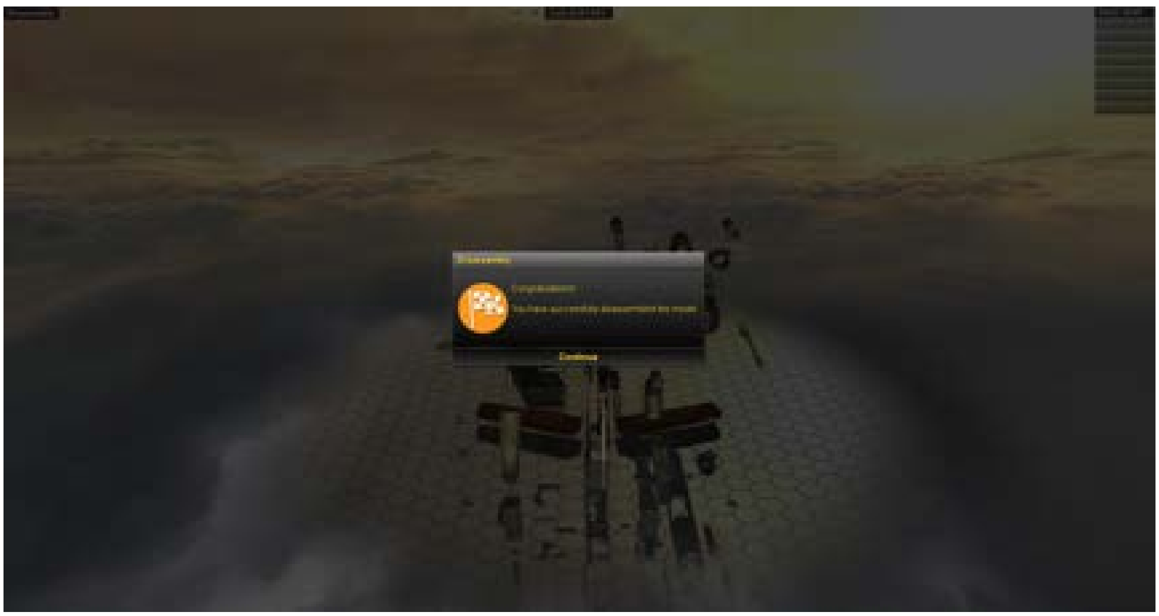


Fig. 1. Example screenshot from the completion of the Colt 1911 disassembly. Submit the screenshots for credit.

Assignment 2: Detailed Firearms History

Objective of Assignment

The purpose of this assignment is to undertake a detailed inquiry into the history, mechanism, and operation of a firearm of your choosing.

Instructions

Prepare a one page paper which critically discusses and addresses the following:

1. Discuss how the firearm was developed and other firearms or events which led to the development of the firearm
2. Explain the mechanism by which the firearm operates in detail
3. Outline any notable usage throughout history and in criminal activity
4. Articulate any challenges such a firearm would place on a firearms examiner

Assignment 3: Admissibility of Firearms Examination

Objective of Assignment

The purpose of this assignment is to evaluate your critical thinking regarding issues in forensic science, specifically the admissibility of firearms examination testimony.

Instructions

Prepare a one page paper which critically discusses and addresses the following:

1. Explain challenges to the scientific basis and reliability of firearms examination
2. Identify legal precedent/rulings on the admissibility of scientific evidence and expert testimony related directly to firearms examination
3. Define and explain any potential errors within the methodology
4. Deliver your opinion *with justification* on whether firearms examination should be admissible

Paper Format

Please use the following formatting for your paper:

- Include a title page and bibliography. Note: These are not included in your page count
- *Font:* Times New Roman, 12 pt., single space
- *References:* American Chemistry Society (ACS) style (in text and bibliography)
- *Graphics:* If you use figures to reinforce your argument, ensure that they are appropriately cited, and include appropriate numbering and captions. *Note:* figures do not count toward your page count
- *Tables:* If used, include appropriate numbering and captions. Note: tables do not count toward your page count
- For each element of the prompt, demarcate the location it is addressed in your paper with a footnote

Lab 1: Examination of Ammunition and Components

Objective of Lab Exercise

Become familiar with ammunition as evidence and the different components of pistol, rifle, and shotgun ammunition. Learn how to properly measure different cartridges and to become familiar with how to classify the different cartridges based on the features measured. Observe the different components of ammunition, types of bullets, and how to determine the pellet size based strictly on the diameter of the pellets.

Lab Instructions

This lab is comprised of four different sections: *(1)* examination of cartridges, *(2)* classification of bullets, *(3)* analysis of shot/shotshell pellets, and *(4)* reconstruction considerations of ammunition.

Section I: Examination of Cartridges

You will be provided with a set of different cartridges, an image of the cartridge case set provide is given in Figure 2.

Fig. 2. Images of the cartridge case set provided for the lab. The set includes a 9mm Luger, 40 S&W, 45 ACP, 38 SPL, .223 Rem, .308 Win (left to right).

You will confirm the identity of ***at least TWO*** of the provided cartridges through measurement of the cartridge and comparison to the Sporting Arms and Ammunition Manufacturers' Institute, Inc. (SAAMI) standards and specifications. Measure the following features on different cartridges provided using digital calipers:

1. Outer neck diameter
2. Base diameter
3. Rim thickness
4. Cartridge case length
5. Cartridge length
6. Shoulder diameter

Figure 3 is provided to clarify and illustrate where to take the measurements on a given cartridge case. The standard sizes for ammunition are provided on the SAAMI technical specification webpage and the specific cartridges are available in Figures 5 and 4 [1].

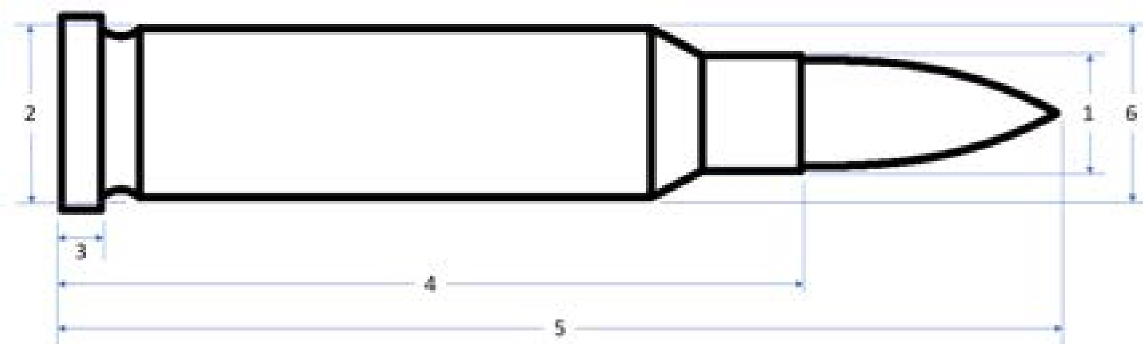


Fig. 3. Measurement positions shown on a bottleneck cartridge. The numbered list above corresponds to this figure.

Record your measurements of the physical cartridge with SAAMI specifications in your notebook to document your activities.

[1]Figures adapted from: *SAAMI Z299.3 and Z299.4 Voluntary Performance Standards.* 2015.

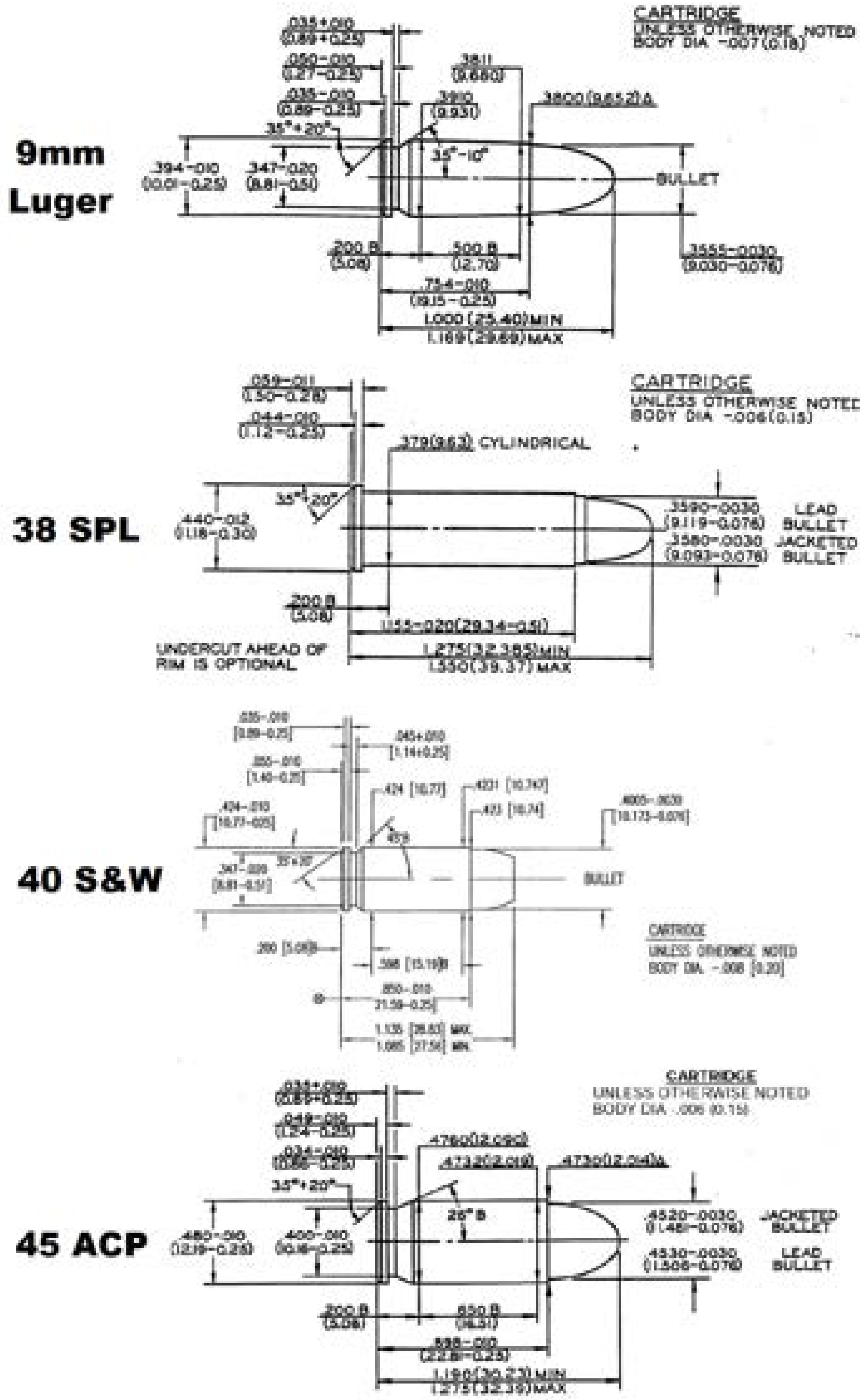


Fig. 4. Standard technical measurements of the provided handgun cartridges.

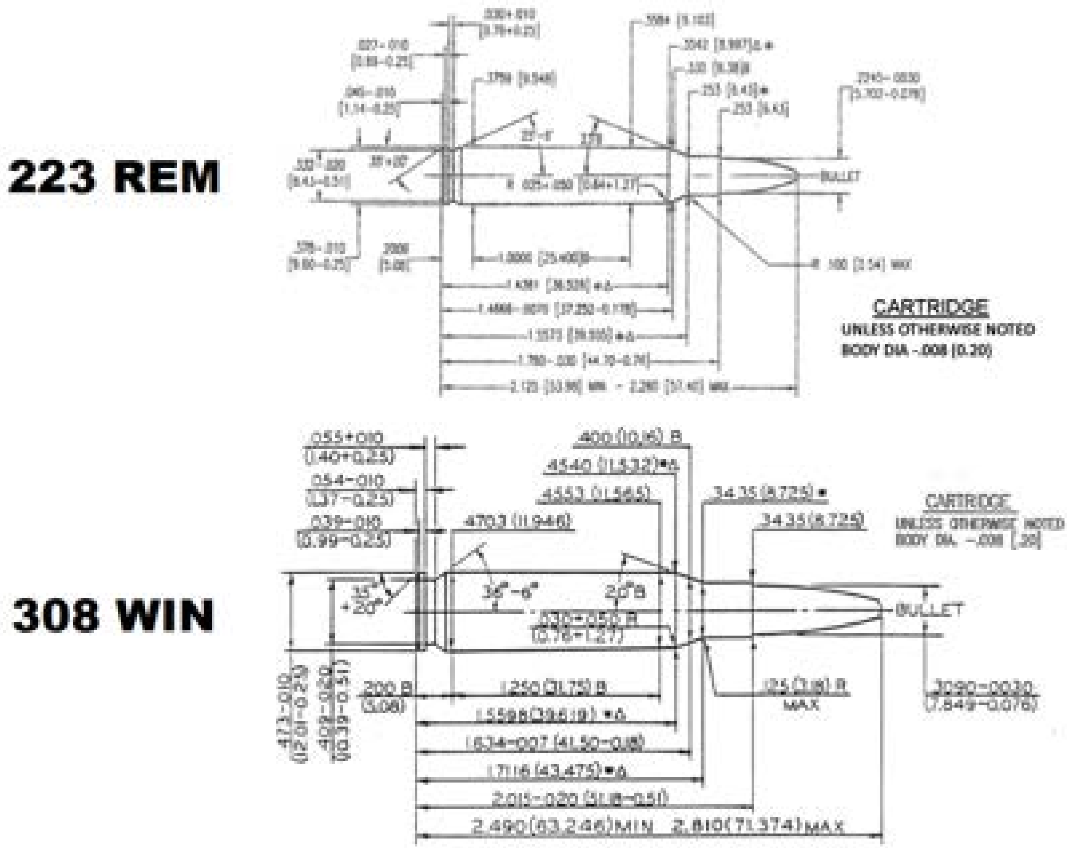


Fig. 5. Standard technical measurements of the provided rifle cartridges.

Section II: Classification of Bullets

Perform physical analysis for the different bullets provided. Include the dimensions and weight of the bullets using the digital calipers and scales. Units of measurement should be consistent and weight should be reported in grains. Provide a sketch of each bullet in your notebook, any notes of your observations, and use the textbook and outside resources to determine the proper nomenclature for the different bullet types. Examples of bullet types are provided in Figure 6 [2].

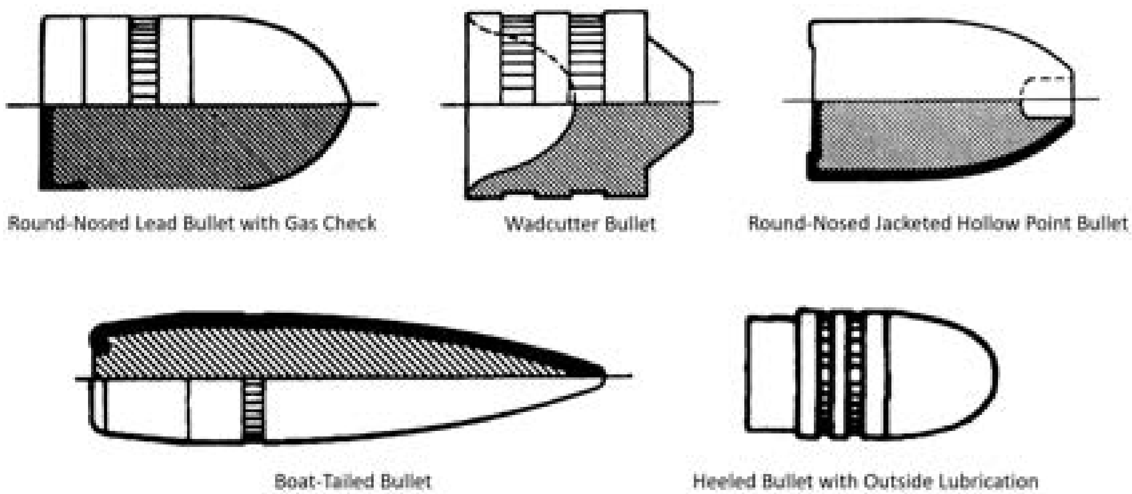


Fig. 6. Illustration of different bullet types.

Section III: Analysis of Shotshells

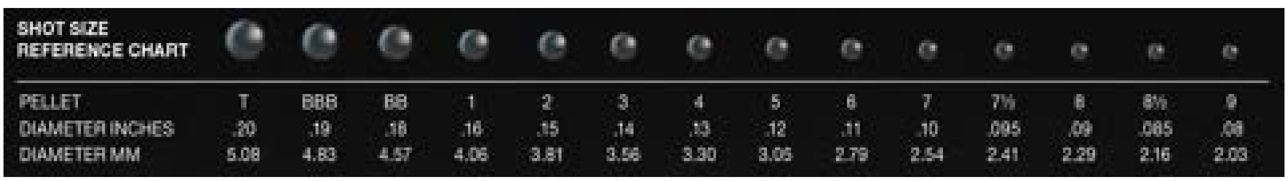
Perform physical examination of the deconstructed shotshells provided. Take observations and describe the difference between pistol/rifle cartridges and shotshells.

Next, examine the provided shot pellets and record observations about the different types. An image of the provided shot pellet set is given in Figure 7. At minimum, record the type of shot and diameter of each pellet type. For the diameter, measure at least 5 pellets and report the mean for the sample.

The measurements that you take of the different shot should be compared to the known values in Figure 8 and the known buckshot measurements provided in Figure 9 [3]. Use the exercise as a calibration of your measurement abilities so that you can identify the questioned sample using the measurement reference charts provided.

[2]Figure adapted from: *Forensic Ballistics in Court: Interpretation and Presentation of Firearms Evidence*, Brian J. Heard. 2013, John Wiley & Sons, Ltd.
[3]Figures adapted from: *Shotshell Science*, Federal Premium Ammunition. 2019.

Fig. 7. Illustration of different shot pellets.



SHOT SIZE REFERENCE CHART

PELLET	T	BBB	BB	1	2	3	4	5	6	7	7½	8	8½	9
DIAMETER INCHES	.20	.19	.18	.16	.15	.14	.13	.12	.11	.10	.095	.09	.085	.08
DIAMETER MM	5.08	4.83	4.57	4.06	3.81	3.56	3.30	3.05	2.79	2.54	2.41	2.29	2.16	2.03

Fig. 8. Shot Pellet reference chart with sizes.

BUCKSHOT SIZES

PELLET	DIA. INCHES	DIA. MM
No. 000	.36	9.14
No. 00	.33	8.38
No. 0	.32	8.13
No. 1	.30	7.62
No. 2	.27	6.86
No. 3	.25	6.35
No. 4	.24	6.10

Fig. 9. Buckshot reference chart with sizes.

Section IV: Reconstruction Considerations of Ammunition

Use tape to seal the shotgun wad cup and fill until level with 00 Buckshot. The purpose of this exercise is to determine the number of projectiles that would be present on a scene given this ammunition is used. Such an exercise can also be completed in reverse; where the diameter in combination with the number of projectiles/shot can be used to reconstruct the ammunition used. Data for common shotshell loads are given in Tables **??** and 1. If time permits, complete this exercise with different size shot. Use your shot weight measurements to determine the approximate number of shot that are in the load. Given these data, use the tables to infer the optimal shot size for each of the provided wads.

Extra Credit Exercise

In supplement to this exercise, you can demonstrate the calculation of gauge (typical measurement of shotguns) to bore diameter (caliber). An n-gauge diameter means that a ball of lead (density 11.34 g/cm^3 or 0.4097 lb/in^3) with that diameter has a mass equal to $1/n$ pounds, that is, n such lead balls could be cast from a pound weight of lead. Therefore, an n-gauge shotgun or n-bore rifle has a bore diameter (in inches) of approximately:

$$\begin{aligned}
&M = V \times \rho \\
&M = \tfrac{\pi}{6} \times D^3 \times \rho \\
&\text{Gauge} = \tfrac{\text{Ball}}{\text{lb}} = \tfrac{1}{\text{lb/Ball}} = \tfrac{1}{M} \therefore \\
&\text{Gauge} = \tfrac{6}{\pi D^3 \rho} \\
&\text{Gauge} = \tfrac{6}{\pi \times D^3 \times 0.4097} \\
&\text{Gauge} = \tfrac{4.658}{D^3}
\end{aligned} \tag{1}$$

where: M is mass, V is volume, ρ is density, $\frac{\pi}{6} \times D^3$ is the volume of a sphere, and the density of lead is 0.4097 lb/in^3.

To receive credit, please complete the following table in your notebook:

Gauge	**Bore Diameter (in)**
	0.775
12	
	0.663
67.62	

Notebook Requirement for the Lab

For this lab, you will have to annotate the procedures as you complete the lab. Provide any observations you draw as you complete the lab. Make sure to include the following for each respective section:

Section I Sketch of the physical cartridge with labeled measurements. Include the SAAMI measurements used to confirm the cartridge.

Section II Notes and sketches of the different bullets. Include a discussion of the characteristics asked for in the instructions.

Section III Record of the type of shot, diameter of each pellet type, and the identification of the unknown sample.

Section IV Notes and observations asked for in the instructions.

Extra Credit Completed table of gauge and caliber.

Finally, the formal completion should include an overall reflection of the exercise.

Table 1. Average Pellet Count – Steel Shot

Payload Weight										
Shot Size	**3/4 (21.25)**	**7/8 (24.81)**	**15/16 (26.58)**	**1 (28.35)**	**1 1/8 (31.89)**	**1 1/4 (35.44)**	**1 3/8 (39.98)**	**1 1/2 (42.52)**	**1 9/16 (44.30)**	**1 5/8 (46.06)**
7	316	-	395	422	475	527	580	633	659	685
6	236	-	295	315	354	394	433	472	492	512
5	182	-	228	243	273	304	334	364	380	395
4	144	168	180	192	216	240	264	288	300	312
3	118	136	143	158	178	197	217	237	247	257
2	94	-	117	125	141	156	172	187	195	203
1	77	-	97	103	116	129	142	154	161	167
BB	54	-	67	72	81	90	99	108	112	117
BBB	46	-	58	62	70	77	85	93	97	101
T	39	-	49	52	58	65	71	78	81	84
Weight of Shot in Ounces (Grams)										

Table 2. Average Pellet Count – Lead Shot

Payload Weight														
Shot Size	**1/2 (14.17)**	**11/16 (19.49)**	**3/4 (21.25)**	**7/8 (24.80)**	**1 (28.35)**	**1 1/8 (31.89)**	**1 1/4 (35.44)**	**1 5/16 (37.21)**	**1 3/8 (39.98)**	**1 1/2 (42.52)**	**1 5/8 (46.06)**	**1 7/8 (53.15)**	**2 (56.70)**	**2 1/4 (63.78)**
9	292	402	439	512	585	658	731	767	804	877	951	1097	1170	1316
8-1/2	249	342	373	435	497	559	621	652	683	745	808	932	994	1118
8	205	282	307	359	410	461	512	538	564	615	666	769	820	922
7-1/2	175	241	262	306	350	394	437	459	481	525	569	656	700	787
6	112	155	169	197	225	253	281	295	309	337	366	422	450	506
5	85	117	127	149	170	191	212	223	234	255	276	319	340	382
4	67	93	101	118	135	152	169	177	186	202	219	253	270	304
2	43	60	65	76	87	98	109	114	120	130	141	163	174	196
BB	25	34	37	44	50	56	62	65	69	75	81	94	100	112
Weight of Shot in Ounces (Grams) (3% Antimony)														

Lab 2: Exterior Ballistics/Analysis of Projectile Trajectories

Objective of Lab Exercise

Become familiar with exterior ballistics and the simulation of trajectories for reconstruction of shooting incidents.

Lab Instructions

Use the PointBlack Ballistics software to analyze a series of ammunition loads. You will need to enter the provided load data into the software and calculate the trajectories for each load. Pairs of similar caliber ammunition need to be compared to demonstrate the differences in ballistic performance. These load data are provided below. Note: You may not need all of the information provided.

Table 3. Handgun Comparison: Nominal .38 ammunition pair – 9mm Luger & .38 Special

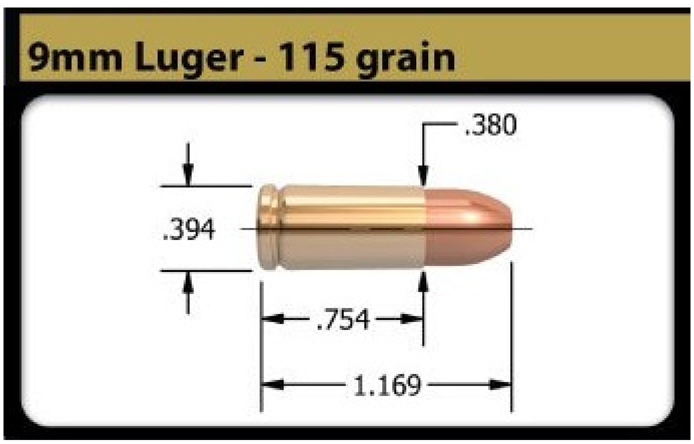
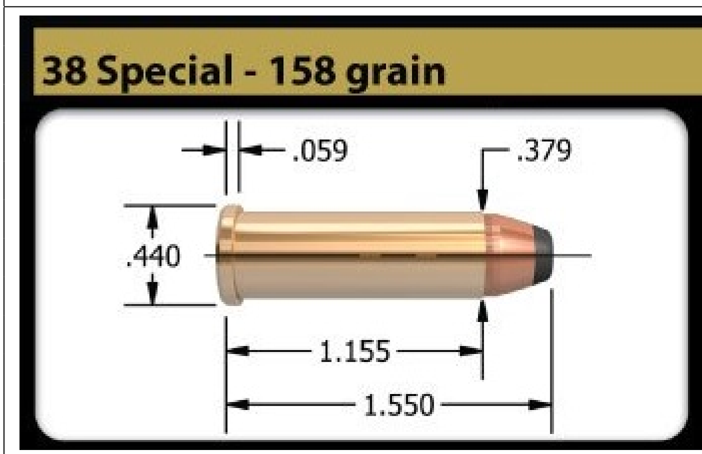
	Ballistic Coefficient 0.109 Muzzle Velocity 1083 ft/s Bullet Weight 115 gn Powder Type SR4756 Powder Charge 6.0 gn % Load Density 101% Primer Type Rem 1 $\frac{1}{2}$
	Ballistic Coefficient 0.182 Muzzle Velocity 810 ft/s Bullet Weight 158 gn Powder Type HS-6 Powder Charge 6.5 gn % Load Density 46% Primer Type WSP

Table 4. Rifle Comparison: .223 Rem and 5.56mm

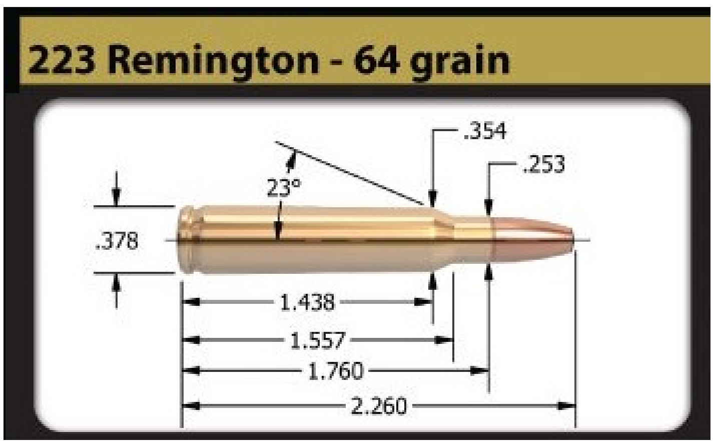
<table>
<tr>
<td>
</td>
<td>Ballistic Coefficient 0.231
Muzzle Velocity 2932 ft/s
Bullet Weight 64 gn
Powder Type CFE 223
Powder Charge 26.0 gn %
Load Density 97%
Primer Type WSR</td>
</tr>
<tr>
<td>
</td>
<td>Ballistic Coefficient 0.498
Muzzle Velocity 2476 ft/s
Bullet Weight 85 gn
Powder Type H4895
Powder Charge 23.0 gn %
Load Density 102%
Primer Type WSR</td>
</tr>
</table>

Table 5. Rifle Comparison: .30 Caliber ammunition pair – 30-30 Win and .300 Win Mag

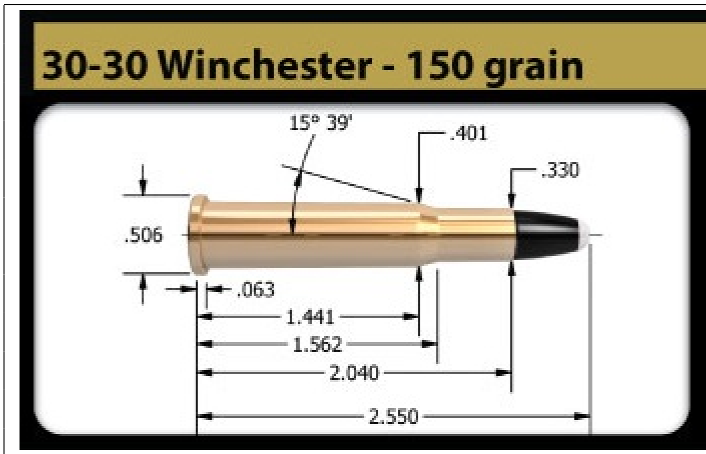
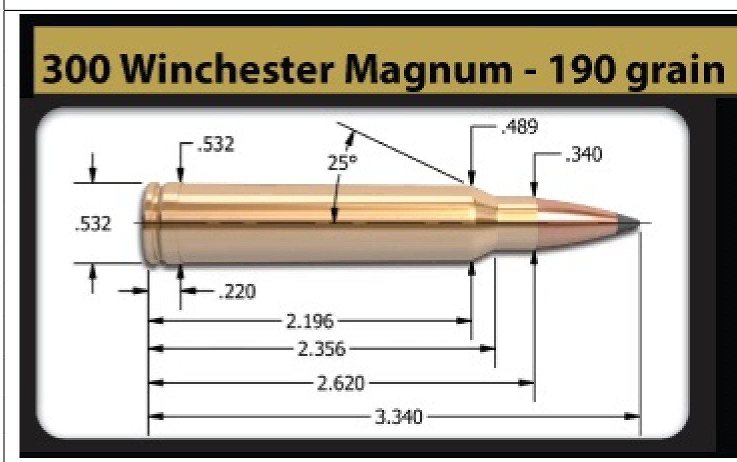
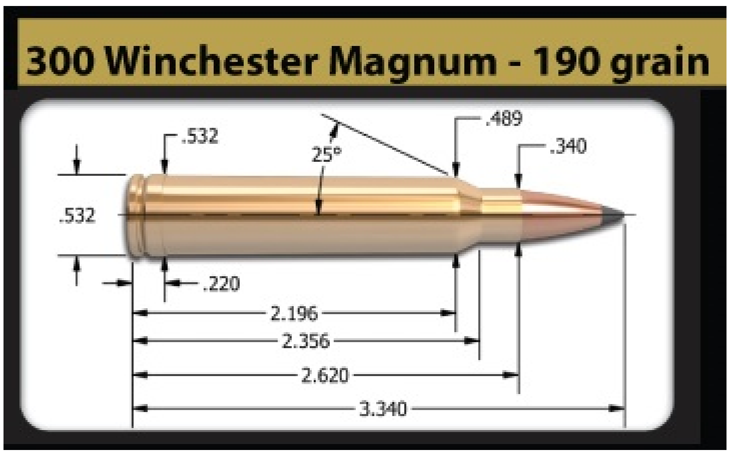
	Ballistic Coefficient Muzzle Velocity Bullet Weight Powder Type Powder Charge Load Density Primer Type	0.232 2247 ft/s 150 gn IMR 4895 32.0 gn % 96% WLR
	Ballistic Coefficient Muzzle Velocity Bullet Weight Powder Type Powder Charge Load Density Primer Type	0.597 2949 ft/s 190 gn RL17 68.0 gn % 85% WLRM

Table 6. Rifle Comparison: .300 Win Mag – Different Powders



Load 1:

Ballistic Coefficient	0.597
Muzzle Velocity	2647 ft/s
Bullet Weight	190 gn
Powder Type	H4831SC
Powder Charge	68.5 gn %
Load Density	86%
Primer Type	WLRM

Load 2:

Ballistic Coefficient	0.597
Muzzle Velocity	3063 ft/s
Bullet Weight	190 gn
Powder Type	Magnum
Powder Charge	86.0 gn %
Load Density	105%
Primer Type	WLRM

Table 7. Additional parameters for the PointBlank software. Hold these constant across all loads for consistency in comparison. The altitude value corresponds to St. Paul, MN.

Parameter	**Value**
Altitude	759 ft
Tempterature	70 F
Sight Height	1.50 in
Uphill / Downhill Angle	0

Instructions for Software Installation and Usage

1. Copy the *'PointBlank_Software'* folder to your computer.
2. Open the folder and start the run the *PBPatcher* application.
3. A window will pop up stating that you are running PointBlank for the first time. Click *OK* and it will install all files in the folder.
4. Once the status of all items has changed to green and progress is *Ok*, click the *Quit* button to close the installer.
5. In the folder, run the *'PointBlank'* application.
6. Wait for the software donation clock countdown, then click close.
   - The welcome screen is a general help file for the PointBlank program. Take a moment and browse through the various topics to become familiar with how the program operates.
7. On the top toolbar, click the *Ballistics* tab. A *Data Copy Selection* window will pop-up. Select *Do Not Copy*.
8. Enter the provided information into the appropriate fields on the left of the program window.
   - Refer to Table 7 for some of the constant parameters.
9. Once all fields have been entered, click the *Compute Ballistics* button in the bottom left corner to calculate the trajectory.
10. There are tabs across the bottom of the program window with the results of the simulation. You may want to go to the *Settings* tab on the toolbar and change the *Maximum Range* to 200 yards.
    - **Table Data:** a table of the calculated trajectory.
    - **Trajectory:** a plot of the calculated trajectory.
    - **Energy:** a plot of the energy (ft/lbs) of the projectile throughout the trajectory.
    - **Wind Drift:** a plot of the projectile trajectory with the addition of various cross wind speeds.
    - **MOA Table:** a table which calculates the Minutes of Angle (MOA) for the firearm and ammunition. A MOA is an angular measurement used in the sighting of the firearm.
    - **Misc:** Additional miscellaneous options and calculators.
11. Just below the top tool bar, select the *Load 2* tab. This will allow you to add the second ammunition in the comparison pair.
12. Repeat Steps 8–10.
    - Note: the data tables and plots will have data for both entered loads.

Notebook Requirement for the Lab

Record your notes and observations about the calculated trajectories. Include the trajectory comparison plots for each ammunition pair generated by the PointBlank software. Provide a discussion of the differences between the ammunitions/loads and how this has effected the trajectories. Reflect on the influence that wind has on the trajectory, challenges an investigator may have in reconstructing an accuracte trajectory, and errors that could be present in the reconstruction of a trajectory.

Lab 3: Cartridge Case Impressions and Marks

Objective of Lab Exercise

Become familiar with the terminology and position of cartridge case markings and impressions based on the class characteristics of firearms.

Lab Instructions

Determine the breechface impressions, firing pin impression, firing pin aperture, ejector mark, and extractor mark by observing the placement of these features. Not every firearm will have extractor and ejector marks. Several example markings are given in Figure 10 [4].

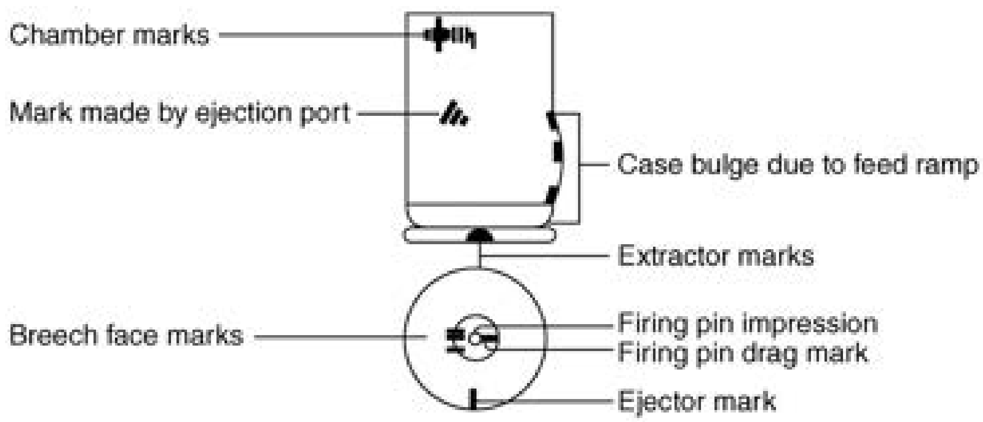


Fig. 10. Illustration of markings present on cartridge case after firing. Note that not all cartridge cases will have all marks.

Notebook Requirement for the Lab

Record observations in your notebook in the form of words and sketches. Thoroughly document your observations of the cartridge cases. Make sure that you document the relative position of the markings among one another. Attempt to determine the number of potential firearms which created the set based on class characteristics.

[4]Figure from: *Forensic Ballistics in Court: Interpretation and Presentation of Firearms Evidence*, Brian J. Heard. 2013, John Wiley & Sons, Ltd.

Lab 4: Cartridge Case Comparison Microscopy: Known Matches

Objective of Lab Exercise

Learn the fundamentals and technique of performing cartridge case comparisons with a comparison microscope using known matches.

Lab Instructions

Classify cartridge cases fired by the same gun using both physical and microscopic comparison. Physical comparisons include the presence and types of marks on the breechface, extractor and/or ejector placement, along with the head stamp on the end of the cartridge case. Also conduct microscopic comparison of the impressed toolmarks on the primer surface using a comparison microscope. Note whether you are able to identify consecutive matching striations (CMS) on the primer surface and provide the counts for instances detected. Remember that CMS relates only to striated toolmarks which are created by movement causing shearing/alteration of a surface (*e.g.* firing pin aperture shearing) and not impressed toolmarks (*e.g.* impressions from breechface). Capture photographs and take sketches of features that cartridge cases fired from the same gun possess.

You will also be provided with 3D scans (.x3p files) of cartridge cases fired from the same firearm. Use the Cadre Forensics 3D Viewer and Sensofar SensoComp softwares to open and view these scans. Apply the same process as above and perform virtual comparison microscopy between the KM cartridge case pairs. Capture any features which exhibit significant differences between the cartridge case scans.

An example of consistency between cartridge cases or low inter-variability is provided in Figure 11.

An example of cartridge cases fired from the same firearm which exhibit differences or higher levels of inter-variability is provided in Figure 12.

Notebook Requirement for the Lab

Include all notes about the observations of the cartridges cases. Provide a discussion of the observations which are indicative of the cartridge cases originating from the same firearm, any differences observed, and possible sources of the observed differences. The differences in cartridges cases are important to note since the cartridge cases are known matches and these differences exhibit the intra-variability present within a firearm.

Fig. 11. Illustration of consistency between impressions/markings present on cartridge cases fired from the same firearm.

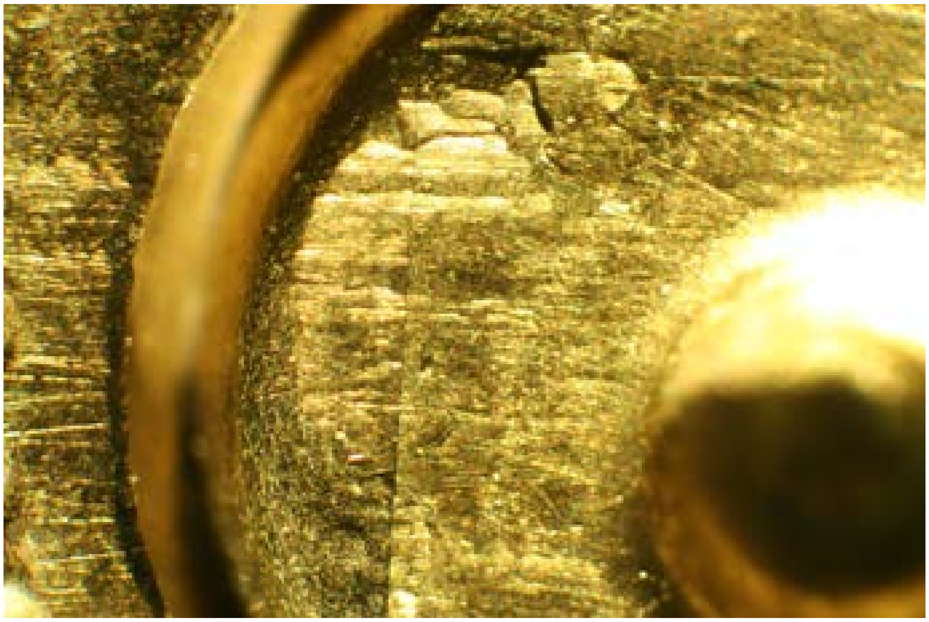


Fig. 12. Illustration of differences between breechface impressions present on cartridge cases fired from the same firearm.

Lab 5: Cartridge Case Comparison Microscopy: Known Non-Matches

Objective of Lab Exercise

Become familiar with the differences between cartridge cases fired from different firearms.

Lab Instructions

Classify cartridge cases fired by different guns using both physical and microscopic comparison. Physical comparisons include the observation of the presence and types of marks on the breechface (see Lab for specifics), along with the head stamp on the end of the cartridge case. Also conduct microscopic comparison of the impressed toolmarks on the primer surface using a comparison microscope. Note whether you are able to identify consecutive matching striations (CMS) on the primer surface and provide the counts for instances detected. Remember that CMS relates only to striated toolmarks which are created by movement causing shearing/alteration of a surface (*e.g.* firing pin aperture shearing) and not impressed toolmarks (*e.g.* impressions from breechface). Capture photographs of features that cartridge cases fired from the different firearms possess.

Similarly to Lab , you will be provided with 3D scans (.x3p files) of cartridge cases. Use the Cadre Forensics 3D Viewer and Sensofar SensoComp softwares to open and view these scans. Apply the same process as above and perform virtual comparison microscopy between the KNM cartridge case pairs. Capture any features which exhibit similarities between the cartridge case scans.

Notebook Requirement for the Lab

Include all notes about the observations of the cartridges cases. Provide a discussion of the observations which are indicative of the cartridge cases originating from different firearms, any substantial differences or similarities observed, and highlight any similarities found between the different breechface impressions. The similarities between these cartridges cases are important to note since the cartridge cases are known non-matches and therefore exhibit the inter-variability present within a firearm.

Lab 6: Cartridge Case Comparison Microscopy with Questioned Samples

Objective of Lab Exercise

Perform a comparison between questioned samples as in casework to determine if two cartridge cases were fired by the same or different firearms using the concepts from Lab Exercises and .

Lab Instructions

Classify the unknown cartridge cases by using both physical and microscopic comparison and reach a conclusion about the source of the firearm (*i.e.* same source or different source). Physical comparison includes the observation of the presence and types of marks on the breechface (see Lab for specifies), along with the head stamp on the end of the cartridge case. Also conduct microscopic comparison of the impressed toolmarks on the primer surface using a comparison microscope. Note whether you are able to identify consecutive matching striations (CMS) on the primer surface and provide the counts for instances detected. Remember that CMS relates only to striated toolmarks which are created by movement causing shearing/alteration of a surface (*e.g.* firing pin aperture shearing) and not impressed toolmarks (*e.g.* impressions from breechface). Capture photographs of features that cartridge cases fired from the same gun possess.

Notebook Requirement for the Lab

Include all notes about the observations of the cartridges cases. Provide your conclusion and the rationale for whether the cartridges were discharged from the same firearm or different firearms, differences or similarities observed, and possible sources of the cartridge case observations.

Lab 7: Bullet Comparison Microscopy: Known Matches

Objective of Lab Exercise

Become familiar with the basics of bullet comparisons using known matching samples.

Lab Instructions

Begin with physical comparison of the different bullets by applying the same concepts as the bullet types lab. In addition, measure the width of the land and groove engraved areas and comment on the total number of lands and grooves in the original rifle. *Note: If exclusions can be made based on the physical characteristics, then microscopic comparison is not necessary.* If comparing bullets, and you observe striations within a land engraved area (LEA) which meet CMS criteria, an identification can be made. An example is given in Figure 13 where CMS criteria have been met in a comparison.

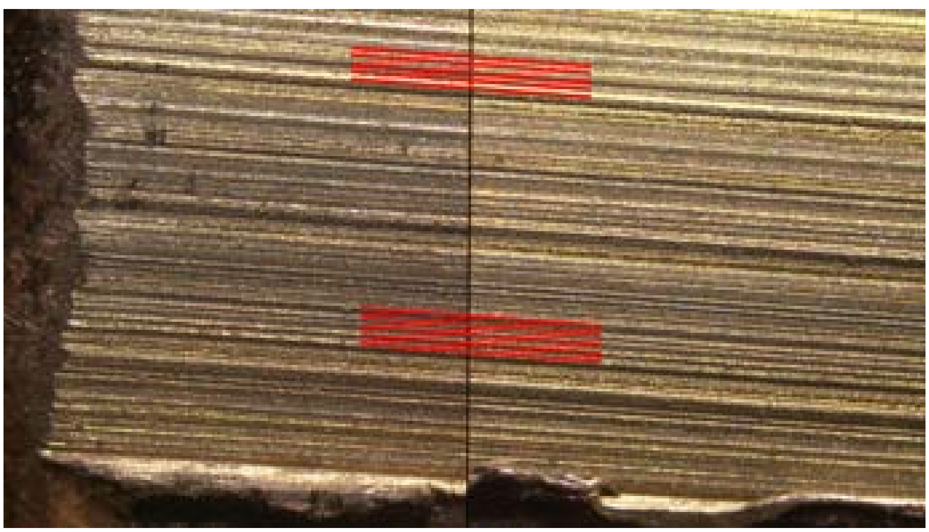


Fig. 13. Illustration of 2D CMS criteria being met with two groups of five CMS present in a LEA.

Notebook Requirement for the Lab

At least 5 photographs that represent the comparison of known match bullets. Include photographs that show both similarities and differences, along with notes for all of the pairwise comparisons. Hint: If a pair of land engraved areas match, all subsequent land engraved areas should match on the bullets, or at least be very similar and not exclusionary.

Lab 8: Surface Metrology and 3D Comparisons

Objective of Lab Exercise

Become familiar with the basics of confocal microscopy and three dimensional capture of firearms evidence. Utilize emerging techniques and algorithms which compare features between known and questioned samples.

Lab Instructions

You will be provided with 3D scans (.x3p files) of bullets. Use the Cadre Forensics 3D Viewer and Sensofar SensoComp softwares to open, view, and compare these scan files. Apply previously learned techniques perform virtual comparison microscopy between the land engraved areas of the bullets. Once you have reached a conclusion from the AFTE Range of Conclusions, use the BulletMatcher Bullet Land Matching Algorithm developed by the Center for Statistics and Applications in Forensic Evidence (CSAFE) to compare the bullet LEAs. Compare your observations and conclusion with the results of the BulletMatcher algorithm.

Notebook Requirement for the Lab

Include all notes about your observations. Provide a discussion of the observations which are indicative of the samples originating from the same or different firearm, deformations, and possible sources of the observed differences. Additionally, provide a comparison of your conclusion with the results of the BulletMatcher algorithm.

Additional Reference Material/Notes for the Lab

The 3D scans you will be using for this lab are all taken by a confocal microscope. A confocal microscope combines the ability of the optical microscope to use inter-changeable objective lenses to achieve greater magnification and surface resolution. During a scan, multiple 2D images are captured at different depths in the sample. The 3D structure is reconstructed from the series of images through a process known as optical sectioning. An example scan of a LEA on a bullet fired by a Ruger P-95 is given in Figure 14.

The raw topography data are provided in .x3p format (XML 3D surface Profile). This is the current standard for storage and exchange of topography and profile data (ISO 25178-72). Each x3p file contains four records:

1. Header, data types, and axes definition
2. Meta data regarding the instrument and user
3. Profile Data (x, y, z)
4. Checksum of the xml-document

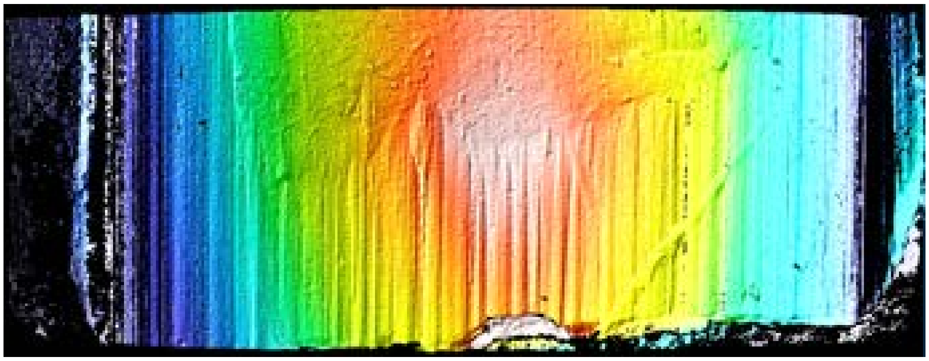


Fig. 14. Scan of a LEA from a confocal microscope. Captured from Sensofar SensoCOMP 1.0. software.

The actual raw profile data is stored as a surface matrix where each row and column represent a pixel of the image, x and y respectively. The value within each x,y cell is the z value (depth) corresponding to that pixel within the scan. An illustration of a surface matrix is given in Table 8.

Table 8. Example surface matrix of depth measurements Z across a scan of dimension $X \times Y$.

	X_1	X_2	...	X_n
Y_1	$Z_{(1,1)}$	$Z_{(1,2)}$		$Z_{(1,n)}$
Y_2	$Z_{(2,1)}$	$Z_{(2,2)}$		$Z_{(2,n)}$
...				
Y_n	$Z_{(n,1)}$	$Z_{(n,2)}$		$Z_{(n,n)}$

After comparison, you also used the BulletMatcher Bullet Land Matching Algorithm developed by CSAFE to compare the bullet LEAs. The following is a step-wise discussion of the processing methodology used by BulletMatcher. Firstly, the surface matrix can be used to render and view the LEA. This will be the start of processing.

Fig. 15. Example virtual LEA rendered from its surface matrix.

Next, a “representative” cross section for the bullet land engraved area to be used for comparison is determined. Striated toolmarks on a bullet LEA are generally best expressed at the heel (bottom) of the bullet. Note that the heel of the bullet may sheer off which can be problematic and adjustment may be necessary in such cases. A black line has been added to illustrate the identified representative cross section on the virtual LEA rendering in Figure 16.

Fig. 16. Example virtual LEA rendered from its surface matrix.

At this location in the surface matrix, the bullet profile is extracted. The extracted profile is now two dimensional since it is a cross section where the x-axis represents width of the LEA and the y-axis represents the height of the LEA. A plot of this profile is given in Figure 17

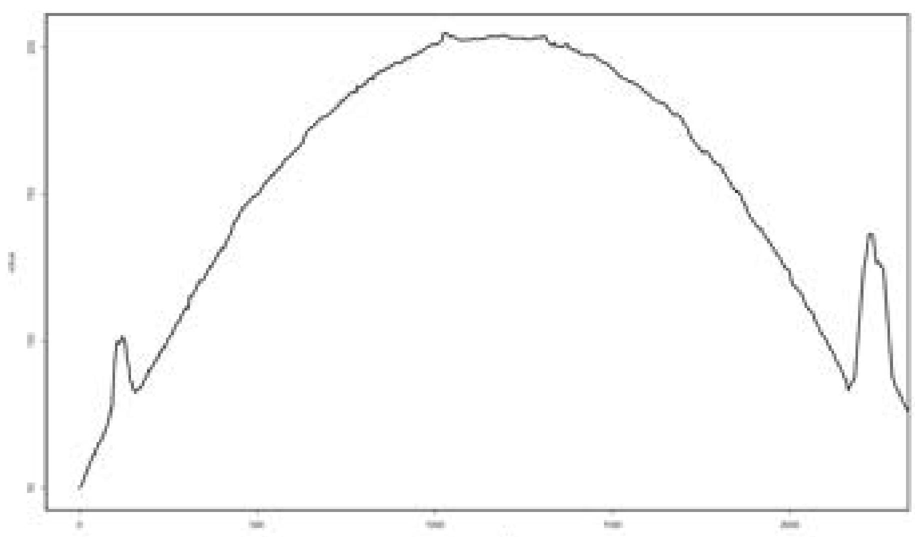


Fig. 17. Extracted cross section of the LEA at the identified position illustrated in Figure 16.

The extracted profile is then cropped at the shoulders of the LEA. These are given by the upward protrusions at each end of the plot. The shoulders and the areas beyond these points are not used for comparison. Figure 18 shows how the above profile is cropped.

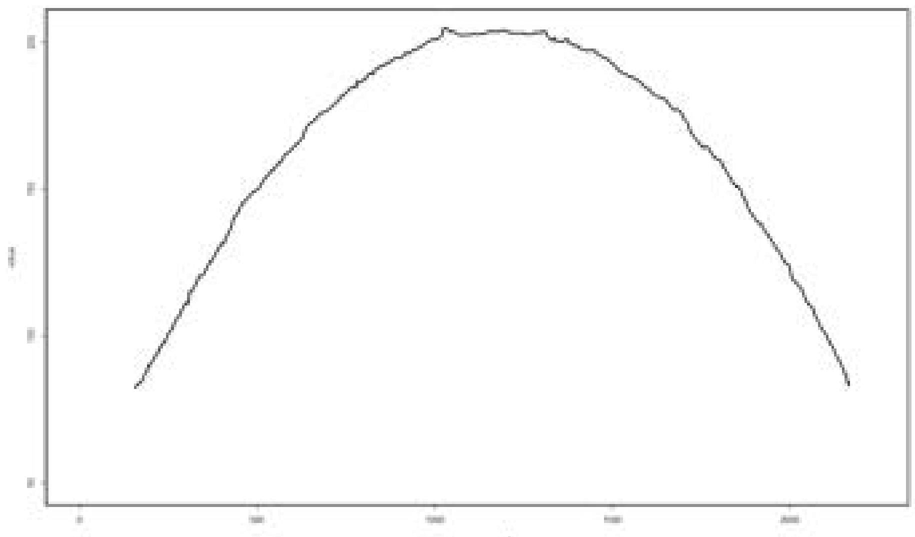


Fig. 18. Extracted cross section of the LEA at the identified position illustrated in Figure 16.

The global structure (curvature) of the bullet dominates the overall appearance of the profile and masks the detail/striations. To remove this, a curve is fit to model the structure. The regression curve for the structure has been overlaid with the cross section profile and is shown in Figure 19.

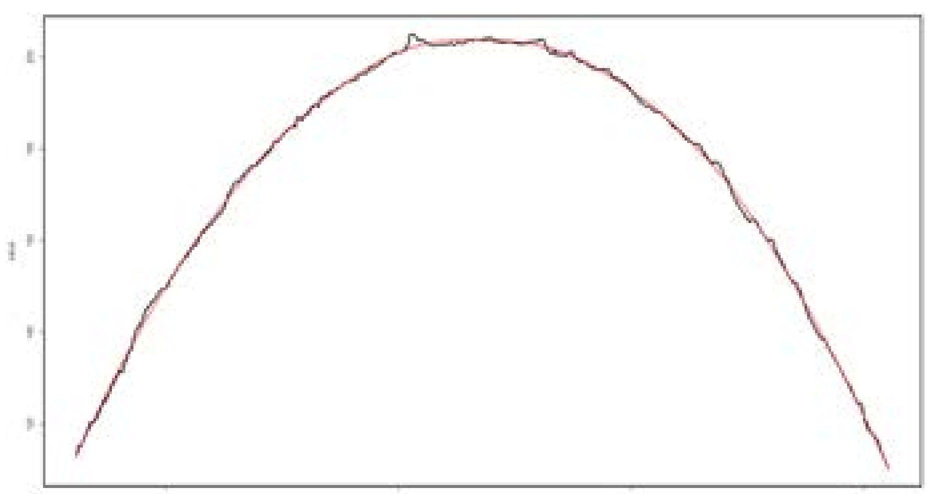


Fig. 19. Curve (red) which was fit to model the global structure of the bullet overlaid with the cross section profile of the LEA.

Once calculated, the regression curve which models the global structure is subtracted from the cross section. Removal of the global structure results in solely the bullet signature for the LEA. The bullet signature is the change in the surface topography of the bullet caused by its passage through the gun barrel. The signature is unique to the firearm and analysis/comparison of these ballistics signatures, firearm examiners can connect a firearm to the bullet. The resultant bullet signature after subtraction of the global bullet curvature is shown in Figure 20.

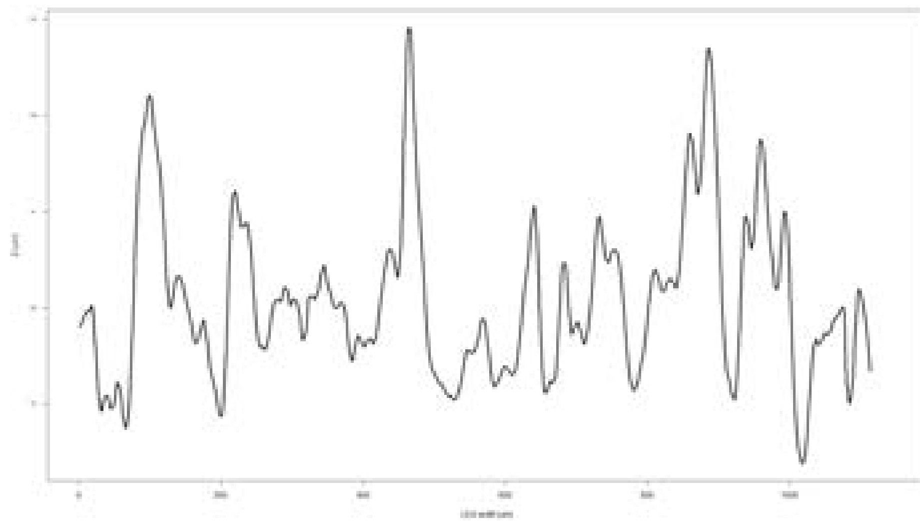


Fig. 20. Extracted cross section of the LEA at the identified position illustrated in Figure 16.

This process can be repeated for a test fire (known exemplar) which has also been scanned. The bullet signatures can be aligned and compared to determine a conclusion. An example of a known match LEA has been overlaid with the bullet signature and is shown in Figure 21.

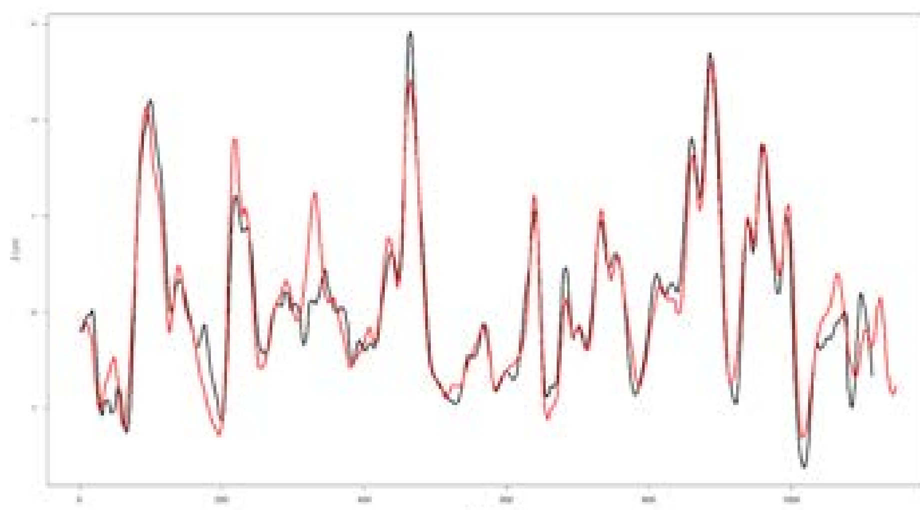


Fig. 21. Extracted cross section of the LEA at the identified position illustrated in Figure 16.

Often, a correlation between the bullet signatures is done and the cross-correlation function (CCF) of two digitized profiles is used to demonstrate the similarity between the signatures. If two bullet signatures are identical and aligned, the CCF between the curves will be 1, as they are identical. If two signatures are similar but not identical, the case if the two bullets fired from the same firearm, the CCF would be less than one but still relatively high. If two bullets are fired from different guns, their signature patterns should ideally have no correlation at all but will be less than bullets fired by the same firearm. For the signatures shown in Figure 21, the CCF was 0.95. Observable are a few differences between the signatures which can be attributed to the intra-variability of a firearm. For reference, experimental distributions[5] of CCF values for KM and KNM bullets are given in Figure 22.

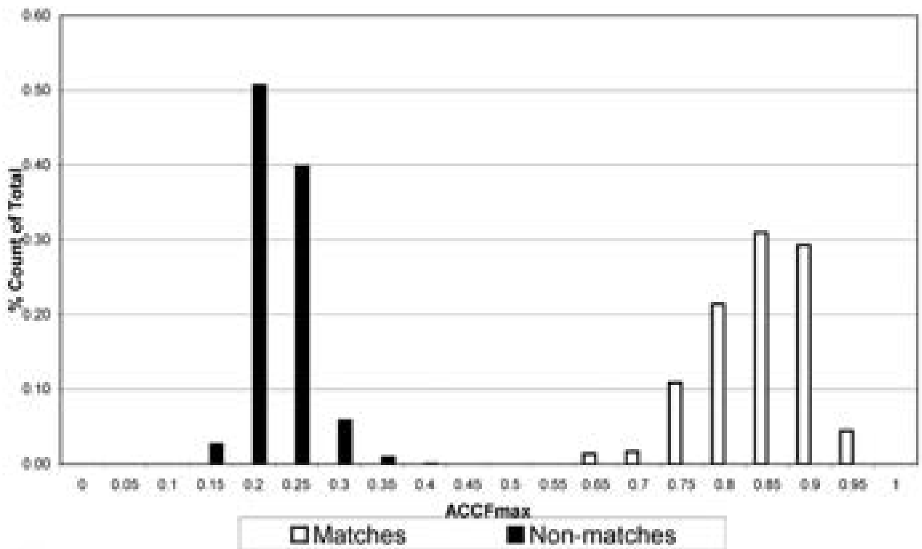


Fig. 22. Plot of 8010 cross-correlation comparisons between test fires from consecutively manufactured breech faces. No overlap of data was observed between matching (same breech face) and non-matching (different breech face) comparisons.

The BulletMatcher algorithm also provides a 'predicted probability of match' using the features of the bullet signature (peaks and valley of striae) which is based upon a trained Random Forest decision tree model to help differentiate between a match and a non-match.

[5]These data are from:
Weller TJ, Zheng A, Thompson R, Tulleners F. Confocal microscopy analysis of breech face marks on fired cartridge cases from 10 consecutively manufactured pistol slides. *J Forensic Sci*. 2012; 57:912–7.