5-2020

Flash Lab: A High-Speed Imaging Laboratory

Cody D. Hatch
Utah State University

FLASH LAB: A HIGH-SPEED IMAGING LABORATORY

by

Cody D. Hatch

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Mechanical Engineering

Approved:

____
Tadd Truscott, Ph.D.
Major Professor

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Barton Smith, Ph.D.
Committee Member

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Ryan Berke, Ph.D.
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah

2020

ABSTRACT

Flash Lab: A High-Speed Imaging Laboratory

by

Cody D. Hatch, Master of Science

Utah State University, 2020

Major Professor: Dr. Tadd Truscott
Department: Mechanical and Aerospace Engineering

To help students become better acquainted with high-speed instrumentation and measurement techniques, a high-speed imaging laboratory for the College of Engineering is equipped with a high-speed camera and schlieren imaging device. The laboratory will be used for labs in classes, such as Instrumentation, Thermal/Fluids Lab, Experimental Solids, and Mechanical Experiments. In addition, graduate students will use it for research purposes. The laboratory also has the potential to have a course associated with it that would include the image processing techniques for a variety of applications (e.g., a course on high-speed imaging). The scope of this project will be to create a training/orientation course for the laboratory and equipment, develop experiments and course work for the Thermal/Fluids Lab course, and to help design a storage area into a workable lab space. The goal of the experiments is to expand the exposure of thermal/fluids phenomena as well as introduce modern measurement techniques. The experiments designed will be built off previous successful experiments. All results of the experiments should match the literature cited. With this new lab it will be used as a recruiting tool as well as a resource for funding from donors and bringing in more

research opportunities to Utah State University. The laboratory will be setup in such a way that its use can be expanded to meet the needs of the department, faculty, and students.

(79 pages)

ACKNOWLEDGMENTS

I give special thanks to my family, friends, and colleagues for their encouragement, moral support, and patience as I worked my way from the initial proposal writing to this final document. I could not have done it without all of you.

Cody D. Hatch

CONTENTS

LIST OF FIGURES

INTRODUCTION

To better acquaint students with high-speed instrumentation and measurement techniques, this project renovated a storage space into the Flash Lab, a dedicated laboratory equipped with a high-speed camera and a schlieren imaging device, for the College of Engineering. Optical measurement techniques are becoming more reliable and robust. When it comes to making measurements with high-speed cameras there are physics laws and limits of the equipment that all can learn without hands on experience. Learning to use the equipment becomes an art to capture the physics within the limits of the equipment.

This lab is patterned after the Edgerton Center at Massachusetts Institute of Technology (MIT). The Flash lab will be a great addition to the capabilities and facilities of the College of Engineering at Utah State University (USU).

The room will be used for labs in classes, such as, Instrumentation, Thermal/Fluids, Experimental Solids, and Mechanical Experiments. In addition, graduate students will use it for some of their research. The lab also has the potential to have a course associated with it that would include the image processing techniques for a variety of applications (e.g., a course on high-speed imaging). This new lab will be used as a recruiting tool as well to get funding from donors and draw more research to Utah State University. The laboratory will be setup in such a way that its use can be expanded to meet the needs of the department, faculty, and students.

The scope of this project is to create a training/orientation course for the laboratory and equipment, develop experiments and course work for the Thermal/Fluids Lab course, and to help design a storage area into a workable lab space.

TRAINING AND ORIENTATION COURSE

Creating a training and orientation course is important to the use of this lab for two reasons. The first, is the expensive and sensitive nature of the equipment that will be used in the lab. The second, is the nature of the experiments that can be done in this lab requires additional training so that all are aware of the potential risks and how to mitigate them.

Safety is a concern with the capability to launch projectiles in the lab (e.g., pellets and arrows). To ensure the safety of the students in the lab, as well as those students outside the lab, safety procedures need to be considered. In visiting and talking to the Range Managers at The Cache Valley Public Shooting Range (CVPSR) and Top of Utah Archery (TOUA) the safety issues with shooting projectiles indoors have been discussed and addressed in the Standard Operating Procedure (SOP), see the Flash Lab Orientation Course and Appendix A in this document.

Canvas Course Walkthrough

A Canvas course is used to train students and faculty on the proper use of the lab. All those that want access to the lab will need to complete the course. The course is setup so that it is self maintained and very little should need to be adjusted. This section will show a general walkthrough of the course of what students and faculty will see. Figure 1 thruough Figure 17 show screenshots of the Canvas course. All screenshots are from the student view.

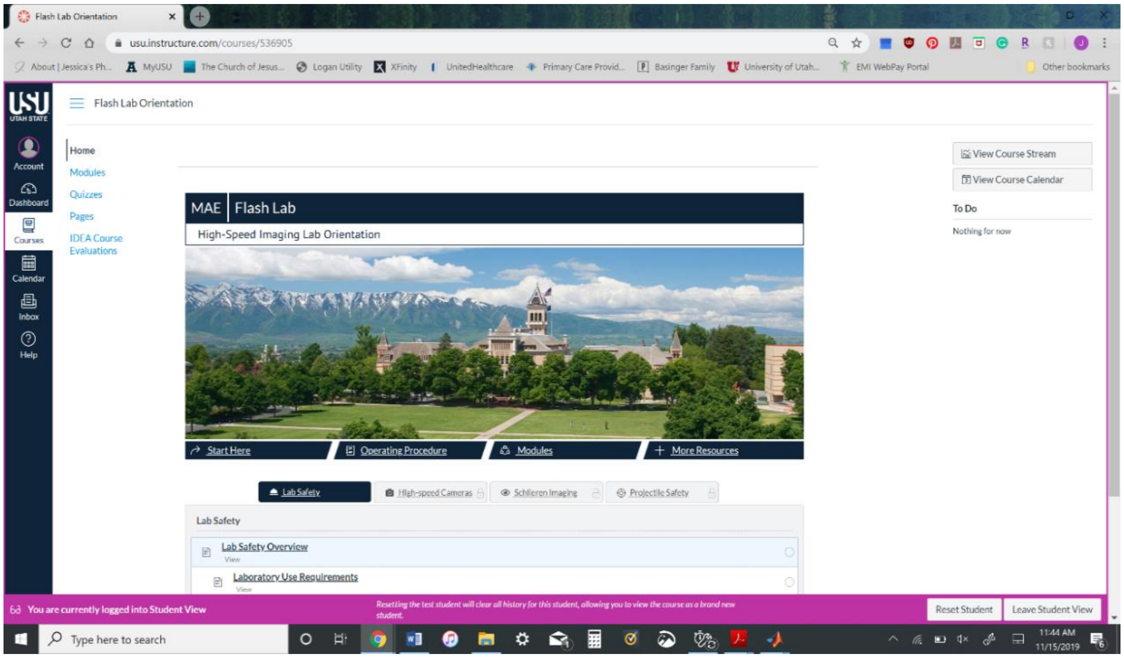

Figure 1. Home page of the course

Figure 1, displays the home page of the course. From the home page, the Start Here tab, Operating Procedure tab, and Modules tab, as well as More Resources, are all accessible from the home page. Also, each individual module can be accessed at the bottom of the home page and the student's progress can be seen. The Home Page is set up this way for two reasons. First, to give the course a direction and flow for new students and second, for easy navigation for returning students to find specific content. Figure 2 is the Start Here page and gives a brief overview of the lab and summarizes its uses. From the Start Here page tabs for the modules and operating procedures are located.

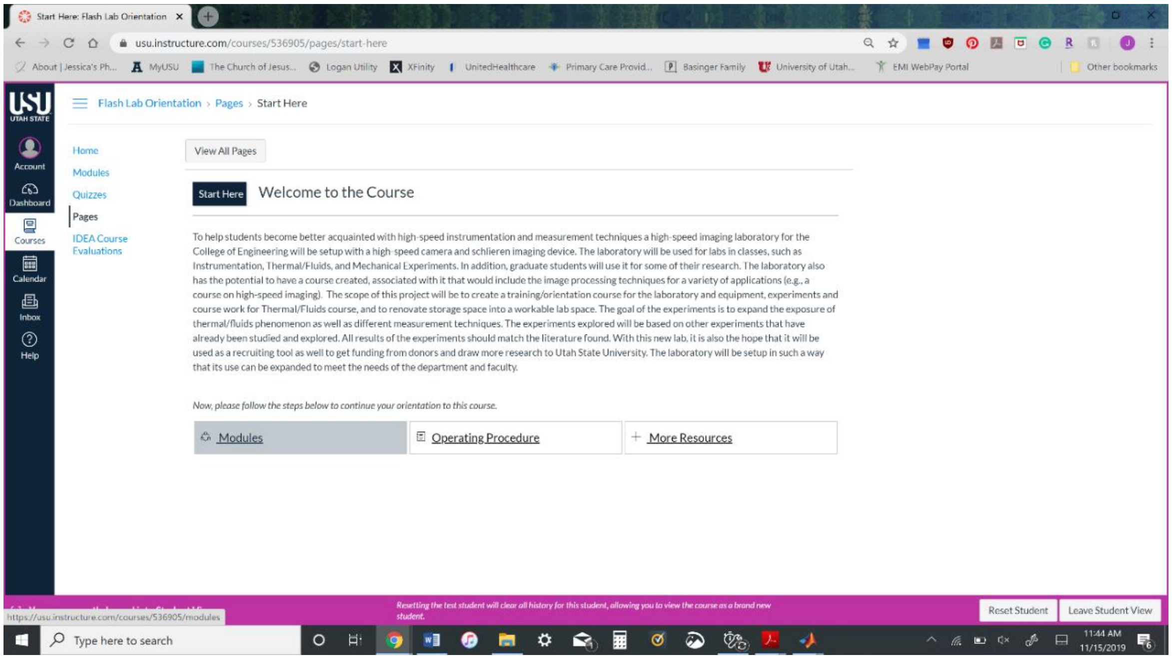

Figure 2. Start Here page

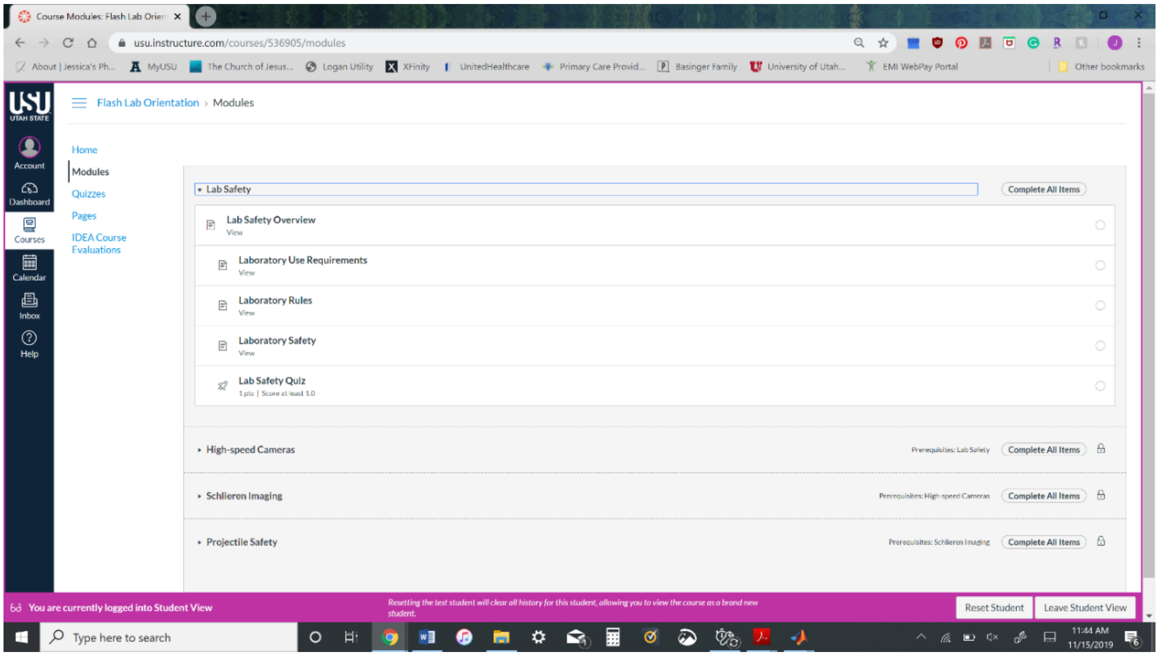

Figure 4. Module Page, Module 1 expanded.

Figure 3 shows the Module page where students can navigate each module and go back to review previous content. Figure 4 shows the first page of Module 1, all other modules are set up the same. By giving a brief overview and videos, as well as excerpts from the SOP that pertain to that module.

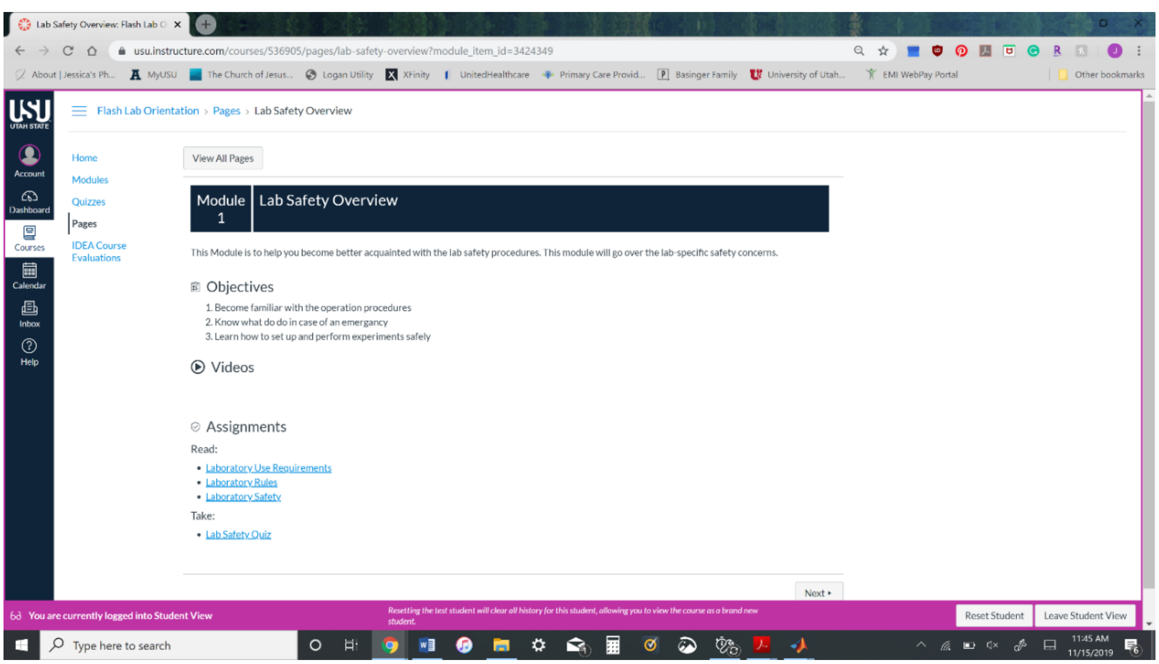

Figure 3. Module 1: Lab Safety Overview page

Figure 5 is a reading from Module 1 and all other assigned readings have a similar format.

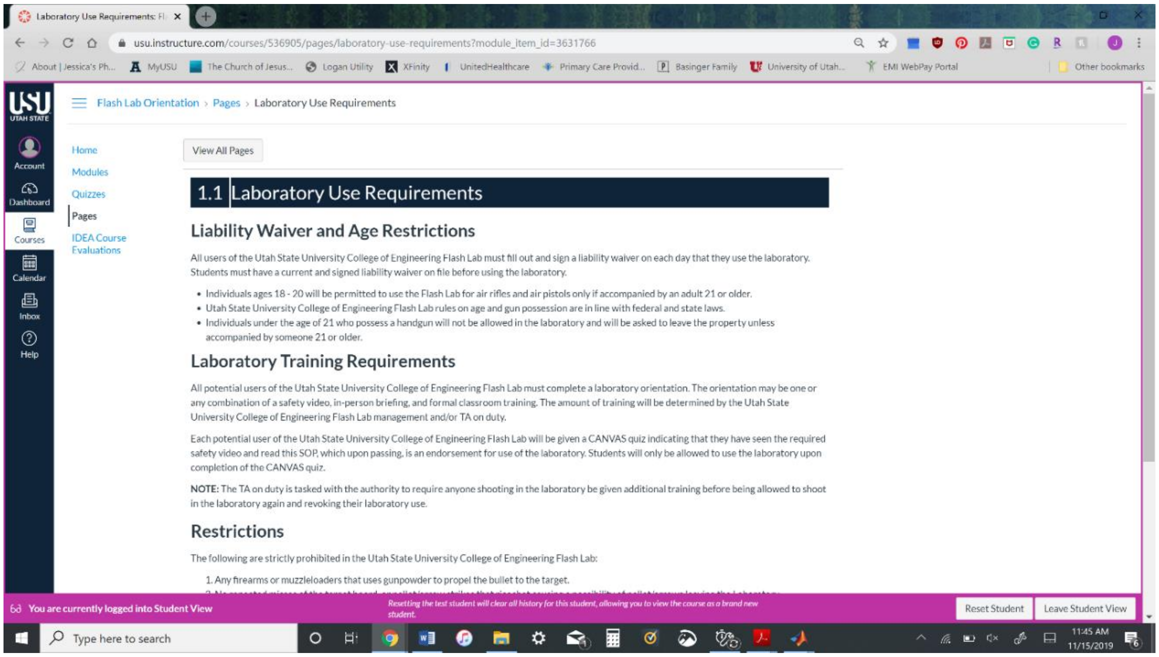

Figure 5. First reading assignment in Module 1

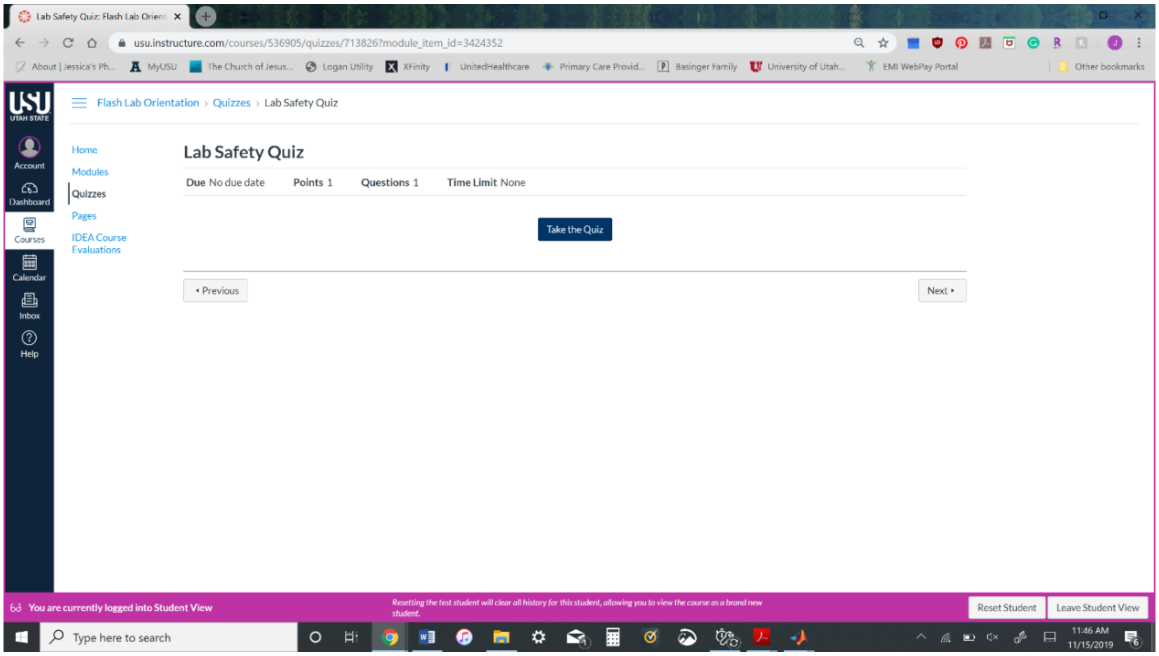

Figure 6. Lab Safety Quiz page

At the end of each module a quiz is given asking the student if they have read or watched the assigned material, as shown in Figure 6 and Figure 7.If a student needs to come back to finish the training at another time, the student can see which modules have been completed, are in progress, and are locked, all from the Home Screen.

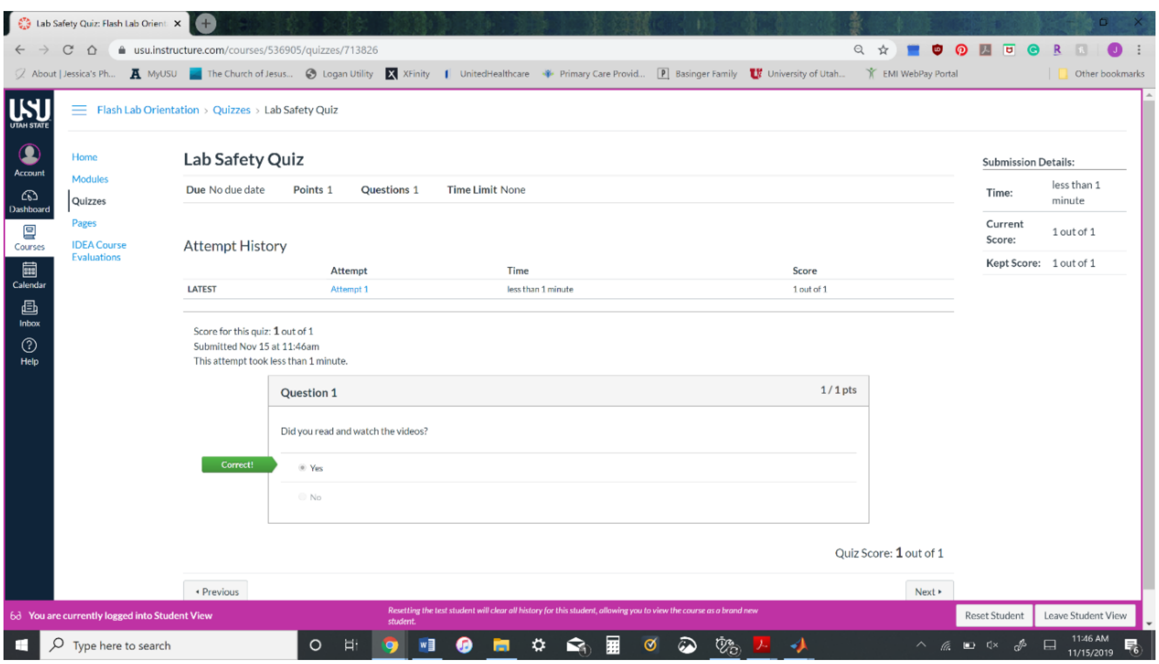

Figure 7. The answer of the quiz to Module 1

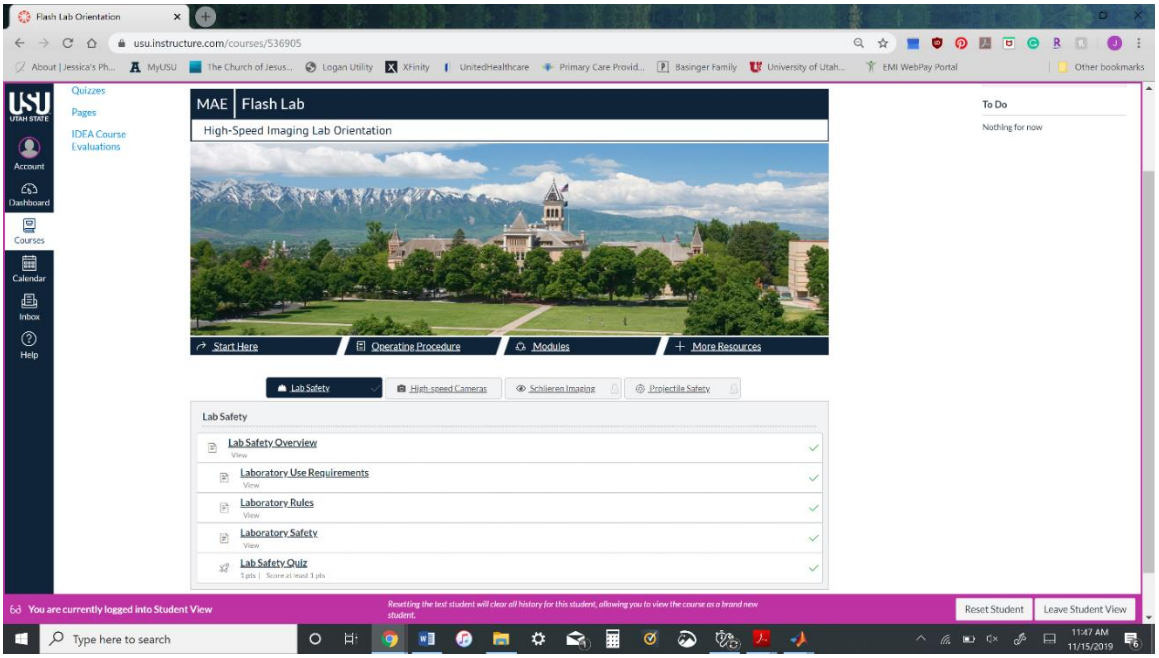

Figure 8. Home page after the first module is completed

Examples are shown in Figure 8 through Figure 10. The student can also see their progress on the Module page, as shown in Figure 11 Through Figure 13.

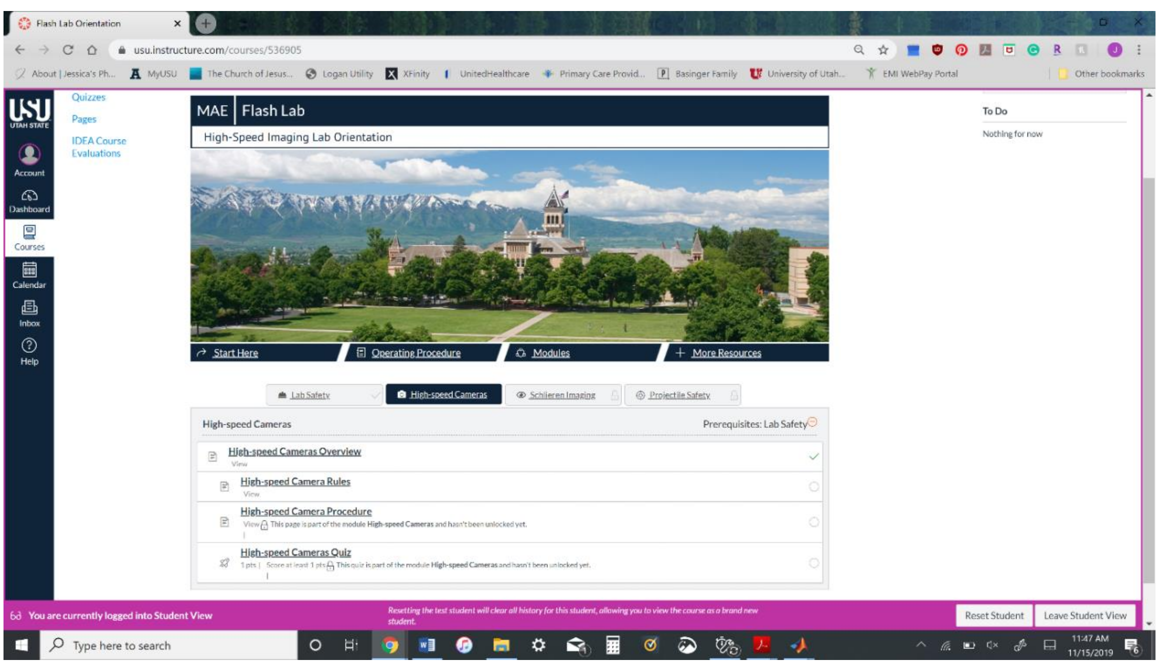

Figure 9. Home page on the second module (incomplete)

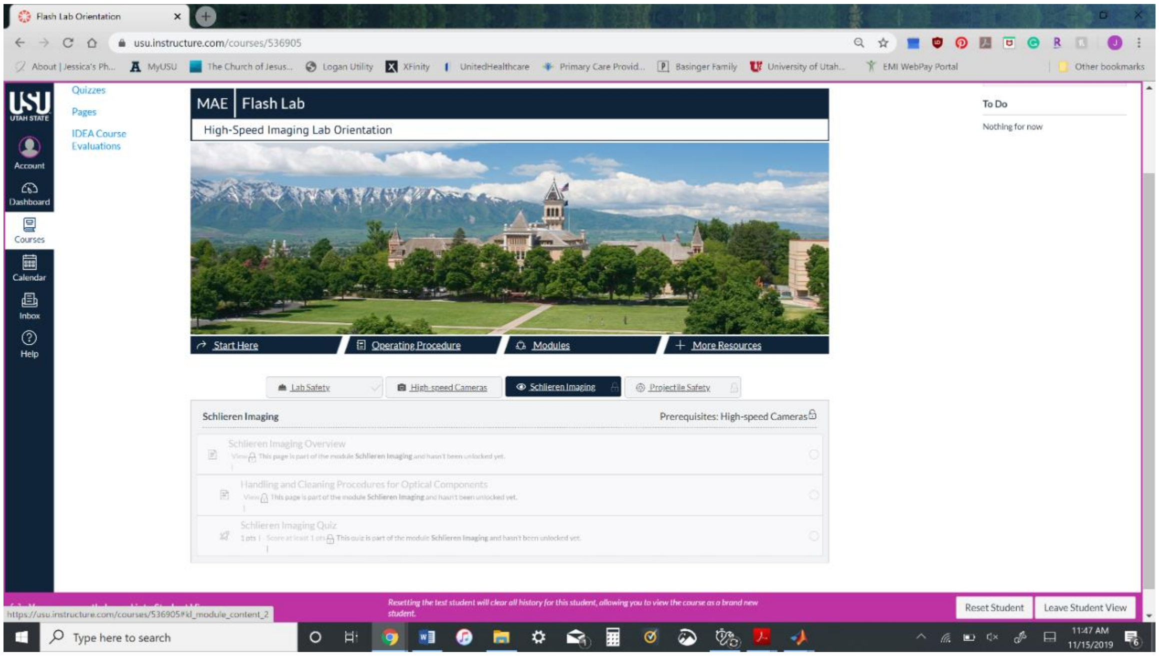

Figure 10. home page on the third module without completing module 2 (locked)

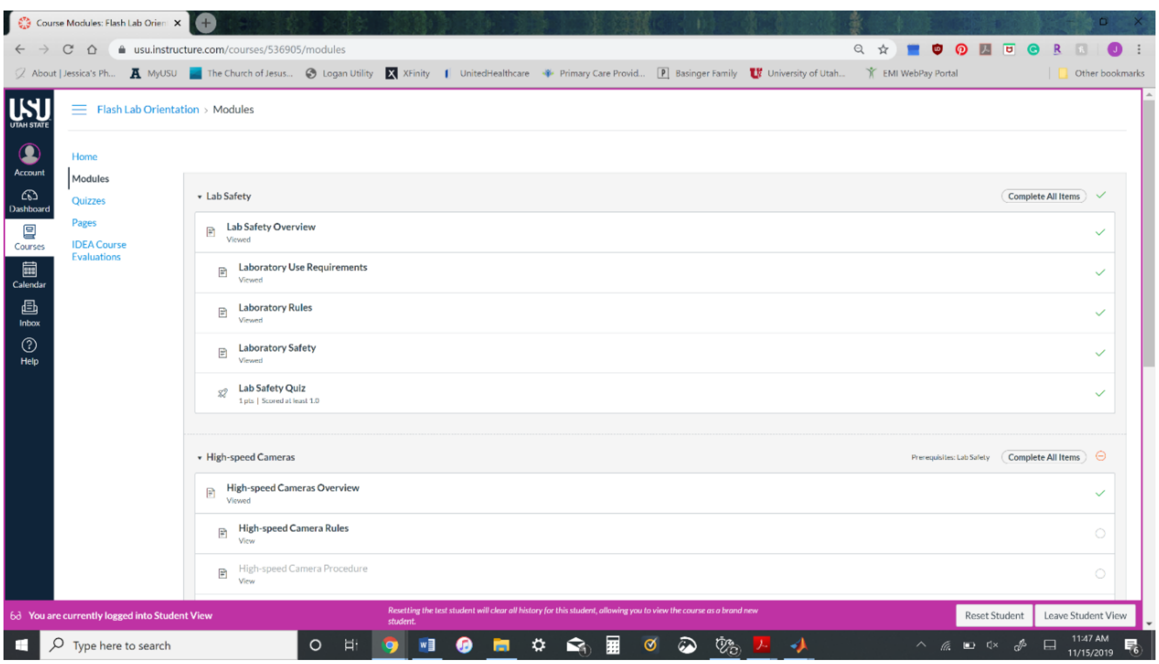

Figure 11. Module page (expanded) showing the progress of the student through the modules

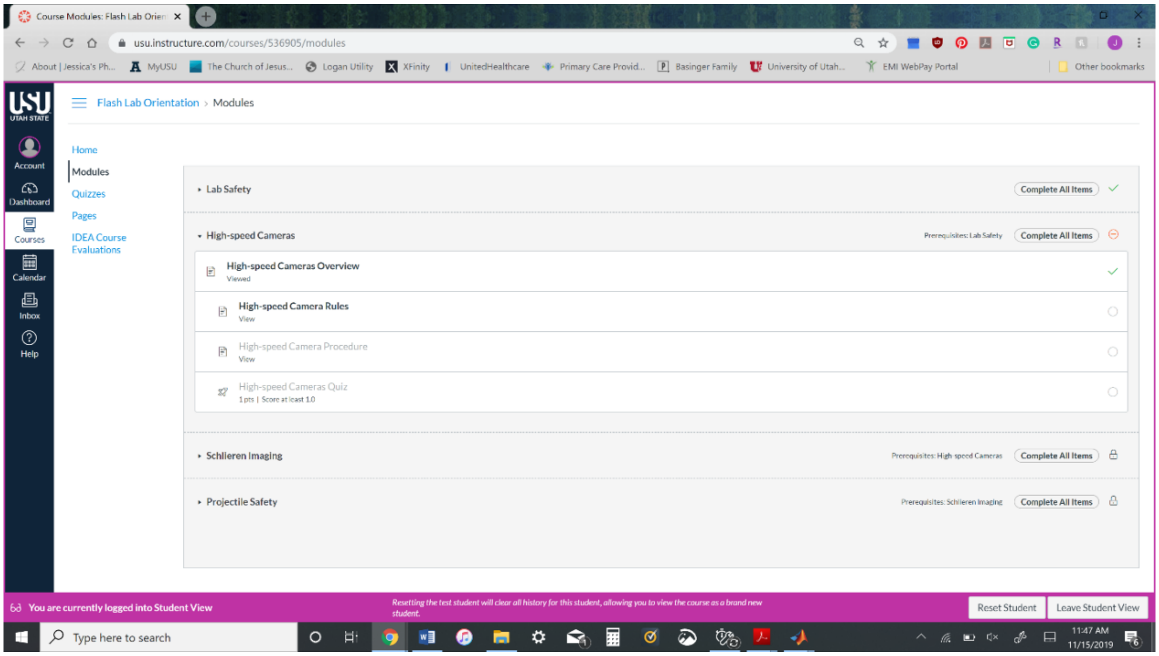

Figure 12. module page (collapsed) showing the progress of the student through the modules

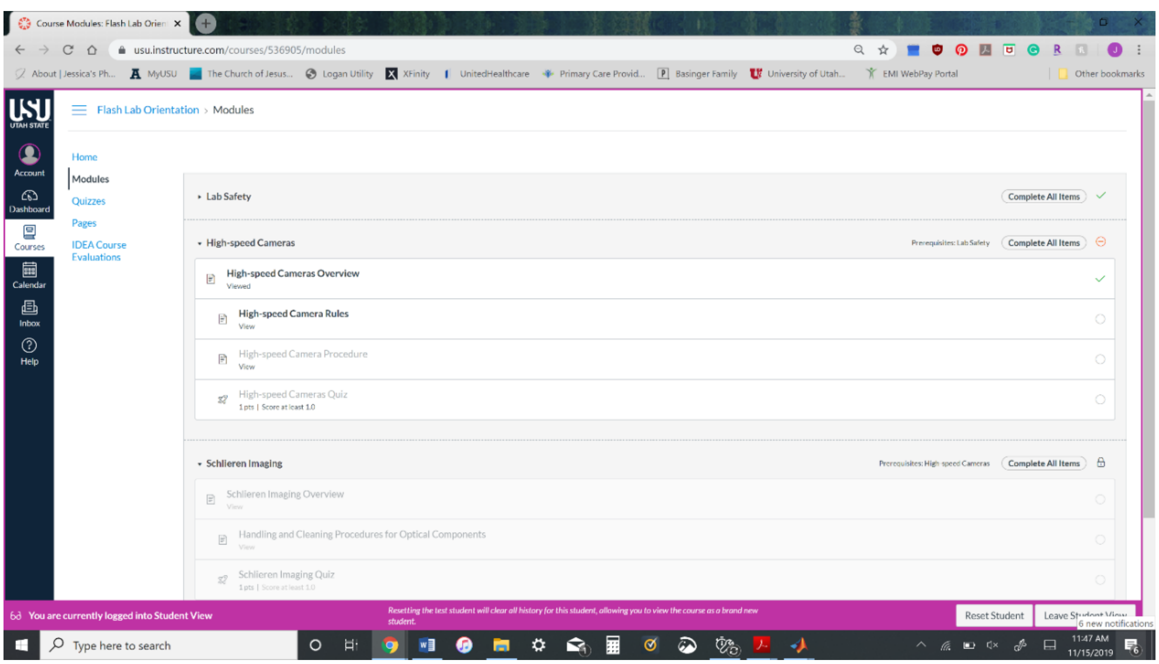

Figure 13. module page (collapsed) showing the progress of the student through the modules and the next module locked

The Operating Procedure page, as seen in Figure 15, contains all the excerpts used for reference in this course. To help navigate the SOP there is a collapsible table of contents in the upper right-hand corner, this can be seen in Figure 14 in which it has been circled. When the table of contents is expanded, each of the sections labeled is a quick link to that section in the document, this is illustrated in Figure 16 and Figure 17.

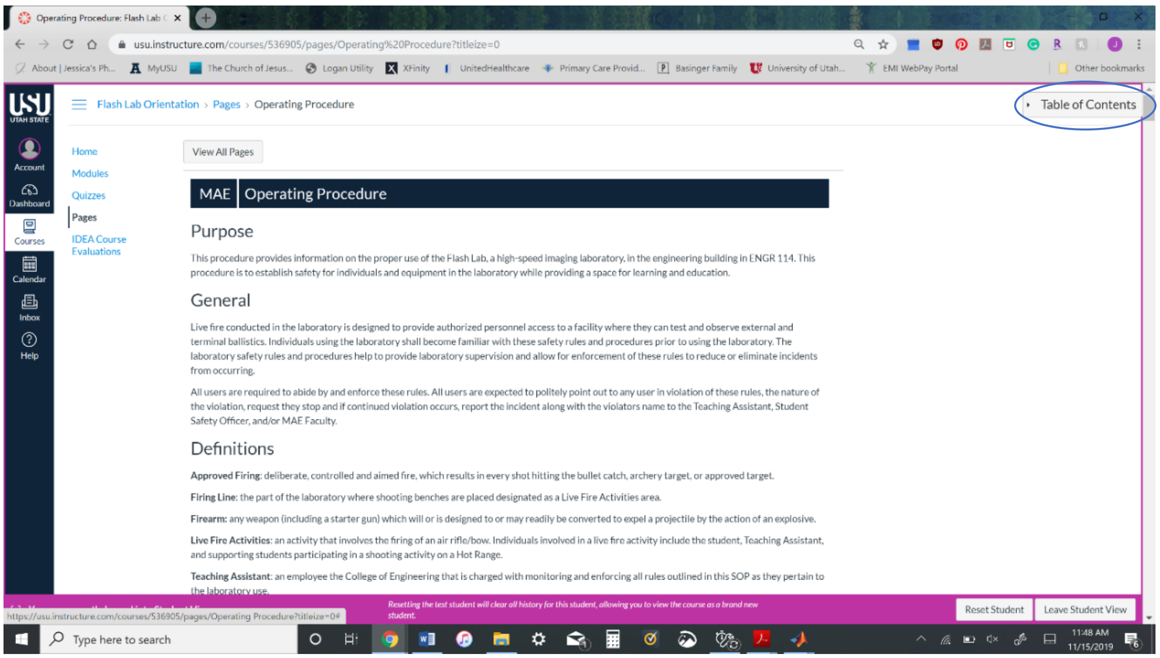

Figure 14. Operating Procedure Document Page showing where the table of contents

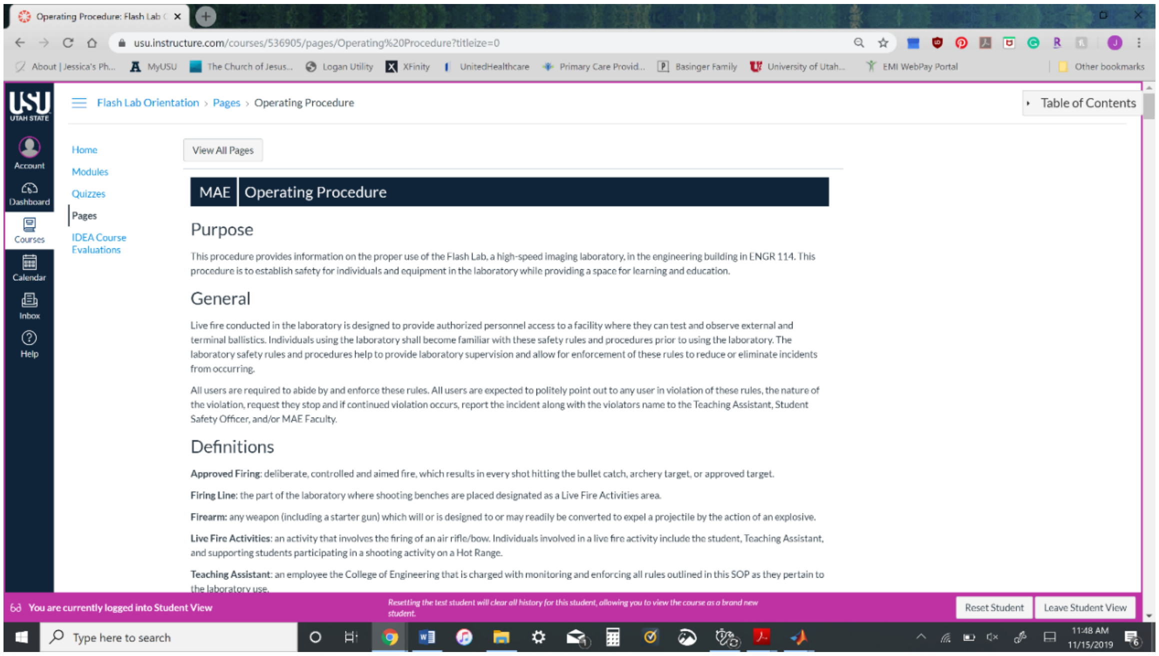

Figure 15. Operating Procedure Document Page

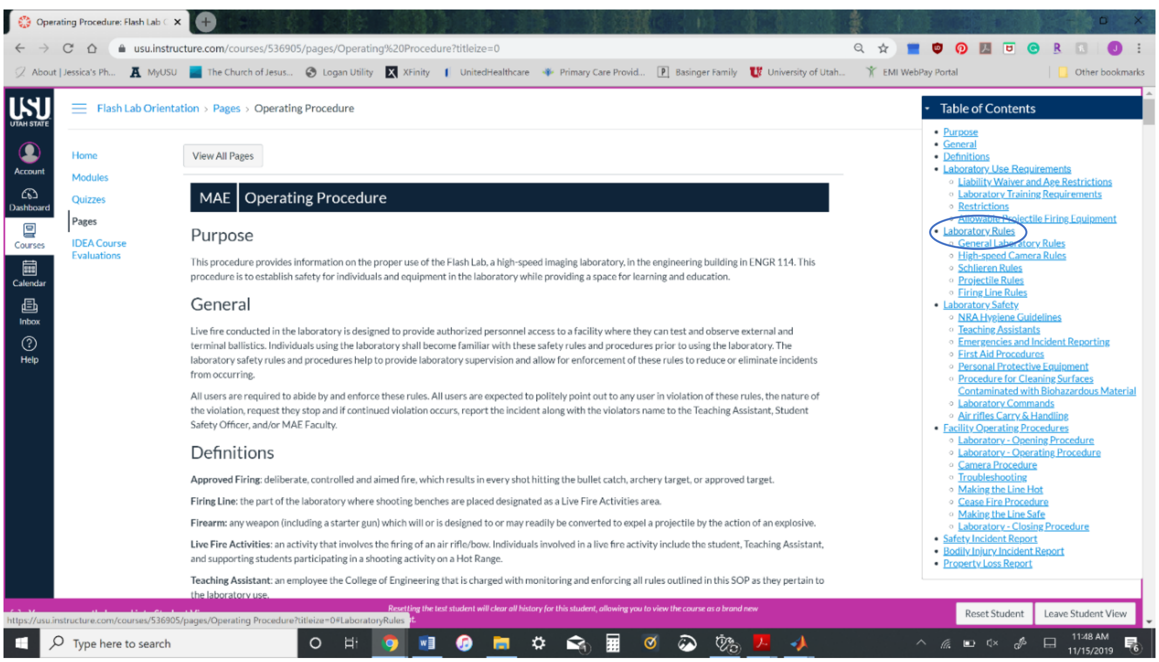

Figure 16. Operating Procedure Document Page, Table of Contents Expanded showing inter page links

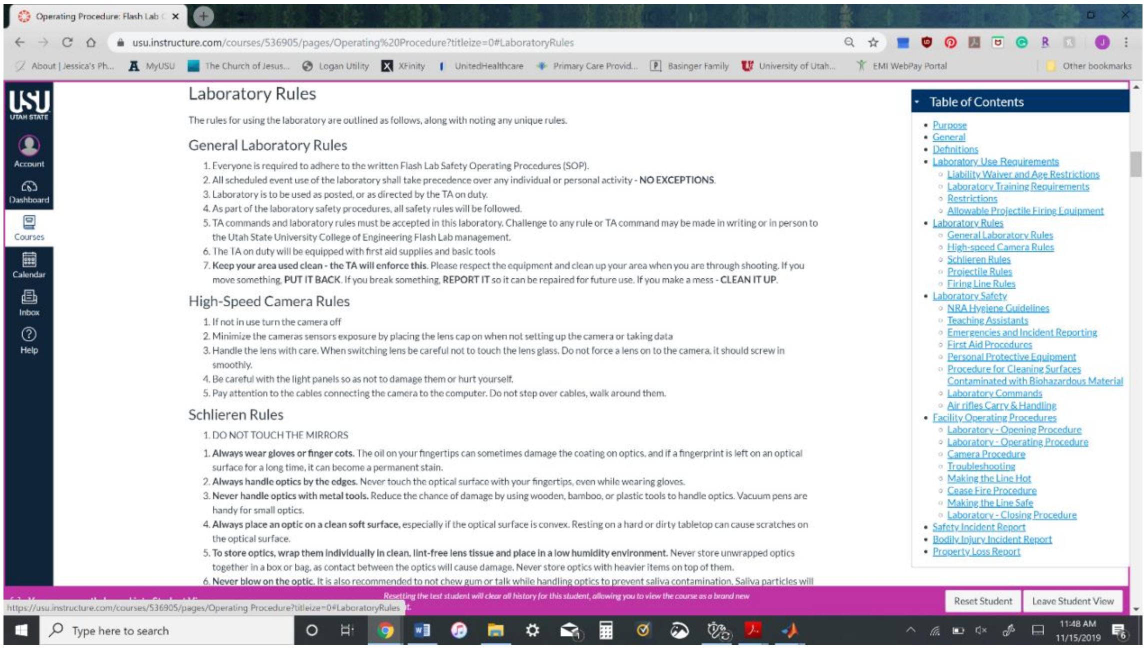

Figure 17. Operating Procedure Document Page, Table of Contents Expanded jump to Laboratory Rules

EXPERIMENTS

These experiments were chosen to be implemented into the Thermal/Fluids Lab and are designed to be simple enough that students could learn and understand the phenomenon in two weeks. Each experiment section briefly discusses the experiment and learning objectives, background, and a prompt to be used for the Thermal/Fluids Lab.

Supersonic Ping-Pong Ball

A ping pong ball will be launched down range, using a vacuum powered cannon, at supersonic speeds while students measure the velocity of the ping pong ball with a chronograph and using image processing. This experiment will help students apply modern measurement techniques through the following learning objectives:

- Learning the accuracy of different measurement techniques
- Learning image processing measurement techniques such as lighting, pre-

processing, post-processing, and image manipulation

- Compare the different measurement techniques to determine which one has the least amount of uncertainty

Background Information

Velocity cannot be directly measured using the raw images from a high-speed camera. However, students can determine the velocity through image processing. The high-speed camera saves the event as individual images, which allows for them to be easily imported into MATLAB for image manipulation. In MATLAB, the image is changed to black and white by using edge finding, dilating, and eroding techniques. Figure 18 illustrates a comparison of the raw high-speed images with the post-processed output images.

This allows the computer to track the movement of the ball with much higher precision than with grey scale. The position of the ball is plotted as a function of time and a second order best-fit curve is applied. Taking the derivative of the best-fit curve of the position data gives an equation of velocity as a function of time. An uncertainty analysis can then be applied to the velocity function.

Students will need to have a reference dimension so they can convert from pixels to a distance after which they will compare this answer with what the chronograph measures.

Figure 19 shows a schematic of the ping pong ball cannon. The cannon is designed to launch ping pong balls near Mach 1. This seems unrealistic because ping pong balls hit with a paddle don't go that fast, this is due to the amount of air resistance caused by the low mass of the ball. If there was no air to slow the ping pong ball down

the ball could be accelerated to high speeds. This can be done by placing the ping pong ball in a vacuum and allowing the vacuum seal to be broken rapidly. The pressure difference between the outside air and the vacuum will apply a force to the ping pong ball which will accelerate it down the barrel at approximately Mach 1.

By sealing both ends of the cannon and creating a vacuum on the inside by attaching a vacuum pump. Once a vacuum has been established the seal near the gauge is broken rapidly to allow the atmospheric pressure to propel the ball down the barrel. Without air resistance in the pipe the ball shoots down the barrel at approximately Mach 1.

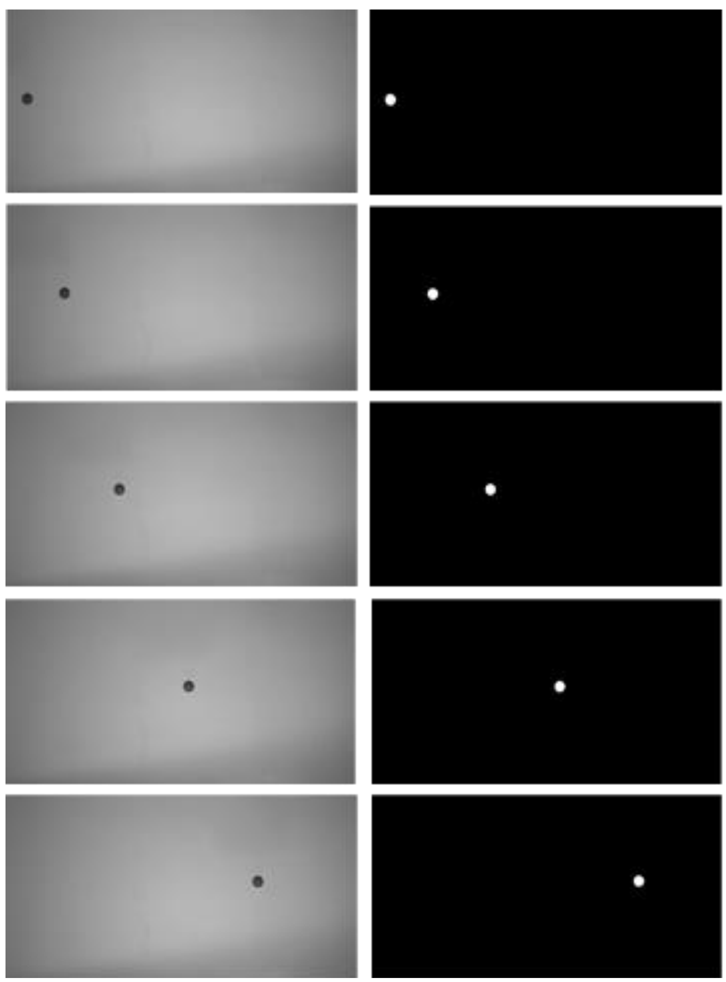

Figure 18. Comparison of pre-processed (right) images to post-processed images (left)

The schematic in Figure 19 is the simplest set up for the ping pong cannon. One option is to pressurize the vacuum seal near the gauge and increase the pressure until the

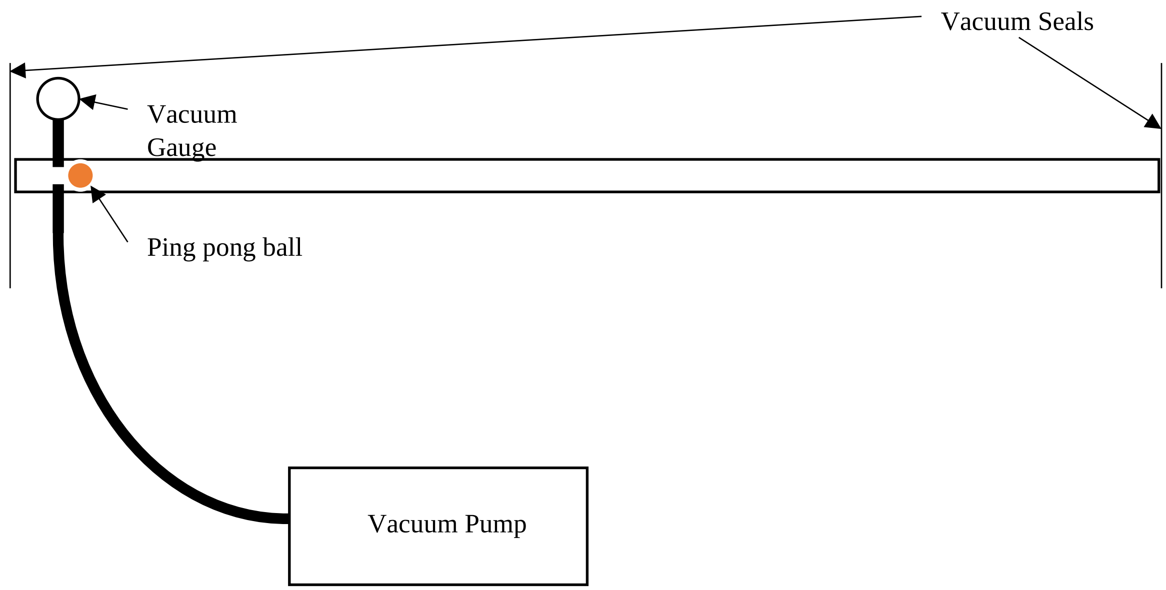

Figure 19. Schematic of the ping pong canon

seal breaks. This would generate a larger force on the ping pong ball to accelerate it at a more rapid pace. Perdue University does this with their ping pong cannon in addition to using a converging-diverging nozzle. This guarantees the ping pong ball will be launched above Mach 1. [3]

Results

By reaching a near vacuum of 24 in of Hg the ping pong ball cannon will fire reliably. Figure 20, shows the velocity of seven shots of a ping pong ball, measured with a Caldwell ballistic chronograph, and calculated by using image processing techniques. The first two shots the chronograph had reading errors. This means that either the ping pong ball not recorded by front sensor or the ball not recorded by rear sensor. Florescent lighting can sometimes interfere with the measurement as well causing the reading errors

or less accurate measurements. All seven shots were fired with a vacuum of 24 in of Hg with the same ball. Under these conditions the balls velocity should have been similar between each shot. The recorded chronograph values support this having an average value of 495.4 ± 27.77 fps at 95% confidence. While the calculated velocity values have an average value of 437.50 ± 160.7 fps at 95% confidence. The main reason for such a higher uncertainty of the calculated velocity due to the uncertainty of the induvial shot velocity due to the resolution of the camera. The camera was setup in such a way where

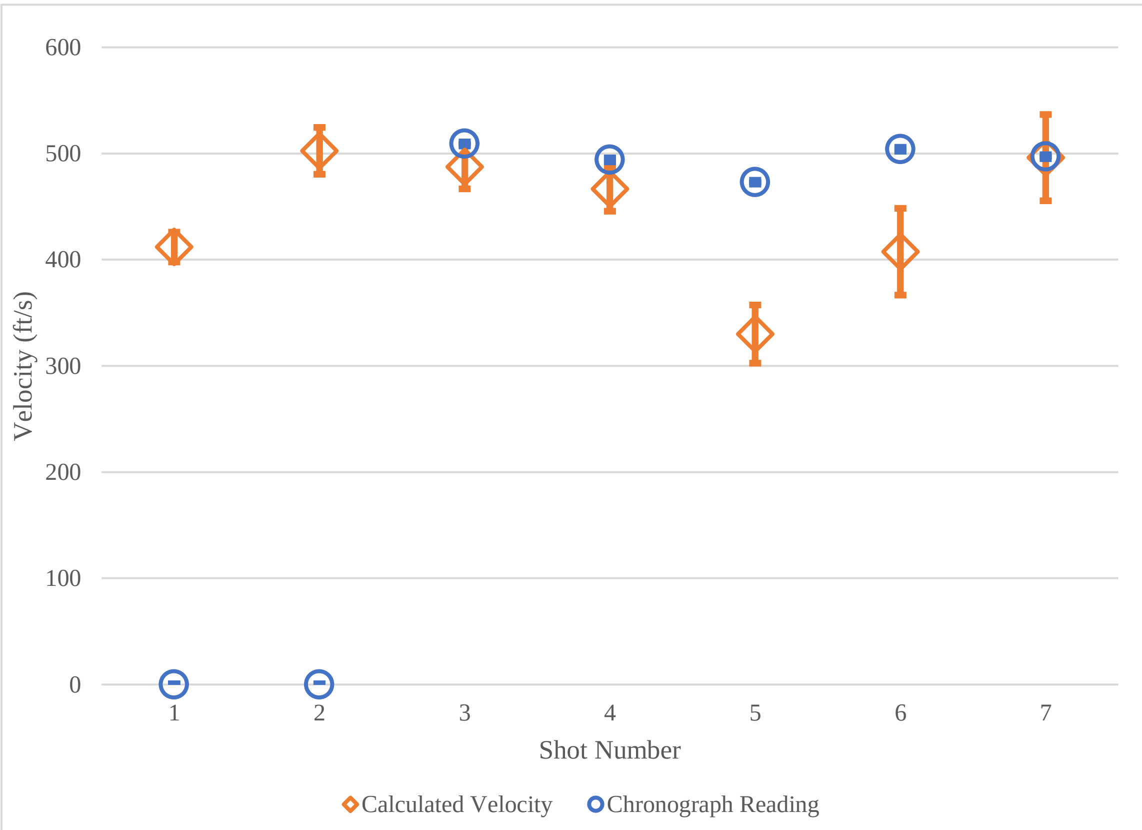

Figure 20. Velocity of each shot of a ping pong ball with the uncertainty of each shot at 2σ

there was only 66 pixels per inch (ppi) if the camera could be moved closer to the ping pong ball the individual shot uncertainties would be much lower and an average could be calculated with a smaller standard deviation between shots. Another way to increase the accuracy of the chronograph would be to replace the fluorescent lights with LED lighting.

Safety Procedure

Detailed in the canvas course and operating procedure under Projectile Rules.

Prompt

Dear Team

Yeager Industries has contacted us regarding a group of chronographs that have recently been recalled. They've asked us to develop and implement a testing procedure to quickly and accurately determine which chronographs are not providing correct results. Yeager Industries has requested a report containing details on the independent process used to determine the velocity of the projectile and any written code for the project. They have suggested using image processing techniques since they have access to high speed cameras but are open to suggestions.

Please be sure to give a velocity uncertainty value that is less than or equal to the stated chronographs uncertainty. If the velocity uncertainty is not less than or equal to the stated chronographs uncertainty, please provide suggestions on how to improve the uncertainty of the image processing or recommend a different method that can provide more accurate results.

Sincerely

E. Federov

Project Manager

Rainbow Schlieren Over a Heated Plate

With high-speed cameras having high resolutions and color capabilities schlieren imaging is being used in new ways. Using a colored filter instead of a knife's edge allows for the information the schlieren image captures to be quantified. Students will measure temperature of air surrounding a hot plate using image processing to calculate the changes in density by the change in color from the image. This experiment will help students apply modern measurement techniques through the following learning objectives:

- Importance of calibration
- Image Processing
- Rainbow Schlieren measurement technique

Background information

Traditional schlieren images are created by focusing a column of light to a point and splitting it with a knife edge. This allows for small changes of index of refraction to be seen. The changes in the index of refraction of the medium are displayed as brighter or darker from the undisturbed background. Rainbow schlieren deflectometry (RSD) images are created by a colored filter are similar to black and white schlieren images created by a knifes edge. There is no way to quantify how much the index of refraction changes with traditional schlieren images. A carefully made color filter with a calibration allows for the changes in index of refraction to be measured.

To calibrate the colored filter the light needs to be focused in the center for the greatest sensitivity and the medium left undisturbed. A series of reference images are taken as the color filter is moved over a known transverse distance. Example of raw images taken for calibration are shown in Figure 21

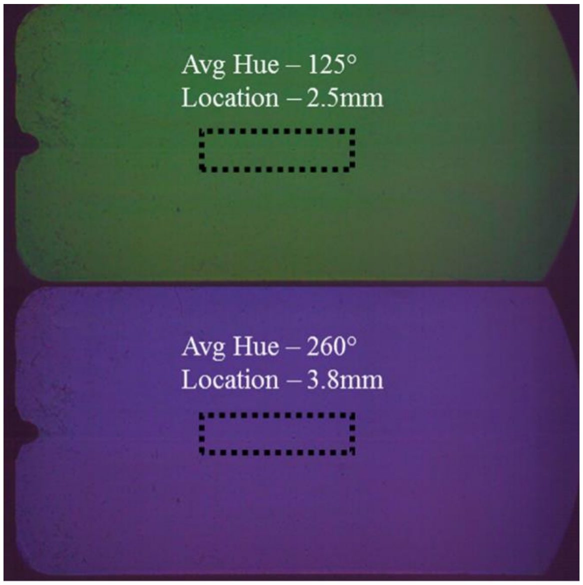

Figure 21. Example screen shots (no postprocessing) used for calibration of distances as a function of hue recorded by the camera. Taken from Figure 4 of Mirynowski et al. [5]

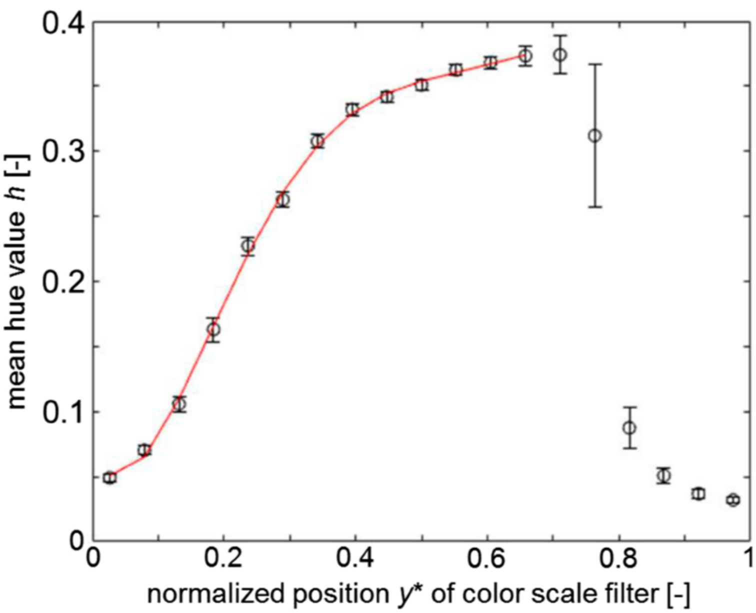

Figure 22. Calibration of a colored filter used by Schulz et al. 31[4]

The images are converted from red, green, and blue (RGB) to hue, saturation, and value (HSV). The hue and transverse distance are then calibrated. From here, either a best fit equation can be used to calculate the transverse distance values or a linear interpolation. An example of a calibration is show in Figure 22.

Depending on the phenomenon being observed requires different assumptions. From Schulz et al., the index of refraction being symmetric in the 2D plane, axisymmetric, and spherical is discussed [4]. The one we will focus on in this lab is the index of refraction being symmetric in the 2D plane. The state variable Z form of the equation is given below from the orientation of Figure 23:

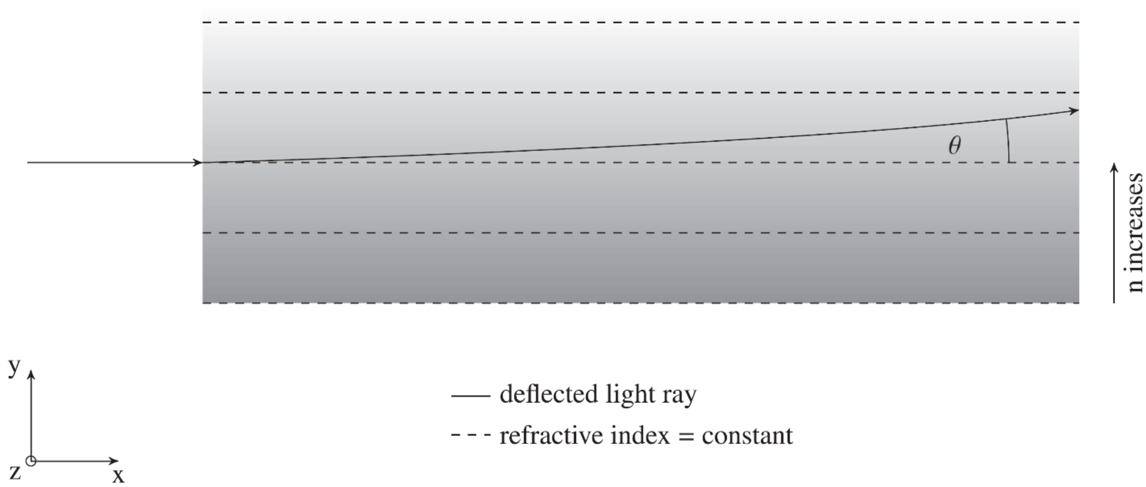

Figure 23. Path of a light ray in an inhomogeneous refractive index field with assumption of symmetry in depth. Taken from Figure 2 of Schutz et al. [4]

$$\left(\frac{\partial Z}{\partial y}\right)_{y,z}(x) = const = \frac{\Delta y(y,z)}{f}\frac{n_\infty}{L}\frac{1}{\frac{\partial n}{\partial Z}} \qquad \textit{Eq. 1}$$

Where $\Delta y(y, z)$ is the interpolated transverse distance calculated by the hue at a point, f is the focal length of the mirror or lens, n_∞ is the index of refraction of the undisturbed medium, L is the length of the inhomogeneous region, and $\frac{\partial n}{\partial Z}$ is how the index of refraction is related to the state variable. By knowing the changes of one state

variable by the change in the index of refraction then any of the other thermodynamic properties can be calculated through isentropic relations. For temperature $\frac{\partial n}{\partial Z}$ is given by

$$\frac{\partial n}{\partial Z} = \left(0.0229 \cdot \frac{T^2}{{}^\circ C^2} + 7.19 \cdot \frac{T}{{}^\circ C} - 1066.6\right) \cdot 10^{-9} K^{-1} \qquad \textit{Eq. 2}$$

Safety Procedure

Detailed in the canvas course and operating procedure under Schlieren Imaging Rules.

Prompt

Dear Team,

Hooke & Co. wants to install a non-contact method of measuring temperature so they can know when their material is safe to handle. They have requested we use a rainbow schlieren set up to measure temperature gradients and would like a detailed report on calibration, performance, and uncertainty. Verify your process with analytical heat transfer equations and discuss any discrepancies between the analytical and measured data. The use of thermal imaging is available for reference and checking your work.

Rob

Project Coordinator

Future Lab Ideas

A list of potential experiments has been compiled that students could do to learn about phenomena that can only be observed with a schlieren imaging device and high-speed cameras. These labs have been divided into subcategories: Flight, Arrow Ballistics,

Bullet Ballistics, Heat Transfer, and Sound.

Flight

Flight is a phenomenon that requires varying pressure gradients. Using a schlieren imaging device students will be able to see the pressure gradients and how it helps and affects flight. A potential lab would be observing the flight of a Frisbee. Students could predict and observe why a spinning disk can glide through the air. In conjunction with the lab to validate the schlieren images, students could also find a Computational Fluid Dynamics (CFD) solution. Students could then work out a potential flow solution and compare the pressure gradients of the solution to the schlieren image and the CFD solution. A lab could be setup to validate the images the schlieren device produces.

From Aerodynamics, spinning cylinders have lift. This is in part to the Magnus effect. Students would be able to analytically find the Magnus force and then measure it. Another lab for student to study hydrodynamic levitation. Students could discover the physics of why a ball or disk can be suspended by a jet of water.

Arrow Ballistics

One of the oldest areas of ballistics is arrows. By observing the midflight characteristics and the pattern of the arrows on the target, students could observe how different arrow midflight characteristics affect the pattern. Some characteristics that could be varied are arrow shaft lengths, arrowhead shapes and weights, and the arrow fletching. Students could explore the relationship between a bow’s draw weight and draw length to the optimal arrow length. Another arrow characteristic that could vary is the arrowhead shape and weight. A relationship could also be formed between the different shapes and weights to see which had a greater effect on the velocity of the arrow.

An arrow fletching has two effects on an arrow in flight, one is to stabilize the arrow, the other to is induce drag. The two extremes are synthetic short fletching and feathered long fletching. Students could think of some experiments to determine which type of fletching would work best for a given situation. Different types of bows act differently. With a recurve bow, as you increase the draw length the heavier the draw weight becomes. With a compound bow, as you increase the draw length the draw weight stays the same. Students could calculate the velocity of the arrows at different draw lengths and determine which is more efficient

Bullet Ballistics

With long range shooting gaining popularity, bullet ballistics has become an area of interest among students. Most bullets travel above the speed of sound. With a schlieren image students can see a shock wave when the bullet breaks the sound barrier. Students could see if the shape of the pellet affects the angle of the shock wave. The ballistic coefficient (BC) is a number that represents a bullet's ability to maintain its initial velocity. A lab could be developed where students could measure the velocity at different distances and calculate and validate the BC.

Barrel Harmonics play a large part in a rifle's inherent accuracy. Students could use rubber dampeners and experimentally find the optimal location for the dampener that would minimize barrel oscillations. They then could derive and an equation to locate the optimal location for the dampeners for the air rifle. Muzzle breaks affect a lot of things in a rifle from reducing recoil to increasing sound level. Students could explore all the different aspects that a muzzle break effects.

Another aspect of ballistics that has become increasingly popular is terminal

ballistics (i.e. what happens to the bullet upon impact). By using ballistics gel, students can calculate energy and momentum transfer. They can also retrieve the bullets from the gel and record the deformed geometry and retained mass to determine its effectiveness.

Heat Transfer

Schlieren images can detect changes in index of refraction, which could help students visualize and better understand heat transfer. By correlating the changes to the index of refraction to the air temperature, students could observe the air movement in a schlieren image. Then using image processing measurement techniques, students could calculate the convection from an object. They could also observe different insulation materials or heat sink geometries to see how effective they are. The last lab that could be done is to compare the schlieren image to that of a Flir camera image.

Sound

Sound waves are created by pressure fluctuations, which can be seen in the schlieren image. There are a variety of labs that students could do. One example would allow students to measure the angle of a shock wave and calculate the speed of an object or sound wave. Mach diamonds are a phenomenon of propellent or gases exiting a nozzle at supersonic speeds. Students could analytically find the locations of the Mach diamonds and compare it to the images taken with the schlieren imaging device and a high-speed camera or still shots.

Every instrument has limitations and areas where it is better suited, another lab could be for student to record what frequencies can be seen by schlieren imaging device and which frequencies cannot be seen. A fun experiment would be to observe a Bullroarer, a device historically used for communicating over great distances. A

Bullroarer makes an interesting sound as it is swung in circles. Students could predict what makes the sound and through high-speed cameras and the schlieren images they could refine their prediction.

Experimental Setup and Data Collection Capabilities

The Flash Lab follows a similar setup to the Thermo/Fluids lab of a sandbox environment for the students to accomplish the labs. Simple guidelines on lab goals and procedures are provided while being open to the students' creativity to solve the problem. Another potential is to have the lab accessible to graduate students to allow them to explore their own questions about phenomena that can only be observed with a schlieren imaging device and high-speed cameras. Some of the capabilities of the lab would be:

- A high-speed camera
- Schlieren imaging setup
- Infrared thermometer
- Flir Camera
- High-speed photography

Possible Industry Contacts

Below is a list of companies in Utah and Idaho that deal with ballistics. Getting their involvement would greatly increase the relevance of the labs and help more students get into the industry.

Utah Companies

- Barnes Bullets (Mona) – Copper Bullet Manufacture
- SilencerCo (West Valley) – Suppressor

- GoldTip Arrows (Murray) – Arrows
- Christensen Arms (Gunnison) – Actions, Barrels, and Rifles
- Browning (Morgan) – Firearms, Bows, Ammunition
- Winchester Repeating Arms (Morgan) – Firearms
- Hoyt Archery (Salt Lake City) – Bows and Crossbows
- Vista Outdoors (Farmington) – Multiple Outdoor Companies (e.g., Federal, Speer, and CCI etc.)
- Easton (Salt Lake City) – Arrows
- Cobalt Kinetics (Washington) – Custom Competition AR-15

Idaho Companies

- Am-Tac Precision (Garden City) – Upper Receiver & Bolt Assembly
- ATK Blackhawk! (Lewiston) – Stock, Pistol Grip, Bi-Pod, & Sling
- Forward Moving Training Center (Boise) – Training donation
- Gem-Tech (Boise) – Suppressor
- Hooker Tactical (Arco) – Scope Camera for training
- Kryptek Outdoor Group (Eagle) – Gun Case
- Lone Wolf Distributors (Priest River) – Trigger Kit, Custom Engraving & Misc. Parts
- MCM Firearms (Nampa) – Custom Kryptek Camo Skin
- MGM Targets (Caldwell) – Switchview Scope Lever
- Nightforce Optics (Orofino) – Scope & Scope Mounts
- Primary Weapon Systems (Boise) – Barrel & Enhanced Buffer Tube

- Seekins Precision (Lewiston) – Lower Receiver
- Unique AR's (McCall) – Hand Guard & custom cutting of IGC logo & Paint Design

RENOVATION

Renovations for the lab started in Summer 2019 with cleaning out the storage room. The majority of the material stored went into surplus. Once the storage room was cleared out our facility's department polished the concrete floor, painted the walls, and added the storefront window to showcase the lab. Compressed air and a vacuum were added, along with a ceiling track to hang the backstop netting for safety measures. We worked with our interior design department to ensure the lab has a clean presentation as well as integrates with the College of Engineering's current design.

Budget Summary

This budget summary includes the estimated and actual cost to setup and furnish the room.

Flash Lab - ENGR 114 - Budget				
Item	Estimated Cost	Actual Cost	Difference	
Furniture (Herman Miller)	$2,569.17	$3,313.99	($744.82)	All Seating and Tables
Motorized Roller Shades	$2,990.00	$2,218.00	$772.00	Three Sections of Blinds (Room Darkening)
Neon Sign	$800.00	$790.00	$10.00	Text: The Flash Lab Color: White
Storage Cabinets	$800.00	$800.00	$0.00	Shelving
Firing Line (Vinyl)	$100.00	$100.00	$0.00	
Door and Wallcovering Vinyl	$4,000.00	$2,375.00	$1,625.00	
Construction	$21,500.00	$21,500.00	$0.00	Storefront Glass, Polished Concrete Floor, Dimmable Lighting, Wall Paint, Electrical, Etc. (Done)
Compressed Air	$500.00	$500.00	$0.00	
Net Track System	$500.00	$500.00	$0.00	Track and Track Rollers (Doesn't Include Carabiners)
Setup and Equipment	$13,314.70	12,779.47	$535.23	Complete List in Appendix B
Personnel	$5,280.00	$3,750.00	$2,280.00	Cody Hatch (1 Semester)
	Total:			
	$52,353.87	$48,626.46	$3,727.41	

CONCLUSTION

The Flash Lab was designed and set-up by collaborating with interior designers, risk management, and USU police to ensure it is a safe, inviting, and practical space. Two labs have been written that can be incorporated with current courses. A list of experiments has been provided that will expand the versatility of this lab space and maximize the use of the proposed equipment. Detailed safety procedures and liability waivers have been implemented to ensure each student and faculty member has a clear understanding of the risks that come with using the Flash Lab. To mitigate any potential accidents, proper training resources have been provided. The precautions put in place will allow students to be safely exposed to a variety of measurement techniques and provide them with more tools for research and projects. The Flash Lab is a great asset to the University and will help better the education of the students attending. The result of this project will help retain and draw in perspective students to the College of Engineering.

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APPENDIX A

Standard Operation Procedure

PURPOSE

This procedure provides information on the proper use of the Flash Lab, a high-speed imaging laboratory, in the engineering building in ENGR 114. This procedure is to establish safety for individuals and equipment in the laboratory while providing a space for learning and education.

GENERAL

All users are required to abide by and enforce these rules. All users are expected to politely point out to any user in violation of these rules, the nature of the violation, request they stop and if continued violation occurs, report the incident along with the violators name to the Teaching Assistant, Student Safety Officer, and/or MAE Faculty.

Individuals using the laboratory shall become familiar with these safety rules and procedures prior to using the laboratory. The laboratory safety rules and procedures help to provide laboratory supervision and allow for enforcement of these rules to reduce or eliminate incidents from occurring.

Live fire conducted in the laboratory is designed to provide authorized personnel access to a facility where they can test and observe external and terminal ballistics.

DEFINITIONS

Approved Firing: deliberate, controlled and aimed fire, which results in every shot hitting the bullet catch, archery target, or approved target.

Firing Line: the part of the laboratory where shooting benches are placed designated as a Live Fire Activities area.

Firearm: any weapon (including a starter gun) which will or is designed to or

may readily be converted to expel a projectile by the action of an explosive.

Live Fire Activities: an activity that involves the firing of an air rifle/bow. Individuals involved in a live fire activity include the student, Teaching Assistant, and supporting students participating in a shooting activity on a Hot Range.

Teaching Assistant: an employee the College of Engineering that is charged with monitoring and enforcing all rules outlined in this SOP as they pertain to the laboratory use.

Student Safety Officer: a student in the College of Engineering that is charged with monitoring and enforcing all rules outlined in this SOP as they pertain to the laboratory use.

Rapid Firing: firing more than two shots in a one second period.

Uncontrolled Firing: firing from the hip, firing an air rifle without the butt of the stock against the student's shoulder, or any other type of firing in which the air rifle/bow is not aimed by having the student's eye aligned with the air rifle/bow sights and the sights aligned with an approved target.

Cease Fire: students stop shooting, air rifle/bows are cleared of all ammunition/crossbow bolts and placed on shooting bench with actions open and muzzle pointed down range.

Hot Range: no Cease Fire is in effect; air rifle/bows may be handled and fired.

Cease Fire Range: Cease Fire is in effect, stay away from shooting benches and **NO HANDLING OF THE AIR RIFLE/BOWS**.

LABORATORY USE REQUIREMENTS

The use of the Utah State University College of Engineering Flash Lab is covered by these Standard Operating Procedures (SOP's). These SOPs define what every person

engaged in live-fire activities must know prior to being permitted to use the Flash Lab. These SOPs define what every student must know to utilize the Utah State University College of Engineering Flash Lab.

Liability Waiver and Age Restrictions

All users of the Utah State University College of Engineering Flash Lab must fill out and sign a liability waiver on each day that they use the laboratory. Students must have a current and signed liability waiver on file before using the laboratory.

- Individuals ages 18 - 20 will be permitted to use the Flash Lab for air rifles and air pistols only if accompanied by an adult 21 or older.
- Utah State University College of Engineering Flash Lab rules on age and gun possession are in line with federal and state laws.
- Individuals under the age of 21 who possess a handgun will not be allowed in the laboratory and will be asked to leave the property unless accompanied by someone 21 or older.

Laboratory Training Requirements

All potential users of the Utah State University College of Engineering Flash Lab must complete a laboratory orientation. The orientation may be one or any combination of a safety video, in-person briefing, and formal classroom training. The amount of training will be determined by the Utah State University College of Engineering Flash Lab management and/or TA on duty.

Each potential user of the Utah State University College of Engineering Flash Lab will be given a CANVAS quiz indicating that they have seen the required safety video and read this SOP, which upon passing, is an endorsement for use of the laboratory. Students will only be allowed to use the laboratory upon completion of the CANVAS

quiz.

NOTE: The TA on duty is tasked with the authority to require anyone shooting in the laboratory be given additional training before being allowed to shoot in the laboratory again and revoking their laboratory use.

Restrictions

The following are strictly prohibited in the Utah State University College of Engineering Flash Lab:

1. Any firearms or muzzleloaders that uses gunpowder to propel the bullet to the target.
2. No repeated misses of the target board, or pellet/arrow strikes that ricochet causing a possibility of pellet/arrows leaving the Laboratory.
3. No disruptive activities, such as loud music or children that are not supervised properly on the firing line.
4. No loaded firearms are allowed in the Utah State University College of Engineering Flash Lab.
5. Pellets or arrow tips that contain lead

Allowable Projectile Firing Equipment

1. Air rifles that are either CO_2 or hand powered.
2. Air pistol that are either CO_2 or hand powered.
3. Bows approved by the professor

LABORATORY RULES

The rules for using the laboratory are outlined as follows, along with noting any unique rules.

General Laboratory Rules

1. Everyone is required to adhere to the written Flash Lab Safety Operating Procedures (SOP).
2. All scheduled event use of the laboratory shall take precedence over any individual or personal activity - **NO EXCEPTIONS**.
3. Laboratory is to be used as posted, or as directed by the TA on duty.
4. As part of the laboratory safety procedures, all safety rules will be followed.
5. TA commands and laboratory rules must be accepted in this laboratory. Challenge to any rule or TA command may be made in writing or in person to the Utah State University College of Engineering Flash Lab management.
6. The TA on duty will be equipped with first aid supplies and basic tools
7. **Keep your area used clean - the TA will enforce this**. Please respect the equipment and clean up your area when you are through shooting. If you move something, **PUT IT BACK**. If you break something, **REPORT IT** so it can be repaired for future use. If you make a mess - **CLEAN IT UP**.

High Speed Camera Rules

1. If not in use turn the camera off
2. Minimize the cameras sensors exposure by placing the lens cap on when not setting up the camera or taking data
3. Handle the lens with care. When switching lens be careful not to touch the lens glass. Do not force a lens on to the camera, it should screw in smoothly.
4. Be careful with the light panels so not to damage them or hurt yourself.

5. Pay attention to the cables connecting the camera to the computer. Do not step over cables, walk around them.

Schlieren Rules

These rules are taken from Edmund Optics [1] and the handling and care section is taken from Thor Labs [2].

1. DO NOT TOUCH THE MIRRORS
2. Always wear gloves or finger cots. The oil on your fingertips can sometimes damage the coating on optics, and if a fingerprint is left on an optical surface for a long time, it can become a permanent stain.
3. Always handle optics by the edges. Never touch the optical surface with your fingertips, even while wearing gloves.
4. Never handle optics with metal tools. Reduce the chance of damage by using wooden, bamboo, or plastic tools to handle optics. Vacuum pens are handy for small optics.
5. Always place an optic on a clean soft surface, especially if the optical surface is convex. Resting on a hard or dirty tabletop can cause scratches on the optical surface.
6. To store optics, wrap them individually in clean, lint-free lens tissue and place in a low humidity environment. Never store unwrapped optics together in a box or bag, as contact between the optics will cause damage. Never store optics with heavier items on top of them.
7. Never blow on the optic. It is also recommended to not chew gum or talk while handling optics to prevent saliva contamination. Saliva particles will often stain the surface.

Handling and Cleaning Procedures for Optical Components

The delicate nature of optical components requires that special procedures be followed in order to maximize their performance and lifetime. Through everyday use, optics can come in contact with contaminants such as dust, water, and skin oils. These contaminants increase scatter off the optical surface and absorb incident radiation, which can create hot spots on the optical surface, resulting in permanent damage. Optical components with coatings are particularly susceptible to this sort of damage.

The content of this guide covers common handling and cleaning procedures that are applicable to many optical components. Due to variation in materials, size, delicacy, etc. of optical components, it is important that the correct handling and cleaning methods are used. What is okay for one type of optical component will destroy another type of optical component. Because of this, we recommend that the guide be read in its entirety before cleaning an optic. If the type or category of optic is not specifically mentioned in the guide, please contact the optical component manufacturer for handling and cleaning instructions.

Handling

By practicing proper handling techniques, you will decrease the necessity to clean your optics and thus maximize their lifetime. Always unpack or open optics in a clean, temperature-controlled environment. Never handle optics with bare hands, as skin oils can permanently damage the optical surface quality. Instead, wear gloves; alternatively, for smaller optical components, it may be helpful to use optical or vacuum tweezers. Independent of the method used to hold the optic, if at all possible, only hold the optic along non-optical surfaces, such as the ground edges of the optic.

Important: The optical surface of holographic gratings, ruled gratings, first surface

unprotected metallic mirrors, and pellicle beamsplitters (this is not an exhaustive list) should never be touched by hands or optical handling instruments. They are extremely sensitive, and any physical contact will cause damage.

Caution: Most crystals (e.g., calcite polarizers, beam displacers, lithium niobate wafers, and EO modulators) are temperature sensitive and can crack if exposed to thermal shock. Therefore, it is important to always allow the package and contents to come to thermal equilibrium prior to opening. These crystals are also much softer than conventional optics, and thus, need to be handled more carefully when cleaning.

Storage

Never place optics on hard surfaces because any contaminant on the optic or the surface will be ground in. Instead, most optics should be wrapped in lens tissue and then stored inside an optic storage box designed for the optic. Typically, the box should be kept in a low humidity, low contaminant, and temperature-controlled environment. Optics are easily scratched or contaminated, and some optical coatings are hygroscopic, so proper storage is important for preserving the optical component.

Inspection

In general, optics should be inspected prior to use and before and after cleaning. It is often necessary to use a magnification device when inspecting an optical component due to the small size of most contaminants and surface defects. Even with a magnification device, it is sometimes useful to shine a bright light onto the optical surface in order to increase the intensity of the specular reflections from surface contaminants and defects.

When inspecting a reflectively coated surface, the optic should be held nearly parallel to your line of sight. By looking across the surface rather than directly at it, you

will see contamination and not reflections. Polished surfaces such as lenses should be held perpendicular to your line of sight so that you can look through the optic.

If a surface defect is located on a clean optical surface, a scratch-dig paddle can be used to categorize the size of the defect by comparing the size of the calibrated defects on the scratch-dig paddle to the size of the defects on the surface of the optic. If the size of the defect on the surface exceeds the manufacturer's scratch-dig specification, it may be necessary to replace the optic in order to achieve the desired performance.

Cleaning Procedures

Always read the manufacturer's recommended cleaning and handling procedures if available. Since cleaning an optic almost invariably involves handling it, please make sure to follow the proper handling procedures at all times when using the cleaning guideline discussed below. Optics can be permanently damaged if cleaned or handled incorrectly.

Before cleaning an optic, take time to inspect the optic in order to determine the type and severity of the contaminants. This inspection step should not be skipped because the process of cleaning the optic often involves solvents and physical contact with the optical surface, which can result in damage to the optical surface if repeated too frequently.

For optics with multiple contaminants, the order with which they are removed can be important so that the optical surface is not damaged by one contaminant while removing a separate contaminant. For instance, if an optic is contaminated with oil and dust, it is possible that wiping the oil off first will scratch the optical surface as the dust is drug along the surface by the wipe.

<u>Blowing Off the Surface of an Optic</u>

Dust and other loose contaminants usually should be blown off before any other cleaning technique is employed. A canister of inert dusting gas or a blower bulb is needed for this method. Do not use your mouth to blow on the surface because it is likely that droplets of saliva will be deposited on the optical surface.

If you are using inert dusting gas, hold the can upright before and throughout the procedure. Do not shake the can prior to or during use. Also, start the flow of gas with the nozzle pointed away from the optic. These steps help prevent the deposition of the inert gas propellant on the optical surface. If using canned gas, hold the can roughly 6” from the optic and use short blasts. Wave the nozzle of the inert gas can over the optic with the nozzle at a grazing angle to the optical surface. For large surfaces, trace a figure-eight pattern over the optical surface.

This cleaning method can be used on almost all types of optics. However, for some optics such as holographic gratings, ruled gratings, unprotected metallic mirrors, calcite polarizers, and pellicle beamsplitters, which can be damaged by physical contact, this is the only approved method for cleaning. Due to the non-contact and solvent-free nature of this cleaning method, it should be used as a first step in cleaning almost all optics.

Caution: The 2 μm thick Nitrocellulose membrane on pellicle beamsplitters is extremely fragile and easily broken by the force of air on the surface. If using canned air with these optics, ensure that the bottle is sufficiently far away so as not to break the membrane.

Caution: The polished escape face on calcite polarizers is very delicate and can be damaged by blowing air too directly at the surface.

Alternative Cleaning Methods

If blowing off the surface of the optic is not sufficient, the following are other acceptable cleaning methods and materials. When cleaning an optic, always use clean wipes and optical grade solvents to prevent damage from contaminants. Wipes should always be moist with an acceptable solvent and never used dry. Acceptable wipes (in order of softness) are pure cotton (such as Webril Wipes or Cotton Balls), lens tissue, and cotton-tipped applicators.

Typical solvents employed during cleaning are acetone, methanol, and isopropyl alcohol (isopropanol). Use all solvents with caution since most are poisonous, flammable, or both. Read product data sheets and MSDS sheets carefully before using any solvents.

Washing the Optic

If approved by the manufacturer, fingerprints and large dust particles can be removed by immersing the optic in a mild solution of distilled water and optical soap. The optic should not remain immersed any longer than necessary to remove the contaminants. Afterwards, rinse the optic in clean distilled water. Depending on the optic, the Drop and Drag or Lens Tissue (applicator) methods can be used to apply a quick-drying solvent like acetone or methanol to the optic to accelerate drying. Avoid pooling of any cleaning solutions as they dry because that tends to leave streaks on the optical surface.

Drop and Drag Method

The Drop and Drag Method can be used for cleaning flat optical surfaces that are elevated above any surrounding surfaces. First, inspect the optic to determine the location of the contaminants. This allows you to plan your drag so that the contaminant is lifted from the surface of the optic as soon as possible instead of being dragged across the

surface of the optic. After inspection, place or hold the optic so that a weak lateral force on the surface will not cause the optic to move. Take a fresh, clean sheet of lens tissue and hold it above (not in contact) the optic so that as you pull the lens tissue it will be drawn across the optical surface. Next place one or two drops of an approved quick drying solvent on the lens tissue being held above the optic. The weight of the solvent will cause the lens tissue to come into contact with the optical surface. Slowly but steadily drag the damp lens tissue across the optic being careful not to lift the lens tissue off of the surface. Continue dragging the lens tissue until it is off of the optical surface.

The correct amount of solvent will keep the lens tissue damp for the entire drag but not leave any visible trace of solvent on the optical surface after the drag is finished. Inspect the optic and repeat if necessary, but only use each sheet of lens tissue once. This cleaning method is preferred by many since the lens tissue is only in light contact with the optical surface. This method can be used successfully to remove small adhered particles and oils from an optical surface. Heavy concentrations of contaminants often require repeated treatments.

Lens Tissue with Forceps or Applicator Method

This method is often used with mounted or curved surface optics that require cleaning with a solvent. Inspect the optic to locate the sources of contamination. Plan a wiping path that will not result in dragging any large contaminants over more of the optical surface than is necessary. If lens tissue is used, it is important to fold the tissue in such a way that the portion of tissue that comes into contact with the optic is not touched. Clamp the folded lens tissue with forceps in such a way that a smooth wipe over the optical surface can be executed. Next, apply a couple of drops of solvent to the lens tissue. The tissue should be damp, but not dripping. If too much solvent was added,

safely shake the excess solvent from the lens tissue. The lens tissue should now be wiped over the optical surface in a smooth motion.

During the wipe, continuously, but slowly, rotate the lens tissue. This will continuously change the portion in contact with the optical surface, which will rotate upward and away from the surface any accumulated contaminants. After the wipe, inspect the optic for any remaining contaminants or streaks and repeat the cleaning procedure if necessary, with a new lens tissue. Streaks tend to form if too much solvent was on the lens tissue or on the optical surface where the edge of the tissue was wiped. If streaks are forming at the edge of the lens tissue, choose a larger applicator or plan a continuous wiping path that eliminates the wiped interface on the optical surface. If a spiral or snaking wipe path is used, it might be necessary to use a slower drying solvent so that the optical surface doesn't dry until the wipe is complete.

Cleaning with Webril Wipes

Webril Wipes are soft, pure-cotton wipers that are highly recommended for cleaning most optics. They hold solvent well, do not dry out as fast as lens tissue or cotton-tipped applicators, and do not fall apart quickly like some other wipes. The outside edges of these wipes may leave some lint, so always use a folded edge when cleaning.

For smaller optics, roll the Webril wipe into a cone with the folded edge at the point, moisten the tip with a solvent and use the point as the wiping area. For larger optics, first cut the wipe into three pieces that are approximately 2.6" x 4". Fold the wipe length wise so that it now measures 1.3" x 4", and then make a fold approximately 1" from the end. Moisten the final folded edge with solvent and use that edge to wipe/clean the optical surface. Using a pump bottle to dispense the solvent will make it easier to hold the optic in one hand while moistening the wipe with the other.

During cleaning, wear gloves or finger cots. Pick up the optic in one hand and then wipe the Webril wipe lightly, continuously, and slowly across the entire surface of the optic so as to avoid streaking. You may need to adjust the amount of solvent, pressure applied to the wipe, and/or speed of the wipe to avoid streaks. Wiping times will also vary with solvent. For instance, if using acetone, you would need to wipe slightly faster than if you used alcohol since acetone dries faster.

Important Notes

- Always make sure optics are cool before cleaning.
- Be sure to follow the outlined handling techniques at all times.
- Cemented optics should not be immersed.

Be cautious when working with cleaning agents. Some may be poisonous or flammable, so read labels carefully before handling them. Through proper handling and cleaning of your optics, you will maximize their lifetime. Please contact our Technical Support team if you have questions regarding handling and cleaning optics.

Projectile Rules

1. Targets will be provided by the lab. Personal targets may be used if they meet the requirements of Utah State University College of Engineering Flash Lab management and/or TA on duty. Plastic bottles, glass targets, tin or aluminum cans, explosive targets, and any other exotic items may not be used as targets at any time without the permission of the Utah State University College of Engineering Flash Lab management and then only in a closed laboratory scenario. **Each student on the laboratory must clean up their bench and targets down range prior to leaving - this will be enforced by the TA on duty**.

2. Exercise caution not to accidentally discharge air rifle/bows in the direction of laboratory property, laboratory signs, and stationary furniture.
3. All shooting can only be done from the firing line.
4. Offhand, sitting, and prone shooting of air rifles are only allowed in allocated bench positions assigned by the TA.
5. If your rounds are not going to hit solidly in the bullet catch - **DO NOT FIRE!**
6. Police up your dropped pellets when finished shooting. All targets are to be removed from down range when finished shooting - but only during a TA called "Cease Fire".
7. All students and spectators on the firing lines and staging areas must wear ear and eye protection. Safety ear and eyewear is available in the laboratory.
8. **ALL air rifles must be unloaded**, cased, or actions open, and trigger locks installed when taken to and from the firing line.
9. Inexperienced students are to advise the TA if assistance is needed.
10. When a "Cease Fire" is called by an TA, **stop all shooting and wait for instruction from the TA**.
11. **NO air rifle/bows are to be handled or moved until the TA gives a Hot Range command**. All air rifles in need of cleaning or repair during a "Cease Fire" must move to a designated repair area as identified by the TA.
12. Firing in a careless manner will not be tolerated. Shoot at your target only.

Do not shoot at any elevation or windage that will allow a bullet to travel out of the bullet catch. **Any pellet/arrow strikes to facility equipment, structures, or the like other than a designated target carry a fine/fee to cover costs of replacement and/or repairs**. Those individuals firing in a careless manner will be dismissed from the laboratory for the rest of the day. A Safety Incident Report will be filled out by the TA and will be reported via email to staff for collection of fees.

13. **NO open carry of a loaded firearm on your person is allowed**. Law Enforcement personnel are the exception.
14. The minimum age to shoot in the laboratory by one's self is 18 for rifle/shotgun and 21 for handgun.

LABORATORY SAFETY

NRA Hygiene Guidelines

- Refrain from eating, drinking, smoking, applying makeup, or otherwise placing hands in proximity to the mouth or nose while in the laboratory or cleaning an air rifle/bow.
- Wash your hands and face with soap and water after leaving the laboratory or cleaning area before eating, or drinking.
- Change and wash clothing after a shooting or air rifle/bow cleaning session to minimize exposure to airborne particulate lead or solvent and cleaning product residues.

Teaching Assistants

Teaching Assistants (TA) will oversee the firing line(s) and laboratory at all

times.

The TA on duty is tasked with:

- Ensuring that all students adhere to the rules and SOPs in this document.
- Stopping and addressing any and all unsafe behavior. The TA will address an individual to inform and point out all unsafe behavior and ensure that they are aware of any safety concerns. The TA may call a "Cease Fire" and address the entire line at his/her discretion.
- Escorting anyone out of the laboratory if the person(s) are deemed a safety risk to others in the laboratory.
- Require anyone shooting in the laboratory be given additional training before being allowed to shoot in the laboratory again.
- Reporting to the professor and/or College of Engineering management any incidents in the laboratory to include:
    - Accidental discharges
    - Personal injuries such as slide bites, and etc. that draw blood
    - Any other incidents deemed reportable

Emergencies and Incident Reporting

In the event of an Emergency please follow these procedures:

- Cease Fire Immediately.
- Notify the TA.
- Follow all instructions given by the TA.
- Offer assistance if you are able.
- Take charge of the situation. Determine seriousness of injury.

- Render aid. First-aid kit is located in the locker.
- Call 911 or the appropriate emergency number(s).
- Direct help to location. Stand post by the main hall to direct emergency personnel as needed.
- There is an Automatic Defibrillator device located in the hall of the engineering building.
- Take notes as soon as practical. Interview witnesses and get written statements. Safety Incident report sheets are located in the locker and on CANVAS.

First Aid Procedures

All personnel rendering first aid should be aware of the precautions surrounding bloodborne pathogens in the event of an accident. The following guidelines should be followed if someone is injured and you come in contact with biohazardous materials including but not limited to: blood, secretions, cerebrospinal fluid, synovial fluid, pleural fluid, pericardial fluid, peritoneal fluid, amniotic fluid, any body fluid visibly contaminated with blood, any un-affixed organ or tissue from a human living or dead, and the disposal of cleaning items and first aid dressings. Universal precautions should be used; all blood and body fluids listed above must be treated as potentially infectious.

Government guidelines can be found at www.OSHA.gov, search for OSHA Occupational Exposure to Bloodborne Pathogens.

Personal Protective Equipment

The following equipment should be used when coming in contact with biohazardous material:

- Gloves, eye and face protection

- Fluid-proof over garments
- Shoe coverings
- Resuscitation mouthpieces for CPR

Procedure for Cleaning Surfaces Contaminated with Biohazardous Material

Only those personnel trained and designated as the Bloodborne Pathogen Team should be in charge of the cleanup procedure. In addition to training, each individual should be inoculated for Hepatitis C. Your local physician is capable of administering the vaccine regimen.

1. An approved Bloodborne Pathogen Cleanup Kit must be used for cleaning if at all possible.
2. If a large amount of blood or other biohazardous material exists on surfaces or on equipment, the area must be roped off with "Caution Biohazard" tape. The personnel in charge of the cleanup must adorn whatever amount of personal protective equipment is needed for protection. The biohazardous material must be wiped up with paper towels or sprinkled with liquid-congealing powder. The paper towels or powder must then be placed in a red biohazard bag.
3. The surface, floor, or equipment must then be decontaminated using an approved germicidal liquid. The solution must remain on the surface for ten minutes or as directed and then wiped off with water. In addition to commercially available germicides, a 1 part solution of sodium hypochlorite (common household bleach) to 10 parts water prepared daily is an effective germicide.
4. For a small drop of blood or other biohazardous material that exists on a

surface or equipment, wipe off with approved germicidal liquid. Do not use rubbing alcohol as a cleaning solution as it does not kill viruses. The solution must remain on equipment or surface for 10 minutes and then wipe off with water.

5. Disposal of Contaminated Material (i.e. paper towels, personal protective equipment, saturated dressing):

All contaminated materials including personal protective equipment must be placed in a red biohazard bag; the bag must be closed with a metal twist closure or tied in a knot. The bag must then be taken to a Biohazard Laboratory for proper disposal.

Laboratory Commands

To Indicate Emergency or Hazardous Conditions:

"CEASE FIRE"

To stop all shooting routinely or, in the case of an emergency, immediately. Participants immediately stop shooting, continue to keep the muzzle pointed down range, remove finger from the trigger, unload and clear the air rifle/bow placing the air rifle/bow on the bench with chamber in view and wait for further instructions.

"MISSFIRE"

To notify the TA and other participants that a round did not fire when the trigger was pulled and to alert other students along the line that a hazardous condition may exist.

To Prepare the Laboratory for Live Fire:

"MOVE FORWARD"

To get students into position to prepare to begin shooting. Students will move from behind the ready line to their assigned position. DO NOT TOUCH AIR RIFLE/BOW! Get comfortable, adjust your position make sure you are on the correct

side of the bench.

"PROTECTIVE GEAR ON"

To prepare the student for a safe experience. Students should put on first their eye protection then ear protection.

"YOU MAY PICK UP YOUR AIR RIFLE/BOW"

To prepare line for firing. Students will pick up their air rifle/bow, sight in on the target, make any final adjustments and prepare to load.

"LOAD"

To notify the students that they may load their first round. Students will load their first round and keep finger off the trigger and stand ready for the next command.

"IS THE LINE READY?"

To determine if all students along the line are ready. All students NOT ready should indicate their status to the TA. Sufficient time will be allowed for the student to complete his/her preparation.

"READY ON THE FIRING LINE?"

To notify all students that the laboratory is about to be under live fire and that if anyone is not ready at that point, he/she should notify the TA; Otherwise await the next command. Students simply await the next command.

"COMMENCE FIRING" or "HOT RANGE"

To declare the laboratory formally open for live fire. The students may commence the prescribed course of fire.

<u>To STOP FIRING and declare the laboratory SAFE:</u>

"STUDENTS, YOU HAVE *x* MINUTES REMAINING"

To alert all students that a general cease fire is about to be called.

"CEASE FIRE"

To stop all firing. All students shall open the bolt/cylinder, clear the chamber, remove the magazine - unload the cylinder and lay the air rifle/bow down with the bolt/cylinder open and wait for further instructions.

"COLD RANGE"

To inform the firing line that the laboratory is safe. The TA is telling all students that all air rifle/bows are unloaded.

<u>Other Common Commands:</u>

"ON THE FIRING LINE"

To tell students to take their assigned place at their firing point and prepare to fire, but do not load.

"CEASE FIRE - ACTIONS OPEN, SAFETIES ON!"

To notify the students to stop firing immediately and all chambers and magazines are unloaded, and students leave the firing line with the actions of their air rifles open.

"GO FORWARD, SCORE TARGETS AND PASTE"

Authorizes students to move down range to score, change, remove or repair target faces.

"RANGE IS CLEAR, YOU MAY HANDLE YOUR AIR RIFLES"

Students may approach the firing line and handle their air rifle/bows since no personnel are down range.

"MOVE OUT OF POSITION AND REMOVE YOUR EQUIPMENT FROM THE FIRING LINE"

Authorizes students to remove their gear.

"POLICE YOUR ASSIGNED FIRING POINT"

Students are to pick up their spent ammunition and clean their firing point of all debris.

"AS YOU WERE"

Means to disregard the previous command just given.

"CARRY ON"

Means to proceed with whatever was being done before the interruption occurred.

"REMOVE PROTECTIVE GEAR"

Students may remove protective gear.

"MOVE BACK BEHIND THE READY LINE"

Means to move behind the ready line and wait for further instructions from the TA.

"YOU MAY GO CHECK YOUR TARGETS"

Students may move down range to the target area.

Air rifles Carry & Handling

1. Except when shooting in the laboratory, all air rifles outside a case "open carry" must always be unloaded, with the magazines/cylinders out and chamber empty and trigger locks installed.
2. Hot Range Procedure: proceed to a shooting bench as directed by the TA. Uncase the air rifle with the muzzle pointing down range ensuring the action is open, only take out magazines and pellets out of the case for the air rifle to be shot. Only one air rifle on the firing line bench at one time.
3. Cease Fire Procedure: Remain behind the firing line and do not uncase any air rifles until the cease fire has been completed and the laboratory is back to a hot range status. Uncase the air rifle with the muzzle pointing down

range ensuring the action is open, only take out magazines and pellets out of the case for the air rifle to be shot. Only one air rifle on the firing line bench at one time.

Cease Fire Procedure

1. When a verbal "Cease Fire" is heard all shooting must stop immediately, unload air rifle ensuring the chamber is empty and remove magazines.
2. Fix actions open and insert empty chamber flag
3. Place air rifles on the bench with muzzles pointed down range, or in a proper rack with muzzles pointing up.
4. Before anyone moves down range, all persons must move behind the firing line and acknowledge the cease fire verbally or visually to the TA.
5. Fly Cease Fire Flag (white flag)
6. Absolutely no air rifle/bow handling during a cease fire. Everyone is either down range at the targets, picking up dropped pellets in front of the firing line, or behind the firing line.
7. Dropped pellets forward of the firing line may be picked up during a cease fire, but the person must then return behind the firing line without stopping at the shooting bench.
8. Chronographs may be set up only when everyone has returned from down range while the laboratory is "Cold". The chronographer should be the only person in front of the firing line. The chronographer may handle the air rifle/bow to line it up with the chronograph but may not load the air rifle/bow until a Hot Range is in effect.
9. Anyone handling an air rifle/bow during a cease fire or carelessly

sweeping people on a Hot Range should be reported to the TA.

10. **AT ALL TIMES THE NRA GUN SAFETY RULES MUST BE OBSERVED**:
    1. Always keep the air rifle/bow pointed in a safe direction
    2. Always keep your finger off the trigger until ready to shoot
    3. Always keep the air rifle/bow unloaded until ready to use

Firing Line Rules

1. Eye protection is always mandatory in the laboratory to include staging areas. Designated spectator areas do not require eye protection, but it is recommended.
2. Ear protection is mandatory at all time in the laboratory designated areas during Hot Range (live fire) activities. Designated spectator areas do not require ear protection, but it is highly recommended.
3. Each firing position is labeled to a corresponding target stand position. Students must only shoot in their prospective shooting lane.
4. Rifle Laboratory: while firing off a bench or otherwise, pellets may not leave the impact area.
5. Pistol Laboratory: pellets may not leave the impact area. Anyone caught firing outside the impact area will be escorted out of the laboratory by the TA after calling a Cease Fire. No warnings will be given.
6. During a cease fire, all air rifles are to be unloaded and empty chamber flags inserted into the chamber.
7. No one is allowed forward of the firing line unless the laboratory has been declared safe by the TA.

8. Once on the firing line, an air rifle's muzzle must be pointed down range at all times.
9. Loaded air rifles must be pointed down range with barrel horizontal at all times.
10. Only one air rifle and matching pellets are allowed on the bench at one time.
11. Only shooting from the bench is allowed, unless approved by the TA.
12. Shoot only at designated targets.
13. If there is a misfire be sure to keep the muzzle pointed down range (preferably on target) for at least 30 seconds, in case it is a hang fire.
14. After a misfire or jam, the air rifle must be cleared. A misfire is when a pellet does not fire after the trigger is pulled. The normal procedure for handling misfires is to:
    1. Keep the air rifle pointed down range (safe direction).
    2. Wait at least 30 seconds in case it is a hang fire.
15. Squib load is when there is less than normal pressure or pellet velocity after the trigger is pulled and the pellet gets lodged in the barrel. The normal procedure for handling a squib load is:
    1. Stop firing immediately
    2. Keep the air rifle pointed down range
    3. Unload the air rifle - make sure the chamber is empty
    4. Insert a cleaning rod down the barrel from the chamber end (if possible) to make sure the pellet is not lodged in the barrel.

16. Only one student's target is allowed per frame, unless approved by the TA.
17. Smoking is not allowed under any circumstance on the laboratory, staging areas, or spectator areas
18. IN ALL CASES THE TA'S DECISIONS ARE FINAL AND BINDING. HIS/HER DECISIONS ARE BASED ON THE CURRENT SITUATION AS IT EXISTS, AND HIS/HER JUDGEMENT DICTATES. THE TA'S DECISIONS MAY SUPERCEDE THE GENERAL PRINTED RULES OR SOP.

FACILTIY OPERATING PROCEDURES

Laboratory - Opening Procedure

All TAs reporting for duty will:

1. Ensure all items are in the locker:
    1. Copy of this SOP
    2. Incident Reports
    3. FULL first aid kit
    4. Tourniquet
    5. Pens/Pencils
    6. Sharpie Marker
    7. Note Pad
    8. Witness statement sheets
    9. Rubber Gloves
    10. Trauma Kit
    11. Laboratory inspection sheets
2. Verify and make ready laboratory items:

1. Lead sleds
2. Shooting bags
3. High-Speed Camera
4. Eye protection
5. Ear protection
6. Targets

Laboratory - Operating Procedure

1. Laboratory inspection:
    1. Ensure that there are no hazards/obstructions between the firing line and the impact area. keep the area clean.
    2. Correct any problems before opening the laboratory.
    3. If a problem is found that can't be corrected immediately you will have to determine if the laboratory can be run safely with the existing problem. For example: If a section of the primary impact area is damaged, the laboratory could still be opened but the affected section/bench will not be used. However, if you determine that the laboratory cannot be operated safely - DO NOT OPEN THE LABORATORY. Report the problem to the professor as soon as possible so that laboratory faculty can address the problem; hang a sign so that every TA coming to the laboratory will be aware of the problem.
2. Supplies:
    1. Extra targets, safety glasses, and ear protection will be made available to student(s) by the TA.

    2. Make sure all target frames are in good working condition. Replace backer boards as needed.
3. For each student using the laboratory:
    1. Student(s) must have passed the CANVAS quiz in order to use any of the laboratory and be assigned a bench by the TA. Students will have seen the laboratory safety video as part of the pre-lab quiz on CANVAS.
    2. Upon passing the CANVAS quiz, TA assigns a bench to shoot from.
    3. When a student(s) have completed their shooting session and laboratory items are returned to TA, dropped pellets policed and bench area cleaned up.
4. In the event of an incident:
    1. **ANY minor injury** - slide bite, forehead scope event, or any other minor injury event that draws blood or otherwise injures a student or by-stander, an incident report will be filled out by the TA and signed by the student(s) - or witness if student(s) is not able to sign.
    2. **ANY Catastrophic or serious/fatal injury** - TA or ANY student/bystander on the laboratory will call a CEASE FIRE! TA will radio all TAs and lab manager on duty to CEASE FIRE on all laboratory and lock-down the entire facility while emergency and first responders perform necessary tasks. Laboratory closure may

be necessary, and in the case of a laboratory closure of this nature, SAFETY FIRST by following first responder and TA directions followed by SAFE egress of students and members from the laboratory to either the main store building or from the property as directed.

3. **ANY Accidental Discharge** - TA will fill out an incident report and have student(s) and/or witness(es) acknowledge and sign report. It will be up to the TA to determine if the student(s) can remain in the laboratory or if their shooting session is concluded.

Camera Procedure

1. Place camera on tripod
2. Set camera so that front face is 52 inches from tank. Measure this from both edges of the camera housing to ensure it is lined up correctly.
3. Plug in power supply
4. Plug in Ethernet
5. Plug in umbilical
6. Connect pickle switch to trigger on umbilical
7. Connect Ethernet cable to laptop
8. Turn on camera
9. Turn on laptop
10. Open PFV and it should automatically detect and display the camera (if not see "camera not detected" under troubleshooting in this document)
11. Make sure lights are turned on
12. In the PFV:

a. Under the camera tab select Save Setup, Load. Go to the Axi_cavity_formation folder and select "cavity_set_up.pcs" (the details of this setup can be found in PFV setup under troubleshooting in this document
b. With the lens cap on the camera select Shading "Calibrate"
c. Under the Data Save tab under save path select the Axi_cavity_formation folder
d. Place lens cap on camera and click "shading" within the program

13. Place target in tank ensuring it is in the center of the tank where the projectiles entering
14. Adjust aperture settings until image is light but not washed out. You can go part way in between aperture settings if needed (generally between 5.6 and 11)
15. Adjust pan so that the target is in the center of the screen and there is no distortion in the string as it descends into the water.
16. Adjust the tilt so that the camera is level with the water (the water level will appear as one line)
    a. Also make sure that the level is about 1/3 down from the top of the screen so that the splash from the projectile can be seen
    b. Adjust focus until target is in focus and make sure the string is in the same location as the electromagnet
    c. If spots are on the glass take a razor and carefully scrape them off

<u>PFV Setup</u>

Under Frame Rate select "2000 fps"

Under Resolution select “512x768”

Under Shutter select “1/7500”

Under Trigger Mode select “center”

Then with the lens cap on the camera select Shading “Calibrate”

Trouble Shooting

Camera not Detected

If it does not automatically detect the camera and the screen comes up blank turn both the program and the camera off, turn the camera on and then the program, if this still doesn’t work:

Check if the ethernet cable is plugged into both the camera and computer network and sharing center click view network status and tasks. Under active networks click local areas connection click on properties, select internet protocol version 4 click on properties, type in IP address “192.168.000.010”and subnet mask “255.255.255.000” click ok and close out of the network connections. This should remedy the problem.

If it still doesn’t work open PFV and go to options on the top bar, configurations and select setup under network configuration and select auto detections, if that doesn’t work manually select the IP address or type it in if it is not listed, click ok and restart the program. If all of these don’t fix it go find a more seasoned member of the splash lab

Making the Line Hot

1. After all students are back from putting out target frames or changing targets and are back behind the benches and the firing line, double check to ensure that no one is down range.
2. After confirming that the laboratory is clear, and it is safe to shoot, the TA announce: "PUT ON YOUR EYE AND EAR PROTECTION. "

3. The TA ensures that the air rifle is unloaded and sets the air rifle in the gun rack.
4. The Students position the air rifle aimed at the bullet catch
5. The TA checks alignment and removes the trigger lock
6. After confirming that everyone on the laboratory has put on their ear and eye protection, announce: "THE LINE IS HOT, YOU MAY COMMENCE FIRING WHEN YOU ARE READY."
7. A TA must always be monitoring the firing line condition. If the TA must help a student and is on duty alone, the line must be shut down until he is free to continue his duty.

Making the Line Safe

1. A couple of minutes before calling a cease-fire, warn students of the upcoming target change by announcing: "LAST ROUND, ONE MORE ROUND BEFORE CEASE-FIRE."
2. Once you have determined that adequate time has elapsed, (couple of minutes for students to fire their last round), then announce: "WE ARE MAKING THE LINE SAFE. CEASE-FIRE, CEASE-FIRE. UNLOAD ALL AIR RIFLE/BOWS AND REMOVE DETACHABLE MAGAZINES. OPEN YOUR AIR RIFLE'S ACTION, PUT THE SAFETY ON, AND STEP BACK AWAY FROM THE BENCHES BEHIND THE FIRING LINE. DO NOT TOUCH ANY AIR RIFLE/BOW UNTIL FURTHER NOTICE. STAY BEHIND THE FIRING LINE UNTIL IT HAS BEEN MADE SAFE."
3. Go down the firing line and inspect all air rifles. Confirm that:

    1. All air rifles are unloaded with detachable magazines removed.
    2. Their actions are open with chambers empty and visible (chamber flags inserted if available) and safeties applied.
    3. If an action cannot be locked open, use an empty case, chamber flag, or other inert object to keep the action from fully closing.
    4. Everyone is standing back behind the firing line, away from the benches.
    5. No one is touching an air rifle/bow.
4. Once you are satisfied that it is safe to go down range, announce: "THE LINE IS SAFE. YOU CAN NOW GO DOWN RANGE AND CHANGE TARGETS. THERE IS TO BE NO HANDLING OF AIR RIFLE/BOWS UNTIL FURTHER NOTICE."
5. Remind students to:
    1. Stay away from the shooting benches and stay behind the firing line while people are forward of the benches down range. Dropped pellet around the benches are not to be picked up now. They can be picked up later when all students have returned back behind the firing line and the TA gives the command to approach the benches.
    2. Take staplers, tape, and any other target items with them down range so as to minimize the time spent down range.
    3. Keep their safety glasses on down range at all times.
    4. Bring their target frames back if they are done shooting.

Laboratory - Closing Procedure

All TAs closing the laboratory will:

1. Make the line safe for the last time. Verify air rifles are empty and cleared prior to directing everyone to case their air rifles before declaring the line safe and allowing students down range.
2. Maintain observation of the line until all students have removed their air rifles from the laboratory.
3. Put any equipment such as sandbags and rests in their storage location.
4. Pick up all trash and dispose of properly. Sweep off shooting area if required.
5. After all students have left the laboratory, turn off all lights and electrical equipment.
6. Close and lock all doors of supply cabinets and other secured storage.
7. Ensure that everyone has left the laboratory.
8. Ensure all items are in locker and replace/refill items that were used for the shift:
    1. Copy of this SOP
    2. Incident Reports
    3. FULL first aid kit
    4. Tourniquet
    5. Pens/Pencils
    6. Sharpie Marker
    7. Note Pad
    8. Witness statement sheets
    9. Rubber Gloves

10. Trauma Kit
11. Laboratory inspection sheets

9. Verify and secure items:
    1. Lead sleds
    2. Shooting bags
    3. High-Speed Camera
    4. Eye protection
    5. Ear protection
    6. Targets

SAFETY INCIDENT REPORT

REPORTED BY:	DATE OF REPORT:
TITLE / ROLE:	INCIDENT NO.:

INCIDENT INFORMATION

INCIDENT TYPE: DATE OF INCIDENT:

LOCATION:

CITY: STATE: ZIP CODE:

SPECIFIC AREA OF LOCATION (if applicable):

INCIDENT DESCRIPTION

NAME / ROLE / CONTACT OF PARTIES INVOLVED

1.

2.

3.

NAME / ROLE / CONTACT OF WITNESSES

1.

2.

3.

POLICE REPORT FILED?	PRECINCT:
REPORTING OFFICER:	PHONE:

FOLLOW-UP ACTION		
SUPERVISOR NAME:	SUPERVISOR SIGNATURE:	DATE:

BODILY INJURY INCIDENT REPORT

Bodily Injury Incident Report found at Risk Management Services web page

https://risk.usu.edu/frequently-used-forms

PROPERTY LOSS REPORT

Online Property Report found at Risk Management Services web page

https://risk.usu.edu/frequently-used-forms

REFERENCES

[1] "Optics," *Resource Page: Edmund Optics* Available:

https://www.edmundoptics.eu/resources/application-notes/optics/cleaning-optics/.

[2] "Optics Handling and Care Tutorial," *Thor Labs* Available:

https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=9025.

APPENDIX B

Equipment Budget Breakdown

Items	Estimated Price	Quantity	Estimated Cost	Actual Cost	Difference
Setup and Equipment					
The Ultimate Archery BackStop Back Stop for Target Shooting	$750.00	1	$750.00		$750.00
Flir Camera	$399.99	1	$399.99		$399.99
Caldwell Ballistic Precision Chronograph Premium Kit with Tripod for Shooting Indoor and Outdoor MPS/FPS Readings	$135.00	1	$135.00	$104.99	$30.01
Powder scale	$99.99	1	$99.99		$99.99
Gun rack	$49.99	1	$49.99		$49.99
Caldwell Matrix Adjustable Ambidextrous Rifle Pistol Handgun Shooting Rest for Outdoor Range	$45.00	1	$45.00		$45.00
CO2 Cartridges	$30.00	1	$30.00		$30.00
Trigger Locks	$24.00	1	$24.00		$24.00
Tape measure	$13.97	1	$13.97		$13.97
Ping-pong balls	$13.00	1	$13.00	$12.28	$0.72
Rimfire Bullet Trap	$100.00	0	$0.00		$0.00
Crossbow	$150.00	1	$150.00		$150.00
10% Ballistic Gelatin Extra Long Air Rifle Block	$79.98	1	$79.98		$79.98
Extra Long Air Rifle Mold	$59.98	1	$59.98		$59.98
Bow rack	$36.16	1	$36.16		$36.16
Hot Plate	$525.00	1	$525.00		$525.00
Thermal couples	$30.00	10	$300.00		$300.00
8020 hardware	$200.00	1	$200.00		$200.00
8020 for apparatuses	$4.00	30	$120.00		$120.00
Calipers	$37.28	2	$74.56		$74.56
Fan	$54.44	1	$54.44		$54.44
Hardware for Ping Pong Cannon	$171.46	1	$171.46	$171.46	$0.00
Ear Protection	$37.32	1	$37.32		$37.32
Back Lights	$100.00	1	$100.00	$175.79	$75.79
Schlieren Imaging Device	$1,000.00	1	$1,000.00		$1,000.00
NI DAQ C Series Multifunction I/O Module	$442.00	1	$442.00		$442.00
Eye Protection	$1.83	12	$21.96		$21.96
Airgun (.177)	$200.00	1	$200.00		$200.00
Computer	$1,500.00	1	$1,500.00		$1,500.00
Light Source	$5,000.00	1	$5,000.00		$5,000.00
Spotlight	$1,000.00	1	$1,000.00		$1,000.00

BCY ARCHERY BACKSTOP NETTING (10'X20')	$359.99	1	$359.99		$359.99
Infrared Thermometer	$230.00	1	$230.00		$230.00
Pellets for Air rifles	$15.00	4	$60.00		$60.00
Shipping			$0.00	$39.80	$39.80
Total			$13,283.79	$464.52	$12,779.47