

Design Improvements to the School of Engineering's Ballistics Laboratory

Declaration of Authenticity

'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.'

Signed:

Date:

Abstract

This report covers the making of several suggestions for the bettering of the performance and usability of the Ballistics Laboratory in the School of Engineering, through several avenues, including: product improvement, partial or total replacement, improvements to operational routines, and is accompanied by information relating to said laboratory, its current uses, some possible future uses, and its general background.

Suggestions made attempt to cover all avenues of improvement, though, of course, it is not possible to predict all outcomes which means that there are very likely some endings which have been overlooked. As this is a possibility with high probability, further investigation and experimentation would be a good investment of time for a future project.

The conclusion is that there are several routes of improvement, which range from ensuring that basic maintenance is performed, to total replacement of the entire laboratory. There are, of course, many of these ideas which are not currently feasible and, as such, should be considered for future projects or undertakings, to better the usability and viability of testing for the School.

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1.0: Introduction

1.1: Aims and Objectives

The aims of this project are to provide improvements to the University's Ballistic Testing Laboratory, in order to allow a wider range testing to be conducted, and to generally promote the ability to perform the tests. This testing would be backed by several companies, who have previously worked with the School of Engineering to test automotive laminated glass, typically representing a windscreen. There are several ways to improve the efficiency of these procedures, the most obvious of which is to redesign the launcher for ease of operation, both in use and maintenance. The other main options for enhancement are the several peripheral devices, being the lights, camera, and data processing equipment. These various approaches will be detailed in their own dedicated sections, later in the report. It should also be noted that a glossary, and a list of equations referred to, shall follow as an appendix post-scriptum.

1.2: Background and Literature Review

The Ballistics Lab exists due to industrial ties with several companies, including Belron and Jeep (Donne, 2018). These partnerships involve testing impact resistance and resilience of various materials that said businesses send samples of, in return for providing the opportunity to perform this sort of testing. Any further details of specifics or exact figures of the tests are corporate secrets, and as such, are not known.

This procedure is necessitated by the hazards that can be found in normal usage of a motor vehicle, particularly that of loose road surfacing aggregate, referred to as chippings. These chippings represent a small projectile colliding with the moving vehicle at what could be considered high velocities and are thus a potential danger to any part of the vehicle with which contact is made. The object of the testing, therefore, is to ensure that there is no major damage, or penetration, to windshields et cetera, even in the event of collisions at the highest velocities reasonably expected on a highway. This also includes repairs made to windshields, such as the *Autoglass* branch of the Belron company, which operates in the United Kingdom (Donne, 2018).

The testing conducted utilizes stone which, coming from nine major quarries across the country, is representative of most road surfaces found in Britain (Donne, 2018). These road chippings are used as test projectiles, to simulate realism in the results, and enable accurate advertising of the capabilities of the tested products, as testing with a standard projectile, such as a steel ball, would not be considered as applicable to the claims being made, with regards to withstanding impacts from flying road debris, even though results from tests using said ball would be more readily repeatable, and thus less random, than those with actual stones. One must also acknowledge that glass an amorphous material (Wood, 2019), thus having no crystalline structure, allowing for microscopic imperfections, two identical plates may perform quite differently, even under the same controlled conditions, in testing (Donne, 2018). As a result, it is possible that, were a standardized projectile used, performance would not necessarily be as uniform as expected.

1.3: Plan of Action and Time Usage

As time management is an essential part of any project, and good organization is preferred, plans must be made. As such, the initial plan for this project was as follows:

1. Perform necessary background research, concurrently investigating the situation at hand.
2. Formulate ideas for solutions to the issues detected in the first step.
3. Pitch those ideas to the client.
4. Manufacture the prototype replacement, as requested.
5. Test said prototype, gather data.
6. Analyze the results, determine the validity of the solution.
7. Come to a conclusion on the success or failure of the project and future plans.

The project, however, took a different route than that that was intended, and the plan, therefore, has had to be reconsidered, as the overall timescale for this project was on the order of six months, and it was month four that the change in route was necessitated, by which point there was little time left available to redesign, manufacture, or perform any testing on any ideas created to that point. It was at the three-month mark that information regarding funding was attained, which told that additional work over the original intent and scope of the project was to be necessitated if funding to produce any example prototypes was to be obtained. By then, time required to do so was quickly running out, and this information would have been significantly more useful at the initial undertaking. Thus, funding was not awarded, and the radical redirection required was the result.

Therefore, the consequence of this was that steps four through six above have had to be substituted out and thence replaced with an alternative approach. That is, the concept of manufacturing a working model of a replacement was cancelled, and in its place, conceptual solutions have been prioritized.

This has thus led to a redefinition of the scope of the project as a whole: it is no longer able to be a practical implementation of designs, but rather a conceptual, hypothetical situation, where the results are operational suggestions, rather than machined metal. The project did not, and does not, intend to cover marketing or financial aspects of any idea, nor implementation thereof, as that would exceed the limits on time allowed.

1.4: A Note on Pressure Curves

Demonstrating the relationship between a change in pressure and time, pressure curves can be used to comparatively measure differences between variations of a piston-and-cylinder-based system. This is pertinent, as in both the present pneumatic system and a chemical-based propulsion, such as a firearm, the simplest method of representation of the mechanics, is a piston inside of a cylinder.

In a firearm, the propulsion is caused by an explosion, which is instigated by the ignition of a contact explosive, which then sparks a propellant, to unleash the contained chemical energy and create the force needed to propel the projectile down the barrel. This is a controlled explosion, that is, the path of least resistance is the piston head, that is, the bullet or other projectile. This ensures that the energy is used in a constructive manner, and not expended in other directions.

Therefore, because of the application of a force upon the area across the base of the projectile, which effectively forms a piston, a pressure will be applied to both it and the barrel, that is, the cylinder walls. Now, as this is neither constant pressure nor volume, the relationship of pressure and time is going to be a curve, not a line, and this can be used as a metric to determine the strength of the barrel required, due to the peak pressure, from breech to muzzle, that is, from the rear to front.

Typically, the pressure will reach a maximum, then start to decrease as the projectile moves down the barrel, but pressure at the start of the projectile's travel in the barrel is the main part of relevance. AS an aside, muzzle pressure is less relevant in a single-shot device, than in a repeating arm, as for all means of repeating arms that are self-loading, that is, semi-automatic, or fully-automatic, utilization of the energy that propels the projectile also cycles the moving parts in the action, thus enabling the loading of the next round, or projectile, and thus allowing the system to continue its operations.

In a single shot weapon, this energy is effectively wasted as recoil and can be transferred into an absorption device such as a spring or hydraulic damper, in the case of a stationary artillery piece; various other recoil absorbing implements in small-arms designs; be absorbed into the mass of the weapon; into the shooter's shoulder, assuming that it is a shoulder-arm, or into whatever else it is mounted on. As the school is dealing with a low power, and relatively heavy, object, the pressures are going to be relatively low. This pneumatic system actually reaches a maximum of two bar (two-hundred kilopascals). The pressure in your typical firearm will be on the order of the three-and-one-half thousand bar (thirty-five megapascals) found in the American M80 Ball round(Cooke, 2010), which is significantly higher than any that can be generated by this compressed air system.

The most important part of this topic is the gradient of the pressure curve in the first few milliseconds of time elapsing from the initialization of the process, as this will significantly impact on the stresses in the system and needs to be monitored. For example, even though there may be two similar cartridges in a firearm, which are of the same caliber, approximate dimensions, and power, different pressures curves can be obtained by having different powder compositions because, of course, stick powder, which is long, cylindrical pieces will burn at a different rate, and thus produce a different amount of energy in a given time thus a different pressure, than flake or small grain powder. Thus, the type of powder used in a cartridge would significantly affect the pressure curve. The slope of a pressure curve is affected by the burn rate of powder, or by the acceleration rate of whatever other propulsion method is used.

For example, during the adoption process for the 7.62x51mm NATO cartridge, by the countries in that treaty organization, France attempted to convert its rifles of the MAS 49 pattern from their 7.5mm

cartridge, which had been developed in the 1920s, to the American T16 cartridge, which had proven to be the cartridge that was going to be adopted by NATO, due to the US Army Board of Ordinance dictating that this would be the result of the trials, regardless of what the British, Belgians, or French had to say otherwise (McCollum, 2019).

Both of these cartridges used a thirty-caliber bullet, had approximately the same overall case length, with the French cartridge being 54mm, compared to the American cartridge of 51mm, therefore, an assumption that it would be a simple enough process to convert the rifles to accept it would seem to be safe, save that the T16 cartridge used a different powder, and a different primer (which is an ancillary issue which has nothing to do with what is being discussed here). This meant that, even though dimensionally they were quite similar and thus re-machining the rifles to accept this different cartridge would be elementarily simple, the pressure curves produced were not identical and thus issues of parts breaking due to overly high stresses occurred within very short time frames, as a result of the increased pressure in the chamber during the instance immediately after ignition. This resulted in the termination of the program, which is why the French never adopted the NATO standard cartridge until the late 1970s, by which point it was a different cartridge for a different rifle (McCollum, 2019).

All of this is to say that ensuring that the system can withstand the maximum pressure that is intended to be used in it is extremely important during design phases, especially if conversion between power sources is to be commenced and followed through.

1.5: Miscellaneous Information

These subsections contain information pertinent to the main body of the report, that could not be readily categorized into their own section yet would be inappropriate to include in an appendix.

1.5.1: Research

This is the act of sourcing, and utilizing, information in order to correctly portray reality when making a point. Alternatively, this is ensuring that the thoughts expressed in a written work are actually factually correct and not blatantly false.

In this report, this verification has been obtained by the use of several books, some websites, and a few other sources, though most of the information is based on the author's prior knowledge and has thus not actually required finding of information, so much as it has required finding research to verify the information presented. The majority of the information that was being verified was that of numerical data, as the basic physical principles outlined in this report are extremely elementary and should be common knowledge for anyone in the engineering field. Those concepts being: the linear properties of elasticity (Hooke's Law), Newton's Laws of Motion, and an understanding of how pressure works. These are all parts of physics that have been well known, and well documented, for several centuries, and should not require much explanation. The other main areas of research were for historical data, verification of information with regards to adding flavor to the report, information on the project's background, and examples to support the points being made with real-world context.

1.5.2: Standards of Formatting

Formatting Standards for this report: headings are numerical, they follow a sub-sectioning practice of primary section, sub-section, sub-sub-section, sub-sub-sub-section, and so on and so forth. Referencing is done in the Harvard style, as is preferred by the school, and a list of all references cited in this paper follows at the end in a list thereof. Appendices are affixed to the end of the paper, after the reference list, to explain some aspects of this paper that may need explanation for the layman, but not necessarily in need of an external reference. The Table of Contents is the first section following the Abstract, which the Table of Contents is then itself followed by a Table of Figures, to outline the locations of all graphical representations of data: images and other visual objects found in this paper.

2.0: The Present Situation

Currently, the Ballistics Lab possesses a low-velocity, large-bore, pneumatic launching device. This may be referred to in the text as an “air-gun”, for the sake of brevity. This air-gun is breech-loading, by way of a sliding breech block, allowing quick and easy insertion of a projectile into the chamber, as in the 75mm M3, shown in Figure 1 below. This projectile is a composite item, consisting of a small rock, being representative of road surface material, and a sabot, or cup, shown in Figure 2, which provides a consistent means of carrying the projectile through the barrel. Further detail will be provided in the sections immediately following.

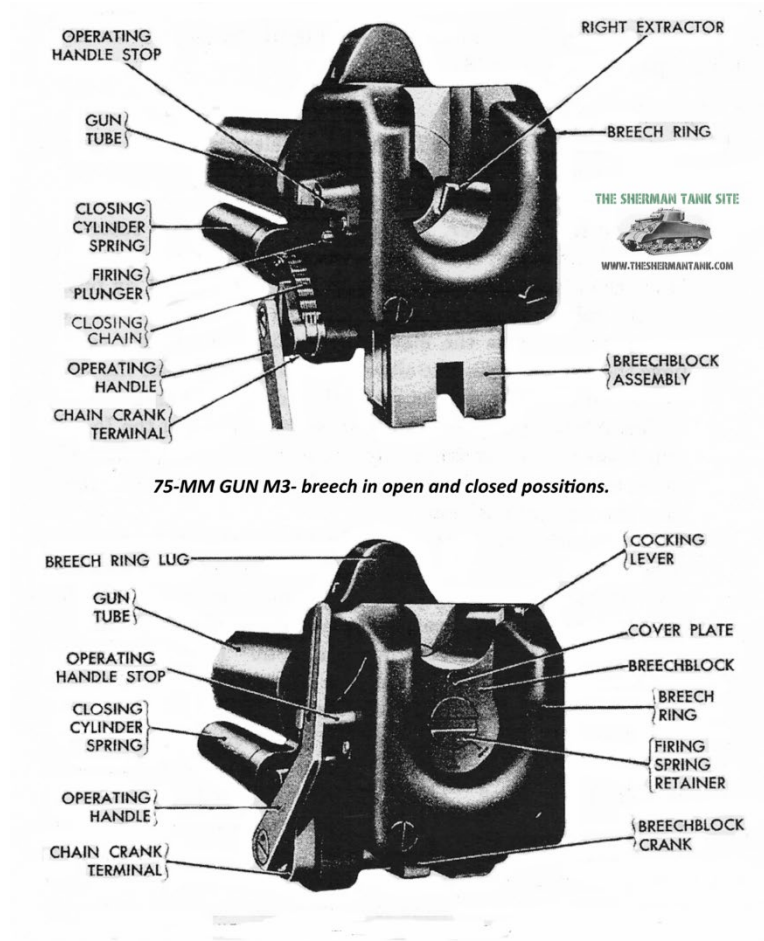


Figure 4. Breech end of 75mm M3, as found in Medium Tank M4, Sherman (Tisor, n.d.).



Figure 3. Projectile and Sabot (Cabela's, 2019).

2.1: Pneumatic Launcher

This launcher operates, towards its upper limit, at a pressure of thirty pounds per square inch (two Bar) in order to produce a muzzle velocity of approximately seventy miles per hour (thirty meters per second) (Donne, 2018). This has, in the past, become less reliable in the low-pressure regions, and is the main reason for researching replacements. The barrel is approximately two meters in length, with a bore diameter of thirty-two millimeters, launching a projectile on the order of five grams in mass. This provides a maximum muzzle energy of two and one quarter Joules, which, in comparison to a firearm of any sort, is very low. For example, the L2A1 Ball round used in the SA80 has a projectile mass of four grams, but when fired in the Individual Weapon, it produces a muzzle velocity of nine-hundred and thirty meters per second (Ministry of Defence, 1985-87), resulting in a kinetic energy (9.1: Equations Utilized in the Writing) of one thousand, seven-hundred and thirty Joules, which is seven-hundred and sixty-nine times more energy than that of the pneumatic-launched projectile.

The basic conclusion here is that the desired results could be obtained in a significantly more compact package, as unlike the two-meter length of the present pneumatic device, the L85 is seven-hundred and seventy-three millimeters in length (Ministry of Defence, 1985-87). As the pneumatic launcher is already licensed under UK firearms law (Donne, 2018), it must be questioned why the jump to chemical propulsion, i.e. using an actual firearm, has not been made. One answer to that question may be ammunition storage, as that brings with it a whole host of other problems, but the benefits, to testing variety and power, should be considered.

2.2: Test Chamber

The testing occurs in a two-room suite located in the rear of Materials Laboratory. The one room houses the launching apparatus, the other, the target. This latter room is climate-controlled, to widen the range of weather conditions that can be simulated, thus allowing for more varied tests. This climate control only occurs in that chamber, as it would be more expensive and less comfortable for the testing parties to share the climate in the control chamber. This also means that, as the temperature is unchanging, the launcher is under more constant conditions, reducing the error that may come from changing the surroundings during testing.

2.3: Peripheral Equipment

The current accessories include: three probes, their associated data-logger, and the laptop computer assigned to process the results thereof. Information on the specifications of these components has been limited, thus so too are any suggestions for replacement.

3.0: Summary of Improvement Ideas

There are numerous areas that may be improved upon, but there are several of greater importance, and of greater ability to be improved. As it stands, there are some things that simply cannot be altered, such as the room geometry, but for the most part, improvements may be made to the apparatus or the associated activities, as will be detailed below.

3.1: Which Aspects could be upgraded?

Having decided that certain aspects could benefit from alteration or alternative solutions, three main categories have been assigned to sort them, as follows:

3.1.1: The Launcher

This has exhibited reliability and ergonomic issues, such as taking approximately fifteen minutes per shot (Donne, 2018), which resulted in the undertaking of this project. As such, this would be the main focus of the work, were funding allocated to do so. This work would constitute either directly attempting to improve the piece in-situ or designing anew. Any replacement design should operate over a range of muzzle velocities, from 30 mph to the higher speed of 70 mph. It should also be more convenient to load, discharge, unload, clean and maintain. Thus, the following requirements are to be the main guidance in the design process:

- Simple manufacture from low-cost materials, to spread the budget further.
- Repeatedly attainable muzzle velocities, to improve consistency in results.
- Ease of use and maintenance, speeding any required repairs.
- Compactness, relative to present, to enable maneuvering of the piece, and personnel.
- Tight tolerances between projectile and barrel, forming an effective gas-seal.

These factors combine to produce an assembly that should be readily maintained and operated, whilst being efficient in performance and ergonomics. The gas-seal would ensure that as much propelling gas could be useful as possible.

3.1.2: Ancillary Equipment

Simply retrofitting the hardware in the computer with newer equivalents, or outright replacing it. Would require indication of necessity from the School, and statements of what specifications would be needed. As this would also need funding to be allowed for acquisitions, this is not a viable option.

3.1.3: Operations

To quote chapter three, page two, section one of the British Army manual for the L85A1 Individual Weapon System (IWS): “Care must be taken...to keep it in a condition that will give correct functioning of the mechanism and continued accuracy.” (Ministry of Defence, 1985-87). This is to say that, in order for proper functioning of the testing equipment to be the norm, proper cleaning regimes must be implemented, so that the operation may be smooth and regular, as should be expected from any piece of apparatus.

3.2: Possibilities

As the customer, that is, the School, has provided little information as to what they actually desire, save for matching performance of the present apparatus, the ability to suggest improvements becomes quite limited, and thus entirely hypothetical. As such, the focus must be placed on items which do not actually require physical constructions be made, in order to be implemented. These ideas are going to be in the realm of ordering operations and maintenance, scheduling and optimization of usage of time, materiel, and personnel to better the use of the laboratory.

In short, the main options for improvements are:

1. Physically replace components, retrofit new parts, or entirely replace aspects of the laboratory.
2. Suggest the above, without implementation of the improvements.
3. Provide means that require not manufacture, purchase, or other means of acquisition, such as alterations of schedules, cleaning, operators, and such.

These suggestions offer a comprehensive enough range of ideas that at least one of them should be an attainable goal. Should none of these prove possible, that will still provide enough material to cover what is required for the purposes of this report, which is a pleasant conclusion. Accepting that possibility is a necessary part of life (Miyamoto, 1645), as without doing so, no progress would happen due to fear of failure: this allows for the focus to be put on the task at hand, and not on worrying about whether success will come. Details of the possibilities for improvement, and indications of success or failure thereof will follow in the successive sections.

3.3: Operational Limitations

It should be noted that the limits placed on this project restrict its capacity to achieve any practical improvements quite severely. Those being space, time, and finance. Details of how these aspects affect the ability to improve on the laboratory are detailed below.

3.3.1: Space

The test chamber is a confined space (approximately two by three meters) with little to no scope for expansion, in terms of additional apparatus, personnel, or higher power devices. This lack exacerbates the issues of ergonomics and operations, because there simply is not the available area to put the people and equipment needed, in any reasonable manner. This would seem to imply that the laboratory was an afterthought in the minds of the architects and was not at all a priority, which has resulted in these severe limitations.

3.3.2: Time

The usage of time has not been the best throughout this project and has served as a constant constraint looming over all that has been done. That said, the overall scheduling of the project has resulted in issues at every step, over a month of term time elapsed prior to the commencement of the project, and it was not until nearly February that confirmation of a declination of project funding was provided, leaving a short period to change direction and reimagine this concept in its entirety.

3.3.3: Finance

The budgetary limitations of a typical third-year project were not made clear until well into the second semester. As a result, planning for this project had far exceeded the apparent intentions of the program, in terms of raw material cost and machining time. Thus, a large change of direction has been required, in order to ensure that a conclusion could be reached. This is, apparently a not uncommon occurrence in the field of commissioned work, and should thus be considered a minor stalling block, rather than the absolute end of all things that could possibly come about. That is, the client asked for one thing, and then decided to alter the deal, which is now having to be compensated for, by changing the scope, and overarching concepts, of the project as a whole.

3.3.4: Construction

The target chamber is constructed from standard concrete “breeze-blocks”, which offer limited ballistic resistance, and thus limit the maximum velocities allowed for projectiles in the laboratory. This would prevent the possibility of replacing the launcher setup with anything of substantially more power, which indicates that there is no desire to do so, or was not when the building was constructed, at least. This would have to be rectified by the addition of armor for the walls, floor, and ceiling, should an increase in penetrative power be desired.

4.0: Proposed Solutions

Here follows a short list of some possible answers to the issues endemic in the current configuration of the Ballistics Laboratory, with provision of options to promote the alleviation of the most egregious offences to ergonomics and usability. Additionally, this section aims to clarify the major ideas of this project, giving explanation of its intent and range.

4.1: Refit Existing Launcher

This would entail replacing seals, valves, and any other potentially worn parts, as to ensure that the piece is in full working order, the system needs to form a sealed expansion chamber when loaded and ready to discharge. This would prevent the loss of pressure, and thus the maximal transfer of energy to the intended useful purpose. Additionally, this option, out of the practical modifications, would potentially prove to be the cheapest, as it would involve merely replacing aging parts, rather than a full rebuild of the apparatus. Therefore, this may prove to be the choice that the customer opts for, based solely on that possibility.

4.2: Alternate Launchers

As modifying the currently installed launcher could have limited potential for improvement, directly replacing it may prove the better option, for ergonomics, power, and reliability. Therefore, two options, which have been selected for their relative simplicity, are explained below. Specifications on material properties, dimensions, et cetera, would have to be calculated to form the optimum set of values, which could take several weeks, given the possible variety of these variables. Pending the adoption of one of these ideas as a possible prototype, there is little value in hypothesizing about what could be done unless there is sufficient data to formulate a solid conclusion. Doing so would result in many different options, but few useful ones, which would result in wasted time and effort which could be better spent developing and refining a specific solution, as selected by the client.

4.2.1: Linear Spring-Based

This concept would, effectively, take the design principles of most simple open-bolt sub-machine guns, such as the STEN (The Editors of Encyclopaedia Britannica, 2018), and give it the functionality of a pinball machine plunger (Glass, 1945); propelling the projectile via mechanical energy, imparted by a coil spring impinging on a bolt, which would carry the projectile. Very few moving parts, simple to manufacture and maintain. The velocities could be altered by means of spring compression, spring constant, or modifying the bolt mass, as Robert Hooke described in the late 17th century (Williams, 2015)(9.1: Equations Utilized in the Writing).

4.2.2: Torsion Spring-Based

Practically speaking, this idea has two variants: an onager-type catapult, using an arm connected to a torsion spring (The Editors of Encyclopaedia Britannica, 2018), or a ballista, which utilizes a pair of arms and springs, with the projectile slung between the pairs (Oxford University Press, 2019). The former would introduce an inherently curved trajectory, which should thus be discounted in favor of the ballista. This would use two torsion bars, with attached swing-arms, to provide the propulsion to the projectile.

Alteration of the velocities in such a system could be achieved by altering the length of the arms, thus modifying the torque output; the draw distance, affecting total force applied; or by changing the torsion springs themselves, which would alter the maximum force available, as per Hooke's Law (Roylance, 2000)(9.1: Equations Utilized in the Writing).

4.2.3: Chemical Propulsion

As this launcher and its associated equipment are already licensed under UK firearms law, as a result of the muzzle energy of the launcher being higher than twelve foot-pounds, or approximately seventeen Joules (Goodson, 2019). Due to that restriction, the possibility of an increase in power, which would allow for a much more versatile range of targetable velocities, would remove the issues of linking in to the central pneumatic system, and would potentially prove more interesting to the operators, as they would be tasked with use of gun powder and the small, controlled explosions that go along with that.

4.2.3.1: Black Powder

Black powder, which is to say traditional gun powder, has been known to humanity since about the eleventh century in Korea, and later China, then along the Silk Road into Europe through Arabia in the thirteenth to fourteenth centuries (The Editors of Encyclopaedia Britannica, 2019). This was then used, and weaponized, there in the form of crude siege artillery and hand-cannons (Center For Fawkesian Pursuits, 1999-2000) which, by the end of the seventeenth century, had become the main armaments of the European armies, supplanting the pike as the primary weapon of war.

Fundamentally, black powder didn't change throughout the course of its existence until the period where it was ultimately replaced by smokeless powder in 1886, when the French military introduced the Lebel rifle and its 8mm smokeless cartridge, fueled by *poudre blanche*, white powder (The New York Times, 1889).

Black powder is, essentially, composed of three ingredients: charcoal and sulphur, as fuels, and an oxidizer, saltpeter, that is, potassium nitrate. This mixture is then ground up into a fine powder, with the ingredients put in the correct ratios, then corned, which is to say, made into grains, or clumps of powder, which makes it easier to store, makes it less affected by water, and enables the user to change the burn rate of the powder by altering grain size (The Editors of Encyclopaedia Britannica, 2019). This is important, as burn rate is proportional to the rate of energy release, which is proportional to the pressure exerted on the vessel the powder is contained in. Generally, a slower acceleration that is controllable is desirable, hence why commercial black powder comes in multiple grades, in terms of grain size.

The issues with black powder are that it produces a significant amount of smoke, which both befouls the mechanism it is being combusted within and the surrounding environment, whilst additionally producing rather noisome and noxious fumes. The potassium and sulfur salts that form a residue, as a result of the combustion process, are also corrosive and would necessitate the frequent cleaning of the barrel of any launching mechanism that were to utilize black powder as a propellant (New World Encyclopedia contributors, 2017).

This was especially true with the muskets of armies of Europe of the seventeenth to late nineteenth centuries, which had to be cleaned with water frequently, and the issue of corrosion would cause more problems than it would really be worth, for this setup, but this could be avoided by using more modern propellants, such as one of the various forms of smokeless powders.

4.2.3.2: *Smokeless Powder*

Smokeless powder does still produce smoke, because it is, of course, a combustion process, and thus produces both smoke and solid reaction products, but rather than the large, voluminous, white clouds produced by the firing of black powder, smokeless powder merely produces a light haze. This is analogous to the difference when burning dry wood as opposed to wet wood, in terms of the amount and type of smoke produced. This was the main reason for its adoption, as it became significantly easier to see, giving a tactical advantage to the troops who were using it, and producing much less carbon fouling, promoting the lifespan of the firearms using it.

Additionally, the pressure curve of smokeless powders, as compared to black powders, are much less variable in gradient (though the maximum pressures are greater): they tend to provide much more constant acceleration, which is desirable because it reduces the changes in the stresses on the mechanism, thus extending the life span and, additionally, increasing the maximum power attainable for a given maximum stress.

The composition of smokeless powders can also be changed to make them significantly less corrosive than black powder, which would lengthen the life span of the item using it and allow for longer intervals between cleanings to occur, in terms of increasing the number of occurrences of charging and discharging between cleanings, though proper maintenance is still important, to deal with any burnt or unburnt residues and anything else which may be deposited in the barrel or elsewhere in the apparatus.

4.3: Periphery

If it is unviable to affect a change to the actual launching apparatus, then modifying the ancillaries could be an alternative. That said, though simply replacing a piece of equipment may be faster than manufacturing replacement parts for the launcher, it may prove more expensive, due to the specialist nature of the equipment in question.

4.3.1: High-Speed Camera

This piece, used to record video footage of the impacts on target, could greatly benefit from replacement. The resolution of the output is severely lacking in comparison to modern cameras, meaning that significant gains in performance could be made, provided a new camera could be sourced, priced within the School's budgetary limitations. The typical cost for this sort of technology, however, would make it prohibitive to acquire, given the scope of this project.

4.3.2: Lighting

The test chamber contains lights for brightly illuminating the target, for bettering the quality of the high-speed film. These lights are presently a type of cold-halogen lamp, but they could be potentially replaced with LED lamps of similar brightness, were any found, as the diodes require less power and produce less heat, as a rule, than incandescence, which relies on heating a filament until it emits visible light, and are likely safer in the event of damage than fluorescents, as those typically contain mercury vapor.

4.4: Cleaning and Manual of Arms

As the impetus for this project was limited performance of the launcher as a result of improper maintenance (the issues that led to the undertaking of this project were fixed by performing a bore sweep with an oiled rag), the law of parsimony (Blackburn, 2016) dictates that the simplest solution is typically the best, therefore to implement a resilient schedule for ensuring proper cleaning of the launcher, as well as the maintenance of the auxiliaries thereof, would be the most suitable option. Naturally, should this option be picked, details will follow later in the report.

5.0: Selected Solutions

Of the proposals seen earlier, only a few are now viable, due to a large number of factors, which shall not be enumerated here, and have been effectively limited to hypotheticals, be they in terms of designs or suggestions. Practical answers, meaning those ideas involving manufacture or procurement of parts, are being ignored, leaving those that are less resource-intensive to implement, such as maintenance and cleaning routines.

5.1: Operations

Standardizing a manual-of-arms for usage and operation of the launcher and its various accoutrements should be a top priority, as regardless of the level of qualification or competency of the present users, they will not be there for eternity, and training of new staff will be required. As such, ensuring that material to do so is readily available would promote ease of use for new personnel.

Any potential operations manual should cover all aspects of the usage and maintenance of the launcher, as does the Operations Manual for the SA80 (Ministry of Defence, 1985-87), suggestions follow below:

1. Safety Rules:
 - Ensuring that no one is in a position to unintentionally be harmed, the launcher or other parts damaged, or the test compromised.
2. Disassembly, Cleaning, and Reassembly:
 - Basic stripping of parts, and detail disassembly when necessary. This is covered in more detail in the next section.
3. Operating under Normal Use:
 - How to load, unload, and discharge the launcher, maintaining operating norms.
 - Target preparation and treatment.
4. Stoppage Drills:
 - How to identify and solve misfires, performance issues, and associated failures.

5.2: Cleaning and Maintenance

Ensuring that all parts of the launcher are clean, corrosion-free, and correctly lubricated, should be a step taken prior to performing any operations involving the launcher. If it is not checked, nor any possible issue found or dealt with, the efficiency of the system may be reduced, should any blockages or friction-inducing elements exist. Additionally, if it is determined to not be in a clean and operable state, steps should be taken to bring it to that state of readiness, as follows:

1. Remove all user-serviceable parts, such as the muzzle-cap, sensors, and breech assembly, taking care to not damage any of them.
 - This enables finer detail cleaning to occur, ensuring better levels of overall cleanliness.
2. Clean any accretions or corrosion from the various sections.
 - This will help extend the lifespan of the system, by reducing wear on the moving parts, and ensuring that there are no blockages to cause stoppages.
3. Lubricate moving parts with the appropriate lubricant, to be determined separately.
 - As with the general cleaning, this aids the overall working of the piece, reducing friction, and promoting the prevention of corrosion.
4. Re-assemble, and ensure that all functions of the apparatus are performing correctly.
 - Functions being that any safety mechanisms are in place and operable, that pressure is held when charged, and that the launching motions can be performed without issue.

Repeat the cycle until everything is operating as intended, before and after each session of use, making sure that, if the piece is to be in storage without use for some time, that a larger coat of oil is applied to preserve it, and that it is covered to mitigate dust accumulation.

As this is a relatively simple piece of equipment, from the perspective of part count, cleaning, difficulty of assembly and disassembly, there should be little difficulty in ensuring that it remains in full, working order. This does raise the inquiry as to why it took so long for the issues due to the lack of cleaning to be attended to, as basic sense dictates that keeping a mechanism clean and in working order should be the most basic operation performed by any operator, as is stressed in the M16A1 manual from the Vietnam War (Eisner, 1969). That a document from fifty years ago covers this and highlights the importance of performing the proper maintenance, which has not been done here, until some remedial action has been performed, quite recently, is rather disturbing, given the relative importance of the experimental work performed with this apparatus.

Additionally, as, when it is disconnected from the pneumatic power supply, there is no possibility of unintentional discharge, no safety equipment should be necessary, though, should the user take issue with the possibility of getting industrial lubricant on their person, or their clothing and belongings, appropriate use of gloves, overalls, and the like should be permitted and, potentially, provided, given that there is sufficient demand from the operators and interest from the customer in doing so.

5.2.1: Lubrication

As proper lubrication of moving parts is essential to correct functioning of any mechanical system, due to friction and ingress of foreign material, various options have to be considered. Essentially, deciding what type of lubricant, dry, wet, or otherwise, then which specific formulations therein, is what is needed here.

As this apparatus is functionally a gun, considering the use of lubricants designed for such items would be a sensible starting point. Other possible options could include natural oils, such as linseed, artificial lubricants, such as mineral oil, or solid lubricants like graphite powder. Alternatively, use of so-called 'self-lubricating' materials, such as brass and some nylons could have the potential to eliminate the necessity of additional lubricants all together.

These options all have advantages and disadvantages, the most obvious failing point being that the suggested linseed oil undergoes a particularly exothermic drying reaction when left in an oxygen rich, dry environment, such as air in a room on a warm day. This can cause the oil, and whatever it is residing upon, to spontaneously combust, which poses a rather large safety hazard to those working around it, should this property not be accounted for. Solid lubricant may cause valves to seize, should the two interact overly much. This would be a major issue in any system where effective gas-seals are important, such as the pneumatic and chemical propulsion-based systems, as pressure would be lost, or possibly not even attained, which would have a severely adverse effect on the performance of the apparatus. Certain rubbers have poor reactions to mineral oil lubricants, so care should be taken in selecting both items, to ensure optimal performance, should rubber gaskets be needed.

5.2.2: Exemplar Maintenance Schedule

As was discussed previously, proper preparation prevents poor performance, and as such an actual schedule for maintaining the laboratory equipment is necessary. Therefore, an example of one follows below, divided into parts of apparatus and time intervals, from essential tasks to be done at every instance, to those that are to only be performed once or twice per academic year.

5.2.2.1: Table 1: The Launcher

Preparation for Daily Use (On a per-day basis during testing periods)	1. Perform a visual inspection of the apparatus to ensure that all parts are present, then check to make sure the system is clear, and not “hot”, that is, not in a position that is ready to be discharged. 2. After conducting this check, ensure there are no obstructions in the bore. 3. Clean all orifices with an appropriately sized cleaning implement 4. Clean the bore with a cleaning rod and an attached cloth. This should first be unlubricated, to remove any detritus material from the barrel, then once clean, lubricated with the previously discussed lubricant, to ensure a low-friction environment for the projectile. 5. Having cleaned the bore, ensure that the ammunition is available, that it is in good working order, then go about the standard operating procedures for loading, discharging, and repetition of the testing.
Post-Operation Cleaning (On a per-day basis during testing periods)	1. Ensure that the device is safe, that it is unloaded, and that all pressure is discharged. 2. Clean and lubricate all moving parts. 3. Ensure that there are no blockages in the orifices. 4. Clean the bore with the cleaning rod and cloth, as in the previous section.

Putting into Long-term Storage (After a bout of testing periods)	1. To prepare for long-term storage, perform all of the actions that would be performed for daily cleaning. 2. Ensure that there is a heavier coat of lubricant applied to better preserve the material and to prevent the build-up of corrosion. 3. Apply a dust sheet, if available, applicable, and appropriate, to help prevent contamination of the apparatus from foreign material
Placing back into Operation (Before a bout of testing periods)	1. On removal from long term storage to prepare for testing, the steps followed to put it into storage should be followed in reverse order. 2. Remove any coverings from the apparatus. 3. Clean off the applied lubricants. 4. Reapply a lighter coat of lubricant, having cleaned the orifices and moving parts appropriately.
Placating Performance Issues (Apply as needed, knowledge should be required)	• Should there be a misfire, that is, a discharge is attempted and there is a failure to correctly do so or, a failure to fire, ensure that the pressure generation is turned off, then release all pressure from the vessel, through the rear, if possible, or vent through to the atmosphere, if not, then, ensuring that everything is turned to off and in the safe positions, slide the breech assembly across and visually inspect. • If it is possible to remove the projectile via the breech then do so, if not, it will be necessary to remove it from the muzzle end, which will necessitate entering the test chamber and, with a ramrod, pushing the projectile back to the breech, where it came from. • After the obstruction has been removed, a visual inspection to ensure that there are no further bore obstructions should be conducted and, after that, inspection of the projectile should be conducted to ensure that there is no damage to it, and then testing may recommence as usual.

5.2.2.2: Table 2: Testing Chamber

Preparation for Daily Use (On a per-day basis during testing periods)	1. Be certain that the launching apparatus is safe and unloaded before entering the testing chamber. 2. Ensure that there are no obstructions to the openings in the test chamber wall that provide access for the projectiles. 3. Remove any other items that may impact on the testing performance. 4. Set the climate control to the conditions required by the day's testing. 5. Set up the target for the test, ensuring that it is clean, intact, and correctly mounted. 6. Vacate the room, then seal the chamber by closing the outer door.
Post-Operation Cleaning (On a per-day basis during testing periods)	1. Remove used targets for storage or further analysis. 2. Clean any debris that may have been created as a result of testing. 3. Disable the climate control system, to return room to normal conditions. 4. Turn off the lights and close the chamber off.
Putting into Long-term Storage (After a bout of testing periods)	1. Make sure that the room is clean and free of detritus. 2. Disable the equipment, by disconnecting power. 3. Apply dust sheets, if provided.
Placing back into Operation (Before a bout of testing periods)	1. Perform a general tidying of the chamber. 2. Remove dust sheets and reenale the equipment. 3. Ensure that equipment is working normally. 4. Test the climate control system for proper functioning.
Placating Performance Issues (Apply as needed, knowledge should be required)	• PAT Testing should be performed on electrical equipment at regular intervals, as required. • Maintain a first-aid kit (FAK), in case of injury, from broken glass or otherwise. • Keep a supply of spare parts, including bulbs for the lamps and fasteners for the test pieces.

5.2.2.3: Table 3: Target Materials

Preparation for Daily Use (On a per-day basis during testing periods)	1. Locate the target materials dictated by the testing program. 2. Ensure that the pieces are in the proper condition. 3. Load test materials into the target holding device as appropriate. 4. Test and adjust, then perform the testing. 5. Reloading of the target should occur after removal of the previous test piece.
Post-Operation Cleaning (On a per-day basis during testing periods)	1. Relocate all used testing materials to the appropriate post-processing or storage locations. 2. Ensure no damage has occurred to unused material, then return it to storage. 3. Clean up any remaining debris that has been created as a result of the testing.
Putting into Long-term Storage (After a bout of testing periods)	1. Make the pieces clean and tidy. 2. Place materials into appropriate storage containers. 3. Secure the storage from personnel and ingress of foreign matter.
Placing back into Operation (Before a bout of testing periods)	1. Remove any buildup of material that may have occurred over the storage period. 2. Unsecure storage vessels, ready for use. 3. Ensure material is still in a usable state, and make it so, if it is not.
Placating Performance Issues (Apply as needed, knowledge should be required)	• Should test pieces be in an unusable state, requisition replacements, then hold an inquiry as to how this failure occurred. • Secure a sure source of a safe selection of spares.

5.2.2.4: Table 4: The Operators

Preparation for Daily Use (On a per-day basis during testing periods)	1. Select who is to operate the testing apparatus for the day's testing. 2. Ensure the availability of replacements in the event of staff unavailability. 3. Go over the contents of the testing regime with the operating staff until everyone involved is confident in what is expected. 4. Secure supply of resources for staff maintenance and allow adequate time for breaks over the course of the day.
Post-Operation Cleaning (On a per-day basis during testing periods)	• Removal of any residues from the apparatus by simple handwashing should suffice.
Putting into Long-term Storage (After a bout of testing periods)	• Ensure that they are in a well-kept state and that any relevant paperwork has been filled out. • Personnel should be able to locate their own personal storage locations, but appropriately sized boxes may be needed in the event that this proves false.
Placing back into Operation (Before a bout of testing periods)	1. Refresh personnel on how to operate the apparatus correctly and safely. 2. Provide time and ammunition to perform test-firings of the launcher, to re-familiarize the staff with its workings. 3. Perform simulated runs with the data processing software to keep personnel up to date with it.
Placating Performance Issues (Apply as needed, knowledge should be required)	• Proper provision of tea should be maintained. • Taking staff opinions about the apparatus into account for future use or adaptation should be considered. • Keeping spare personnel around in event of emergency would be recommended. • First-Aid equipment should be provided as necessary.

6.0: Evaluation

This will aim to summarize the impacts that the proposals made by this project may have, should they be implemented in any way. As such, the segment shall be split into several sub-sections, forming an overall measure of the project and this report. This will enable better understanding of the successes and shortcomings, to ease the task for the reader.

6.1: Time: Allocation and Management

Overall, the amount of work possible on this subject far exceeds the available time which has been allowed for working on it. As such, only select sections of the many available for consideration were able to be chosen. This proved be the crux of many of the issues encountered during the undertaking of this project and could have been handled better. The result of this being limitation in what could be achieved, which was further hampered by poor management of the time that was available.

6.2: Resources

The allocation of resources to this project was a rather mysterious affair, which was not made at all clear until halfway through the timeline thereof. This resulted in the drastic change taken in the project, from a practical proposal, to merely a list of suggestions. If the correct questions had been asked earlier on in the project, this issue could have been dealt with, or potentially avoided, increasing the overall quality of the work.

Whilst the above is true, there are some positives to have come of this: dealing with this adversity has resulted in a project far removed from the original intent, but still answering the same question.

6.3: Results

The various proposals could become useful, given sufficient interest, and could, at the least, form the basis of further research or design work. Overall, several ideas were formulated, and though most of them were denied from implementation, the ideas are still valid and could eventually be used: this would be the intended result of this project, at this point in the undertaking.

7.0: Conclusion

To end this report, it is necessary to provide summation of this project. It had many ideas, a few failures, some successes, and allowed for several suggestions to be posed to those in the position to implement them. The potential for further work in this area is high, and should be considered, if possible.

Thus, the overall conclusion should be to implement a cleaning and maintenance schedule, as described previously as this would be the quickest and cheapest short-term solution to the issues experienced in the operation of the Ballistics Laboratory. This is in spite of the alternative suggestions, which would be more long-term, but also significantly more expensive and time-consuming, which have disqualified them from contention.

7.1: Recommendations for the Future

In future, making use of some of the suggestions made in this paper, at the least the basic maintenance requirements, would be appreciated, as that was the impetus for this project being undertaken in the first instance. This would not necessarily have to be resource-intensive, nor would it have to be overly intrusive, though that decision making process is, ultimately, up to the person in charge of the laboratory, who will hopefully acknowledge the defects brought up in this report, and make some attempt to correct them. Otherwise, allow this to be used as a base for another project to work from, or to derive inspiration for a separate enterprise.

7.2: Suggestions of Further Works

Given that, as has been stated, the project did not reach its intended conclusion, the logical means of proceeding would be to continue in that vein and reach those initial goals. That is, to produce prototypes of the proposed upgrades, replacements, and ancillary changes, to experiment with the variables and create a better experience for those using the laboratory. Thus, a project could be performed on various elements, the main items to consider are:

- Implementation of the suggestions made here
- Design and analysis of variant launcher ideas
- Testing of improvements in general
- Considering specific aspects of testing processes that could be improved
- Investigating further applications of the laboratory.

These ideas could allow for greater usage, and larger ranges therein, of the Ballistics Laboratory, potentially widening the audience that may be interested in utilizing this resource to measure the performance of their own products, which could strengthen the commercial ties that the university appears to value, whilst potentially bringing in more projects, and funding for those, which the school could gather great benefits from.

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9.0: Appendix

A section comprising items which do not necessarily fit into the main body but are likely required due to relevancy and use therein.

9.1: Equations Utilized in the Writing

- Energy:
 - **Kinetic, Muzzle:** *Energy = One-Half of the product of Mass and the Second Power of the Velocity.*
- Springs:
 - **Hooke's Law:**
 - Linear: *Force = Change of Length multiplied by the Spring Constant.*
 - Angular: *Torque = Change of Angle multiplied by the negative Torsion Coefficient.*