Projectile Mass Distribution Following Impacts on Hardened Steel Plate

A dissertation submitted by

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ENG4112 Research Project

Towards the degree of

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Abstract

Hardened steel plate is a commonly used material for reusable targets in shooting clubs, particularly pistol clubs. The use of this plate creates safety concerns as the bullets are destroyed on impact and the bullet mass is deflected in sometimes unpredictable directions. Eye protection is mandatory in situations where steel targets will be shot at close range, however the relationship between shooting club organisers and the Police Weapons Licensing branch can often be strained in disagreements as to whether steel targets are being used appropriately.

The aim of this research project has been to gain a greater understanding of the behavior of lead projectiles after impact with steel plates, particularly the way in which the projectile fragments are distributed upon impact and the relationship between that distribution and the impact angle of the projectile against the target surface. This research will be beneficial to the relevant shooting sports where steel targets are used. It will assist competition organisers in setting targets and knowing what extra measures may be required for the safety of shooters.

The preliminary research of this report led to the selection of Bisplate 500 as the experimental target material, due to its common use as a target material and its availability. The rifle selected for the experiment was chambered in 32-20 Winchester. The legal limitations on where pistols are permitted to be used led to the decision to use a rifle instead as it allowed the testing to be undertaken on private property. The 32-20 cartridge fires a 115 grain (7.45 gram) lead-tin alloy projectile, very similar to the 9mm and .38 super projectiles most commonly used in pistol target shooting.

The experimental component of this research project involved both computer simulation and field testing of projectile impacts on hardened steel plate. The field testing revealed that the projectile fragments are deflected away from the impact site on the plane made by the face of the target. As the impact angle is reduced the fragments are still deflected on the same plane, however eventually the distribution of the fragments becomes biased to the lower side of the target. The critical angle at which there are no longer fragments deflected in all directions is 27.5°. At 24° the fragments are completely deflected below the impact point.

The ANSYS simulations produced results that reinforced the findings of the field testing at impact angles between 90° and 65°. At 65° the ANSYS simulations began to show the fragment distribution become biased toward the lower side of the target and see the beginning of a section at the top of the fragment pattern where there was no evidence of fragments, something not seen in the field testing until 27.5°.

The recommendations at the conclusion of this research project are that the safest way to setup steel targets on a range is to ensure that the plates are as close to perpendicular to the shooting positions as possible. It was identified that because the fragments are predominantly contained within a narrow plane of travel, they would be easily contained within a loop of absorbent material such as rubber conveyor belting.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Chapter 1 - Introduction

Background

Target shooting is a well established sport in Australia and takes many forms. There are approximately a million licensed firearm owners in this country, and the largest sport shooting organisation, the sporting shooters association of Australia or SSAA, has over 175,000 members (SSAA, 2016). Many of these people are regularly involved in organised target shooting events.

In many target shooting disciplines hardened steel plate is used as a target material. This practice is due to many reasons:

- Impacts on steel targets create an obvious audible ring
- The physical reaction of the target to a projectile impact can be used as a visual indicator of a hit, for example if the plate falls over.
- Falling plates can then be used to trigger secondary moving targets such as targets mounted on a pendulum that is released by the initial plate falling
- Steel targets have a very long service life and typically can be in regular use for many years before they show signs of deterioration and become unserviceable.

The drawback to using steel plate targets is that the Lead alloy projectiles fragment on impact with hardened material, and the fragments are deflected away from the surface of the target.
These fragments are commonly referred to as spall or splatter, and can pose a threat to nearby people.
The behavior of these fragments is the chosen topic of study for this research project.

The idea of studying this topic as a research project arose following the experiments undertaken as part of fellow USQ student Lachlan Orange's research project in 2013 where the effects of different projectile designs on the same hardened steel plate were studied. In the testing projectiles were fired at test pieces of steel plate at a range of 25 metres, and as a precaution a polycarbonate screen was used to shield us from any ricocheting bullet fragments. After the testing the screen did not show any obvious signs of impacts with fragments, which led to the question what is the distribution pattern of the projectile mass after impact. After some research it was established that while there was extensive development into armour plating and impacts with bullet projectiles, this work was usually focused on military and security applications where the goals were simply to defeat either the projectile or the armour. There has been limited prior research into the behavior of defeated projectiles after impact, and how to design targets to distribute the projectile mass in the most desirable manner. The limit of study of projectile fragments in armour applications has been the development of polymer anti-spall coatings that are designed to contain the fragments after impact to eliminate any risk of injury to those wearing the armour or those in the immediate vicinity. Applying these coatings to hardened steel targets would be unsustainable due to the cost of the coatings and the rapid depletion of the coatings effectiveness following projectile impacts.

Shooting clubs in Queensland are regulated by the Queensland Police Service, who have the power to place conditions on clubs relating to how targets should be utilised. The officers carrying out these duties often direct clubs according to their own opinions that can have limited scientific backing. The aim of this research project is to establish an idea of how projectiles behave after impacts with hardened steel plate across a range of impact angles to assist in the safe design of shooting ranges.

Steel plate targets are used in a number shooting sports, however the discipline that will be focused on in this study will be close range pistol shooting, specifically International Practical Shooting Confederation (IPSC). The reason for choosing this discipline as the focus for this study is that IPSC involves shooters running through a course and firing at a wide range of targets, many of which will be hardened steel plate and may be shot at very close range. The nature of this competition means that targets could be hit from a range of different angles, and a greater understanding of how bullets behave when hitting these targets will greatly assist participants in safely planning courses and maintaining a harmonious relationship with the police.

Project Aim

The aim of this project was to establish a good understanding of how lead projectiles react when impacting hardened steel plate in any way that is likely to be encountered in a target shooting range. This includes impacts across a range of angles, where the behavior of the fragments may become unpredictable.

This report can be presented to target shooting clubs to assist in how ranges may be set up in the future, and to help them in their relationship with the police.

Objectives

There were four major objectives of this project

- Design and carry out a field experiment that will involve firing projectiles at a hardened steel target across a range of angles. The distribution of the fragments will be catalogued using a reactive medium around the target to view the distribution of fragments.
- Simulate a lead alloy projectile impacting a similar steel plate using ANSYS Explicit Dynamics software.
- Evaluate and compare the results of both experiments.
- Make recommendations based on the findings.

Expected outcomes

The expected outcomes of this research were that there would be a significant amount of experimental data collected that would illustrate how projectiles fragment on impact with steel targets. This data will then be used to make recommendations regarding the use of steel targets in shooting ranges.

Chapter 2 - Preliminary Research

Justification of Research

The study of impacting bodies has a wide variety of applications ranging from passenger safety in vehicle collisions, to military and munitions applications. The latter topic has been the subject of much research and development over hundreds of years with the goal of improving armour and anti-armour capabilities. There is however, limited research in the area of soft projectiles impacting hardened objects where the focus of the study is the behavior of the fragments post-impact. For this reason the following review of available literature has found minimal research regarding the specific topic of this project.

The term 'ricochet' is commonly used when discussing ballistics and often creates misconceptions about the behavior of projectiles and their lethality after impacting hard surfaces. Mohan Jauhari describes ricochets in his experimental report as follows:

'When a bullet strikes a target of sufficient solidarity at low angle it may, while maintaining its integrity, be deflected from its original path as a result of impact and travel in a direction quite different from its original one. Such a deflection of a bullet constitutes a true ricochet' [Jauhari, M. 1969]

The description of a true ricochet in this report implies that to qualify as a ricochet a bullet must remain mostly intact, and that the critical angles for this to occur are quite low, ranging from 30°-55° on steel plate [Jauhari, M. 1969]. Shooting on target ranges will seldom involve the risk of an impact angle this low as ranges are deliberately designed to avoid this possibility. Targets are set so that projectile trajectories are as close as possible to perpendicular to the target plane.

When a projectile impacts a hard target at an angle higher than the critical angle for a ricochet the projectile fragments and disperses its mass over a wide area. These fragments are commonly referred to as spall and their distribution can be observed when using hardened steel targets as a lot of the spall can be recovered from the ground surrounding the target. Generally the fragments are very small and would be unlikely to cause serious injury, however this is to be determined during this research project.

When lead projectiles hit hardened steel bodies almost all the deformation occurs in the lead projectile and the steel target is left undamaged. Targets that have been in use in the City of Brisbane Pistol Club for the past two years have had an estimated 50 000 impacts from lead projectiles and show no signs of localised damage from these impacts. There is evidence to show that the projectile fragments leave the impact site in a conical shape, as there is a clear line of removed paint on the supporting base of these targets where they have been repeatedly hit by bullet fragments. The following graphic shows a typical 'Popper' design target commonly used in IPSC pistol and illustrates the location of the paint damage to the target base, relative to the impact site on the target.

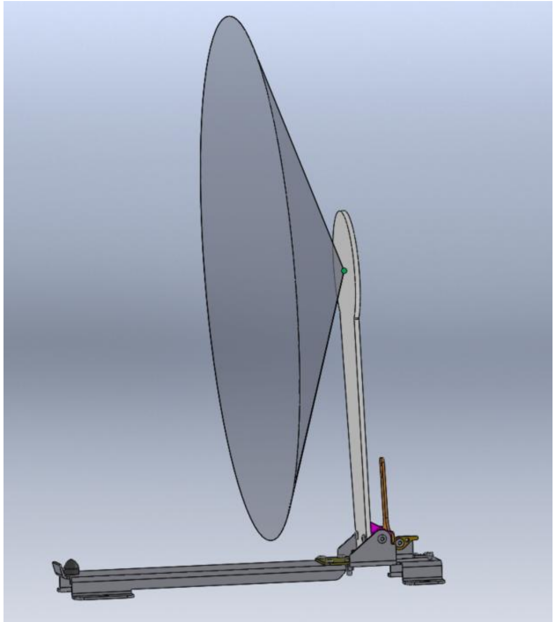

Figure 2.1.1: This illustration shows an exaggerated cone of spall distribution. The target plate on this popper target is set at a 2° forward angle and the impact site is depicted by the green dot at the tip of the cone.

Available Research Documentation

A full list of research documentation utilised is included in the bibliography.

Books:

-Terminal Ballistics
Terminal Ballistics discusses extensive research into armour and projectile design. It provides some insight into the behavior of soft projectiles during high velocity impacts against hard targets (armour) that is relevant to the proposed experiment for this research project.

Journal Articles:

-Bullet Ricochet from Metal Plates
Journal article written in 1969 that discusses an experiment to find the critical angles at which projectiles will ricochet from a selection of materials. While the described experiment differs from the proposed experiment for this research project it provides valuable ideas to help design the experiment and some impact angle values that may help as starting points when locating critical angles of impact.

-Projectile Ricochet and Deflection
Journal article discussing bullet deflections from unintended objects such as buildings and vegetation. Focus is on relatively soft targets buts offers information into critical impact angles.

-The distribution of energy among fragments of ricocheting pistol bullets
British journal article discussing subject matter very similar to the intended experiment. Targets used are softer than the steel plate intended for use in this project which will most likely lead to significantly different results. Projectiles in this experiment maintained a significant portion of mass through the impact, whereas it is expected that projectiles impacting the hardened steel plate targets will fragment considerably and carry far less energy in the resulting pieces.

Online Sources:

Safety, Steel Shooting Guidelines
Supplier of hardened steel targets with well explained recommendations on setting up targets for safe use. Gives a professional opinion on how bullet fragments will be distributed after impact with targets from a source with a commercial interest in the safe use of hardened steel targets.

Projectile Materials

The focus of this research project is lead alloy projectiles as these are the regulation projectile to be used in pistol target shooting. Projectiles intended for uses other than target shooting commonly consist of a lead core encapsulated in a copper alloy jacket. These types of projectiles are prohibited in target ranges as the harder copper alloy jackets are more likely to damage the steel targets, and also pose a greater risk of creating hazardous spall.

Lead alloys can vary between projectile manufacturers but they are predominantly a Lead-Antimony-Tin alloy. Antimony and Tin are added to increase the hardness of the projectile, which is required when projectiles are being propelled at the high speeds achieved from modern firearms. Projectile manufacturer Lyman publishes a Lead alloy that has become very popular with target shooters that consists of 90% Lead, 5% Antimony and 5% Tin [Northern Smelters, 2014].

- 2% tin, 6% antimony, 92% lead (Brinell Hardness: 15)
- 'Lyman No. 2' - 5% tin, 5% antimony, 90% lead (Brinell Hardness: 15)
- Tin/lead alloys: 1:20(BH:10), 1:25(BH:9.5), 1:30(BH:9)
- Pure lead (Brinell hardness: 5)

Common Lead Projectile Alloys [Northern Smelters, 2014]

Target Materials

The material selected for the experimental phase of this research project is Bisalloy Bisplate 500. Bisplate 500 is an armour grade plate designed to be extremely hard and the 500 in the products name refers to its Brinell hardness score. For comparison, mild steel scores around 120HB. Bisplate 500 is a commonly used material for sport shooting targets. Bisplate 500 is a very commonly used target material due to its availability and price.

BISPLATE® 500

MECHANICAL PROPERTIES

PROPERTIES	SPECIFICATION	TYPICAL
0.2% Proof Stress	-	1400 MPa
Tensile Strength	-	1640 MPa
Elongation in 50mm G.L.	-	10%
Charpy Impact (Longitudinal) -20^{0}C (10mm x 10mm)	-	35J
Hardness	477 - 534 HB	500 HB

Figure 2.4.1 - Bisplate 500 Mechanical Properties [Bisalloy, 2016]

Chemical Composition

Thickness (mm)		C	P	Mn	Si	S	Ni	Cr	Mo	B	CE(IIW)⁺	CET⁺
8-100	Maximum	0.32	0.025	0.40	0.35	0.008	0.35	1.20	0.30	0.002	0.62	0.40

⁺Typical Average

Figure 2.4.2 - Bisplate 500 Chemical Composition [Bisalloy, 2016]

Cartridge Selection

The context of this research project relates specifically to pistol target shooting, therefore a pistol-type cartridge was selected for use in field experiments. The most commonly used cartridges used in IPSC competition are 9mm or .38 Super. Australian gun legislation prohibits use of handguns anywhere but approved firing ranges by people possessing a shooting club type licence, therefore if a handgun was to be used for testing the testing must be carried out at a club managed firing range. Time limitations became a problem with organising this, and there were concerns with being able to gain exclusive use of a club range for the required amount of time for testing. Due to these restrictions it was decided to carry out the testing on private property using a rifle, chambered in a pistol cartridge. The rifle selected was chambered in 32-20 Winchester. This cartridge is an old design made popular by use in the mid to late 1800's in lever action rifles. The .32 calibre projectiles are slightly smaller in diameter than the .38 caliber projectiles in use in the .38 Super and 9mm, however the cartridges share projectile designs and both can fire a 115 grain (7.45 gram) projectile. The rifling twist rate in the weapon was 1:12" meaning the projectile completes one full revolution in every 12 inches of forward travel. This was used to calculate the average angular velocity of the projectile at 10400 rad/s .

Chapter 3 - Safety and Risk

General Risk Management

The planned experiments for this research project involve risks, mostly through the involvement of firearms as an energy source, however these risks can be managed through careful planning and responsible management. The University of Southern Queensland's Risk Management Plan has been used to assess the hazards and the complete document can be found in appendix A.

The nature of this experiment was to establish the behaviors of bullets to minimise risk to shooters, however to carry out the experiment it is necessary to put people in the vicinity of the bullet impacts. This is relatively safe, however eye protection will be mandatory during testing as the eyes are the only part of the body vulnerable to bullet fragments.

The primary control to minimise risk in the experiment is limiting access to people during the process. The only people who will be permitted in the testing area will be the researching student (John Stephens) and Ash Proud who is a licensed armourer and firearms safety instructor. Both Ash and John have grown up involved in shooting sports and have a great respect for the danger of firearms handled incorrectly.

Standard range rules will apply to the testing, there will be a nominated range officer to ensure all firearms are only loaded when in use and immediately cleared on completion of individual tests. Only two people will be present during testing.

Commercial Risk Management

The commercial risk of this experiment was low as the only equipment exposed to reasonable risk of damage was a digital chronograph valued at $300.00. The chronograph is commonly used for the intended purpose of accurately measuring projectile velocity and when set up correctly will be safely out of the projectile flight path.

Project Planning

The project was conducted in the following phases:

- Research Phase- covering the academic research component, looking for as much data as possible before physical testing occurs, to try and predict the testing outcomes.
- Simulation Phase- Using ANSYS software a computer simulation of projectile impacts on hardened steel plate will be
- Experimentation phase- multiple days will be spent testing to collect all the required data.
- Data analysis phase- studying all collected data, and identifying significant figures.
- Write up phase- collaborating results and preparing the project dissertation.

Resource Requirements

Resources include:

Resource	Supplier	Cost	Importance
ANSYS Software	USQ	USQ possesses an ANSYS licence.	Critical
Target test plates	LOInnvations/ City of Brisbane Pistol Club	Donated	Critical
Firearms	A.N Proud Gunsmithing	On Loan	Critical
Test frame including paper support for tracking bullet splatter	LOInnovations	On Loan	Critical
Ammunition loading equipment and scales	A.N Proud Gunsmithing	On Loan	Critical
Digital Chronograph	A.N Proud Gunsmithing	On Loan	Critical

Table 3.2.1 - Project Resources

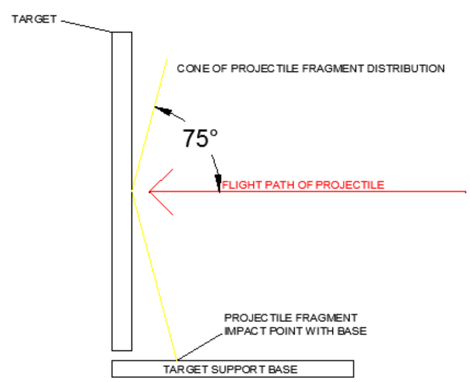

Figure 4.1.1 - Graphical indication of the projectile impact and the subsequent 'cone' of fragments

There is a common belief in sport shooting that when using hardened steel targets the plate should have a slight forward angle (the top leaning closer to the shooter generally within 5° of vertical) with the purpose of deflecting the bullet mass downwards to the ground on impact. An alternative theory suggests that with the angle, a large portion of the bullet mass may be deflected downward, but a portion of it will also be directed upward. With the assistance of the extra angle of the plate, these bullet fragments could potentially be deflected toward nearby people, more so than if the plate were simply set perpendicular to the bullet impact.

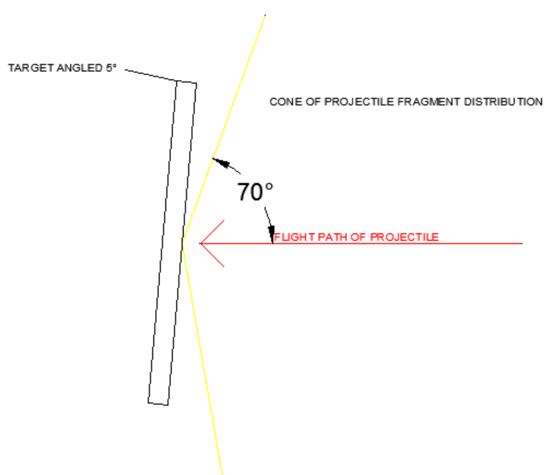

Figure 4.1.2 - Graphical indication of the projectile impact with the plate angled forward 5° and the subsequent 'cone' of fragments

In the planning phase of this research project it was suggested that a possible avenue of experimentation was to use ANSYS Explicit Dynamics software package to simulate the impacts of projectiles, prior to field testing. Academic supervisor of this project Dr Ray Malpress provided a model that had been setup for the certification process of the USQ shock tunnel to be used as a guide for setting up a similar model for testing lead projectile impacts on armour plate.

Some of the key properties for use in the simulation were taken from preliminary testing with the rifle and ammunition to be used for the field testing, and are listed as follows:

	Projectile	Target
Weight	115 Grains (7.45 grams)	N/A
Material Density	11340 kg/m^3	7900 kg/m^3
Modulus of Elasticity	15.7 GPa	200 GPa
Hardness	11 HB	500 HB
Specific Heat	0.128 kJ/kg/K	0.49 kJ/kg/K
Average velocity	540 m/s	0
Angular velocity	10400 rad/s	0

Table 4.2.1: Simulation Input Data

The simulation involved rigidly constraining the target plate and propelling the projectile into the centre of the plate across a range of angles.

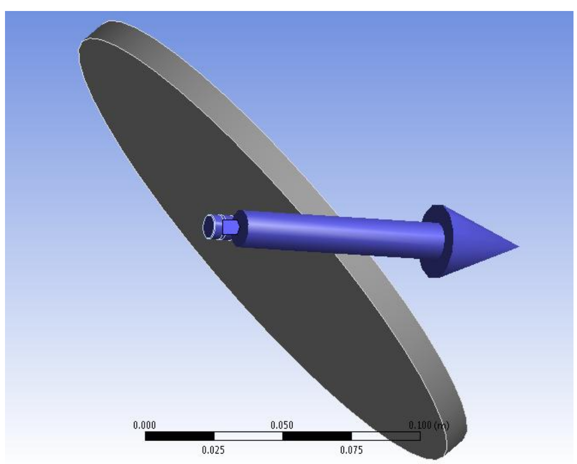

Figure 4.2.1: Projectile velocity vector arrow on 45° impact simulation

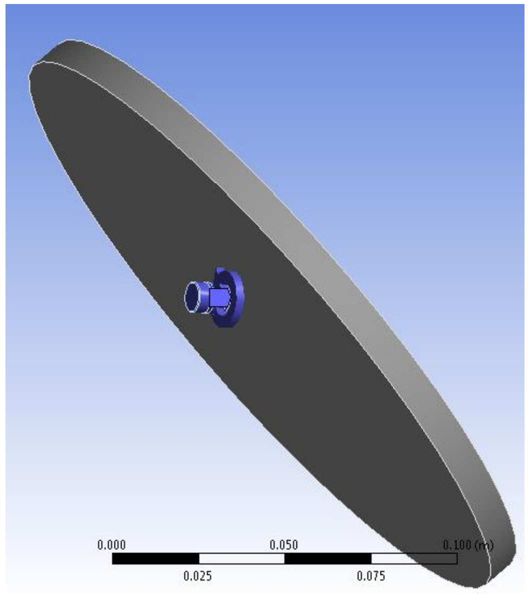

Figure 4.2.2: Projectile angular velocity vector arrow on 45° impact simulation

The simulation run time using a medium mesh took approximately 1 hour and produced clear results, an example of the test results for the 45° simulation is shown below in figure 4.2.3.

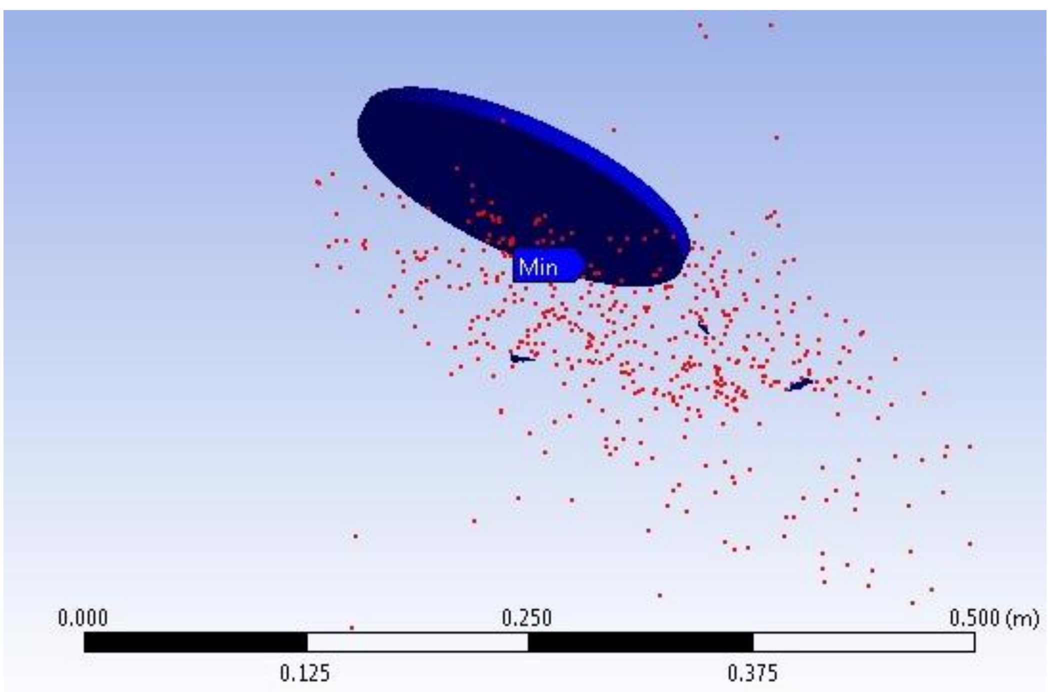

Figure 4.2.3 - Simulation results of 45° impact angle test

From the early stages of this project the field testing component was always intended to be the most valuable data gathering process. While the computer simulation provided some guidance on the likely results, the field testing would definitively show the behavior of projectile fragments in a controlled environment.

The test target was mounted on a rigid steel frame with adjustable mounting brackets and threaded rod as a brace behind the target to hold it at the exact desired angle. A digital protractor allowed the target to be accurately set to the desired angle. The frame sets the centre of the target plate at 1m from ground level. This height was matched for the rifle at the shooting position to ensure accuracy in the testing. For practicality a test range of 25m was selected as a good safe distance while still being able to accurately place all shots in the centre of the target. 300mm diameter cylindrical tubes were fashioned from cardboard to act as a reactive material and mounted around the target test plate. These tubes were easily replaced between shots and showed clear cut lines of damage from fragment impacts.

Figure 4.3.1 - Experiment test frame set at 90°

Figure 4.3.2 - Test frame with cardboard tube in position ready for a test shot.

Testing involved taking three shots at each angle setting, installing a new cardboard tube between each shot. Starting at 90° the target angle was initially lowered in 10° increments as low as 20°.

Field Testing

The most significant observation taken from both the field testing and the ANSYS simulations was that the majority of the projectile fragments were propelled away from the impact point on the same plane as the target face. The fragment pattern was circular, with even distribution around the circle at a perpendicular impact angle. As the target angle reduced (with the top of the target leaning closer to the shooting position), the distribution of the fragments began to thin at the top of the circle until eventually there was a noticeable gap and the circle was no longer complete.

Figure 5.1.1 - Resulting damage of a 60° test shot, it should be noted that the distribution of fragments has begun to thin across the top of the circle, but it is still complete.

27.5° was the shallowest impact angle where the arc consistently contained fragments. Anything below this angle created an arc of undamaged cardboard at the top of the circle.

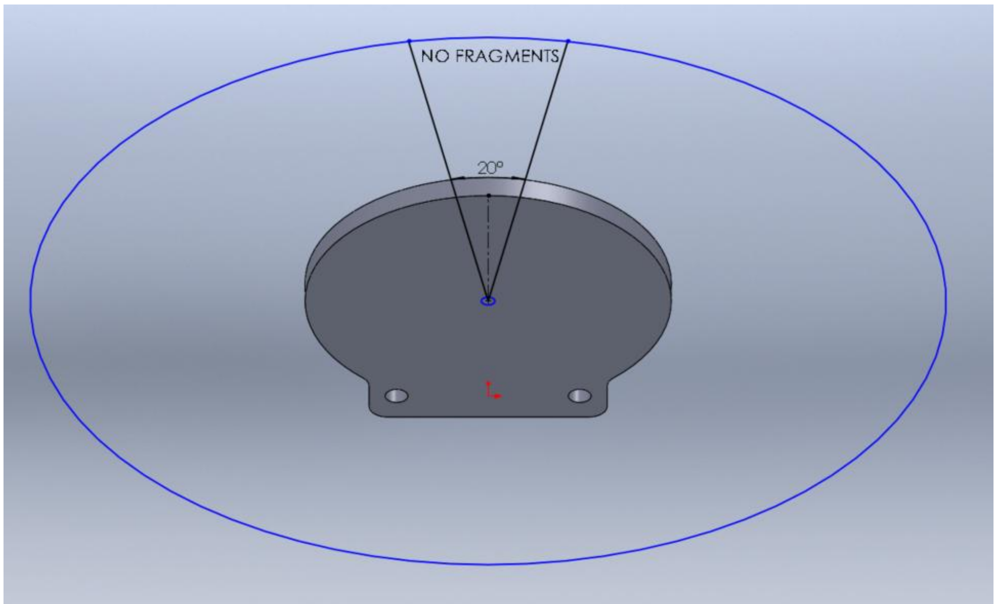

Figure 5.1.2 - CAD depiction of target at 27° impact angle and subsequent arc with no fragment damage to cardboard

At a 25° impact angle there was an arc measuring approximately 35° at the top of the circle where there were no identifiable fragment impacts. Fine angle adjustments and further testing found that at 26° of impact angle the arc reduced to 30°, then at 26.5° the arc was reduced to 25°. The findings of these adjustments are listen in Table 5.1.1.

The critical points identified are as follows:

27.5° - The lowest impact angle at which projectile fragments can be identified travelling directly upward from the impact site, back toward the shooting position.

24° - The impact angle at which point there is no longer any projectile fragments being deflected upward from the impact site.

20° - The point at which the projectile fragments deflect off the target face in such a manner that an arc of distribution can no longer be observed.

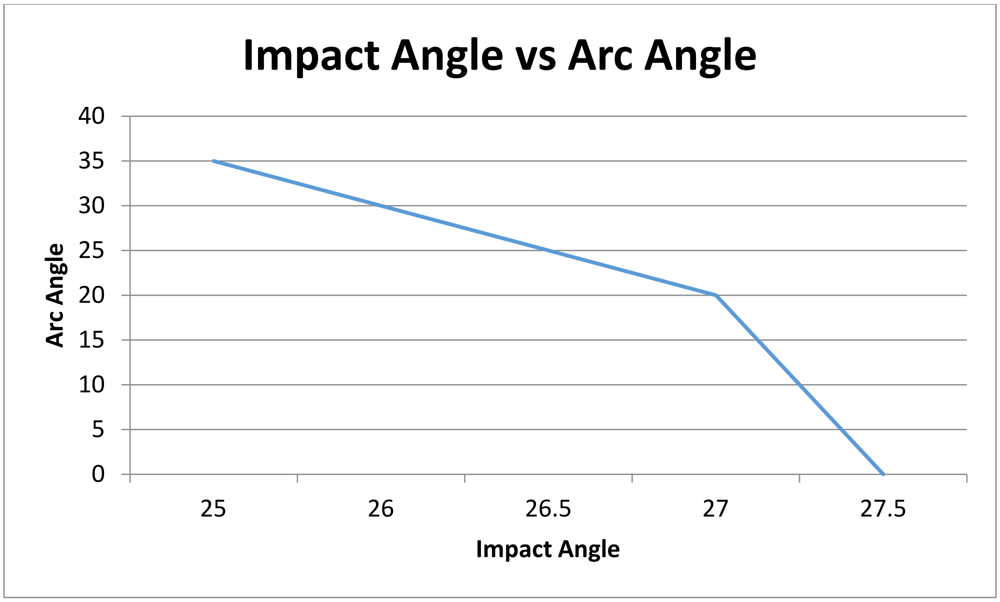

Figure 5.1.3 - Projectile Impact Angle vs Arc Angle

The general measurements of the damage to the cardboard tubes was compiled and the average found for each angle. There were slight differences between the angles of the target plate and the angle of the damage line through the tube, however the differences are small and inconsistent and no conclusions can be taken from them. The differences can be explained by error in the measuring process due to the jagged edges produced by the fragments travelling through the cardboard

Target Angle	Measured Fragment Angle
90°	90°
80°	78.8°
70°	69.7°
60°	58.1°
45°	44.9°
40°	40.1°
35°	36.9°
30°	Angles below 35° became hard to accurately measure, however the results remained consistent with earlier test angles and the fragment pattern remained co-planar with the target face.
25°	
20°	

Table 5.1.1 - Target angles with corresponding fragment damage line angles

Paper was used as a reactive medium to indicate any significant fragments being projected back toward the shooting position. Damage to these sheets of paper was minimal and not present in every test shot. The largest hole measured in the paper was 0.8mm across, which was small in comparison to the damage on the cardboard surrounding the target surface. The ANSYS simulations also showed some outlying fragments beyond the target face plane but these can be considered anomalies in the simulation as the results were not consistent with the field testing or between various ANSYS simulations.

Fragments flying back toward shooting position

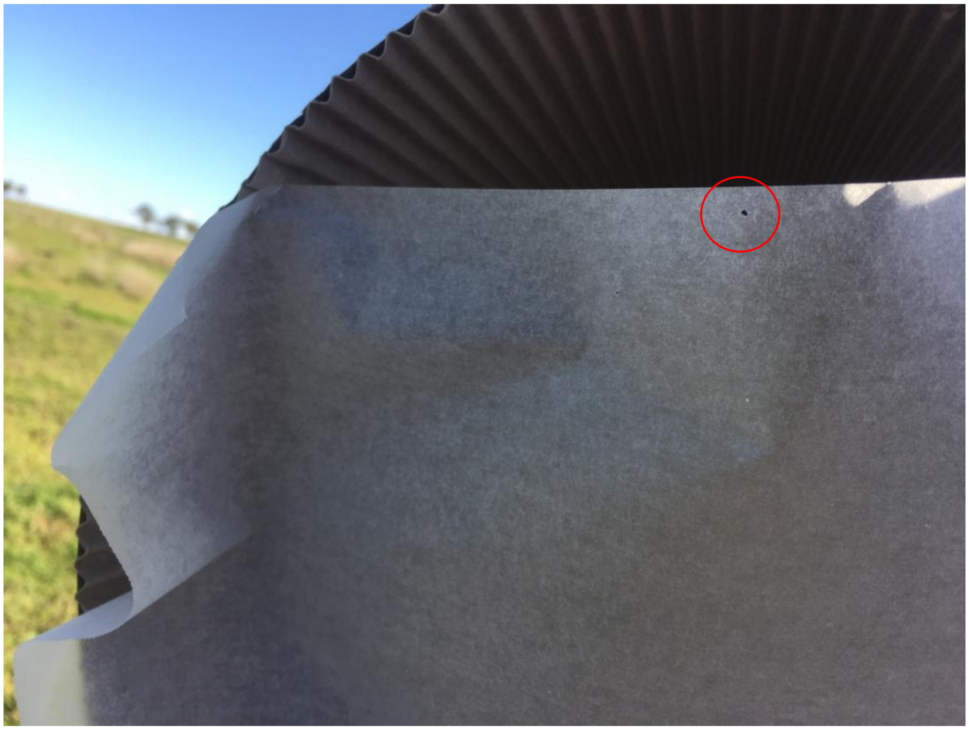

Figure 5.1.4- 0.8mm wide hole in paper indicating a stray fragment

The results from the ANSYS simulations are best shown in visual form, and the following section includes multiple images of the test results at particular angles. The simulations were, for the most part, very similar to the results obtained in the field testing. The key difference between the two was the impact angle at which the fragments were predominantly deflected downwards. The arc described in the field test results where there was no longer any damage present at the top of the fragment damage circle became apparent at a 65° impact angle. The 45° simulation images show the distribution of the fragments to be almost completely below the impact point, whereas the field testing revealed that even at an impact angle as low as 25° there was still a noticeable portion of the fragments impacting the cardboard above the impact point.

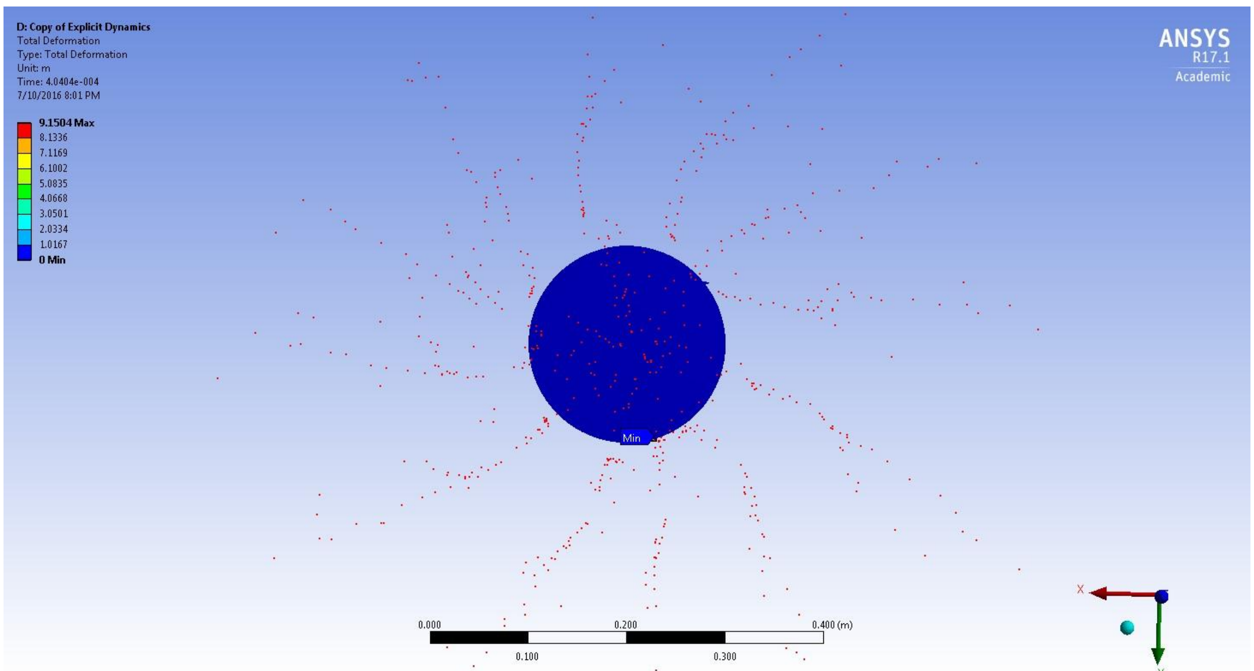

Figure 5.2.1- Front view of the fragment distribution in 90° impact angle simulation. This simulation did produce an interesting pattern in the fragments due to the angular velocity of the projectile.

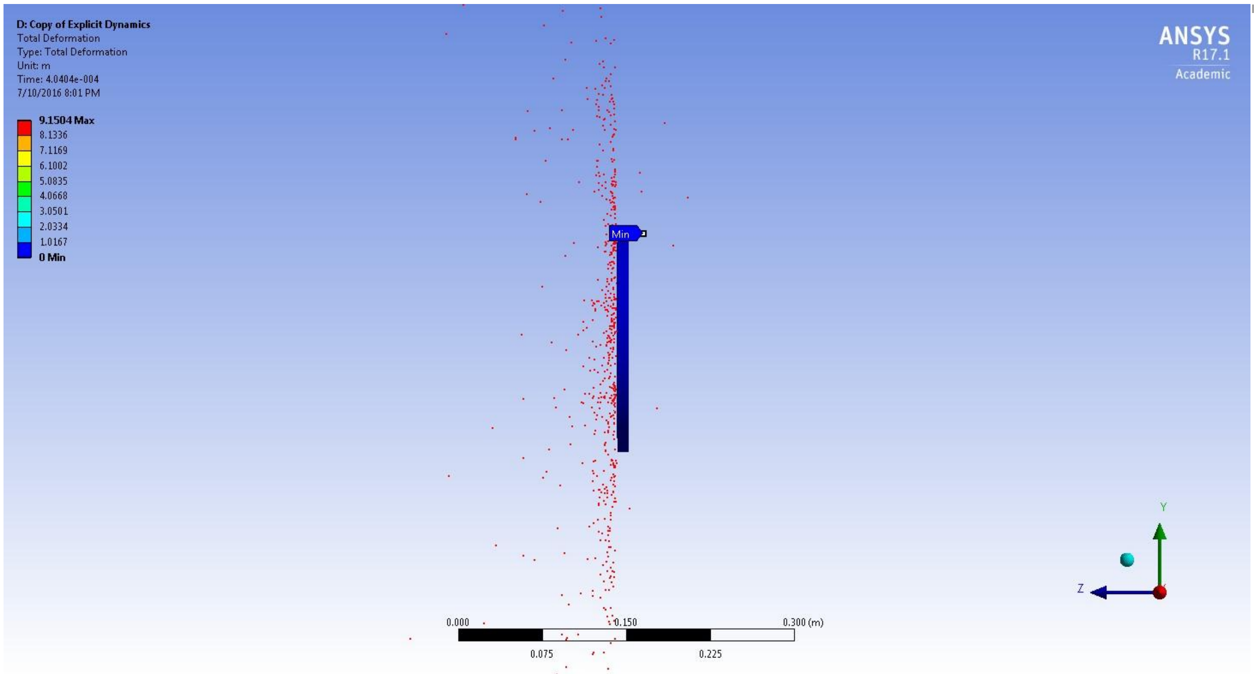

Figure 5.2.2- Side view of the fragment distribution in 90° impact angle simulation

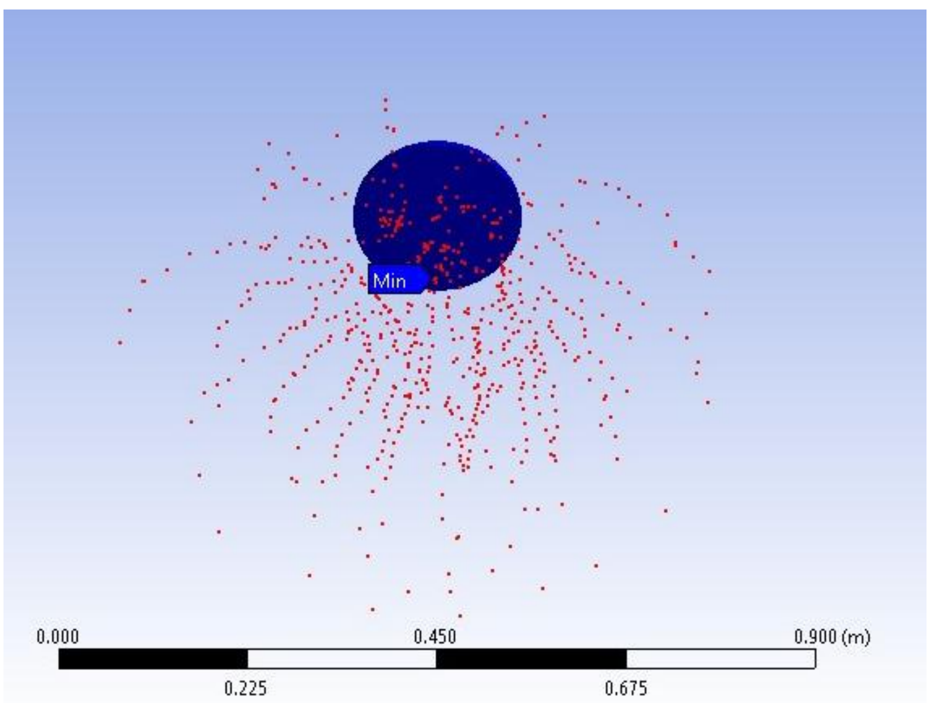

Figure 5.2.3- Front view of the fragment distribution in 60° impact angle simulation

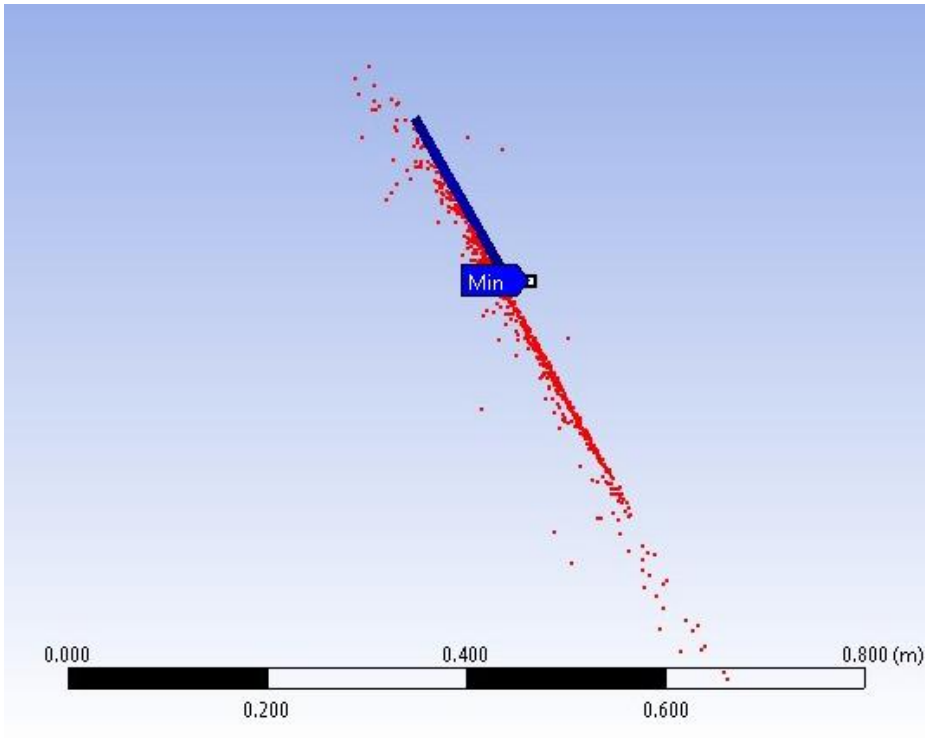

Figure 5.2.4- Side view of the fragment distribution in 60° impact angle simulation

The 60° impact simulation showed a noticeable thinning of fragment distribution at the top of the circle, similar to what was observed in the field testing around 27°.

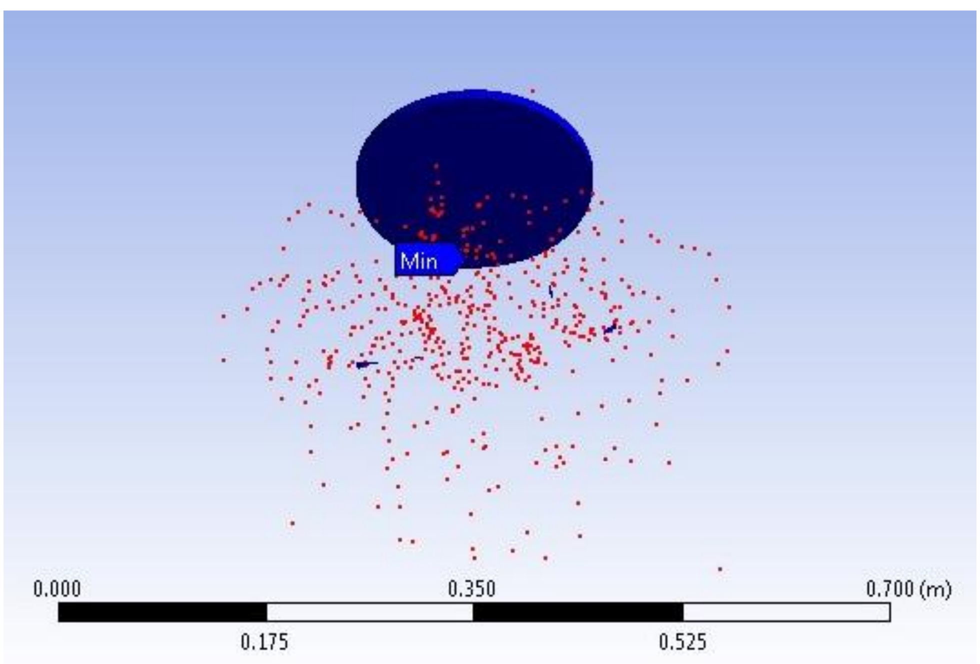

Figure 5.2.5- Side view of the fragment distribution in 45° impact angle simulation

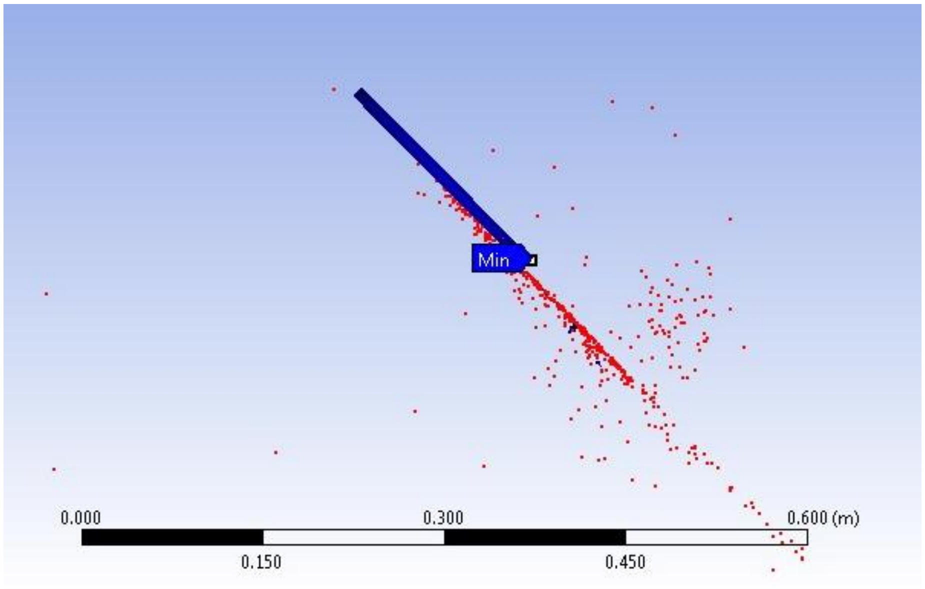

Figure 5.2.6- Side view of the fragment distribution in 45° impact angle simulation

These images indicate that at a simulated impact angle of 45° almost all the projectile fragments have been deflected below the impact zone. This varied from the results found in the field testing as a similar fragment distribution was not seen until around 20°.

The ANSYS simulations provided an interesting guide into the potential behavior of fragmenting projectiles, however the accuracy of the simulation models was brought into question due to the key differences between them and the field test results. Further work would be required to identify the causes of these inaccuracies and attempt to rectify them.

Chapter 6 - Conclusions and Recommendations

The most significant finding of this research project was that contrary to common belief, the projectile fragments were almost completely contained within the plane of the target surface. This leads to the conclusion that the safest place for any person to be in relation to a hardened steel target is as far from the plane created by the target face as possible. it was expected before the experiments were undertaken that the projectile fragments would be projected in a conical shape with the point of the cone at the impact site on the target face, as is depicted in figure 2.1.1, but this was not the case. Repeated tests proved that the flat surface of the target face created a plane that contained the vast majority of the projectile fragments.

Figure 6.1.1 - The clear cut line of fragment damage to the testing cardboard indicating the projected plane on which the fragments travel.

The idea that leaning a target toward the shooting position makes use of the target safer is untrue. While it is true that eventually as the target is leant further toward the shooting position the amount of fragments projected back toward the shooters will reduce to zero, this angle is far beyond what a target will ever be practically set to. Any impact angle greater than 40° will still project a large portion of the projectile mass toward the shooting position. An angle such as that shown in figure 6.1.1

With the projectile fragments being predominantly contained inside of such a shallow plane they would be relatively easy to contain with a loop of absorbent material such as rubber conveyor belting. Conveyor belting is sometimes used to hang targets and has proven to be hard wearing against damage from projectile fragments. With the design of IPSC range layouts constantly changing a method of containing fragments such as a simple loop above the target is likely to be the most effective method as it will contain the projectile fragments even if a shooter hits the target on an shallow angle.

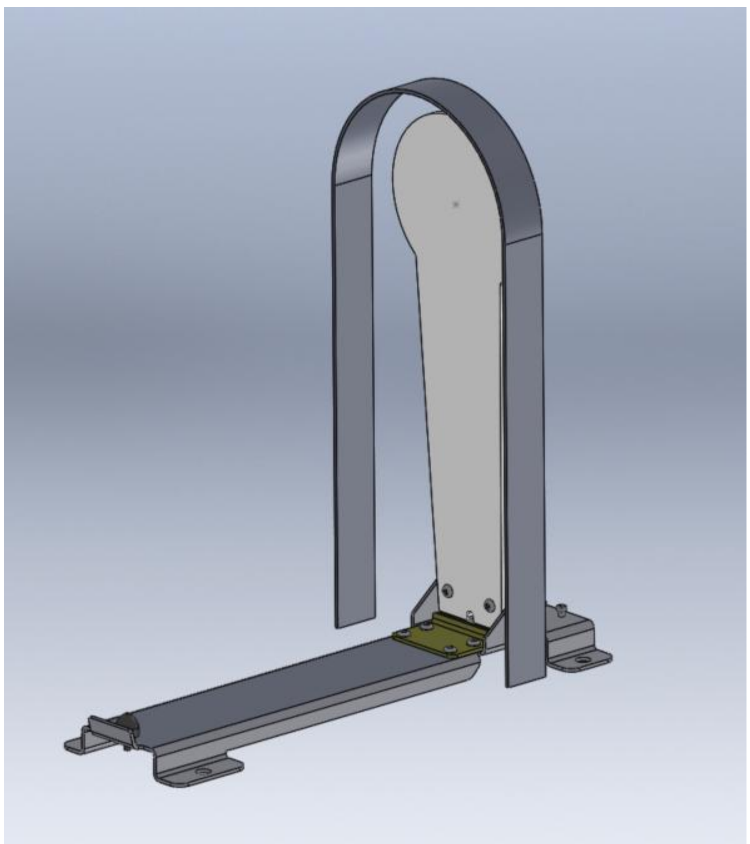

Figure 6.1.2 - a CAD model depicting a possible position of a rubber conveyor belt loop to contain projectile fragments.

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Appendix A - Project Specification

ENG4111/4112 Research Project

Project Specification

For: John Stephens

Title: Projectile mass distribution after impact with hardened steel plate.

Major: Mechanical engineering

Supervisors: Dr. Ray Malpress, USQ School of Mechanical Engineering

Enrolment: ENG4111 – EXT S1, 2016 ENG4112 – EXT S2, 2016

Project Aim: To study the behavior of lead projectiles after impact with hardened steel plate, and the effect that changing the impact angle has on the directional distribution of the projectile mass.

Programme: Issue A, 16th March 2016

1. Examine previous research on similar topics and extract relevant data to assist forming theories about bullet behavior prior to practical testing.

2. Design experiment details and establish limitations ie. what range of impact angles are likely to produce useful data.

3. Perform experiments and collect data. Assess if any variations need to be made to experiments to collect useful data. The practical testing of this project will be the first major milestone as until this occurs the theoretical work will not have a large amount of support.

4. Analyse collected data and establish trends of mass distribution across the experimental parameters.

5. Extrapolate data to establish guides for use of hardened steel plate in sport shooting. The translation of the findings to form useful guidelines for sport shooting clubs will be a significant milestone as a large portion of the value of this research is tied to its relevance and usefulness to these clubs.

6.Present findings to USQ peers and supervisors during Professional Practice 2 residential school.

7. Collaborate findings and write dissertation document. The completion of the dissertation will be the final major milestone of the research project.

If time and resources permit:
8. Recommend possible hardware additions to steel targets to improve safe use.

Risk register and Analysis

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	The Risk: What can happen if exposed to the hazard with existing controls in place?	Existing Controls: What are the existing controls that are already in place?	Risk Assessment: (use the Risk Matrix on p3) Consequence x Probability = Risk Level			Additional controls: Enter additional controls if required to reduce the risk level	Risk assessment with additional controls: (use the Risk Matrix on p3 – has the consequence or probability changed?)			Controls Implemented? Yes/No
			Consequence	Probability	Risk Level		Consequence	Probability	Risk Level	
Example										
Working in temperatures over 35^0 C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Firearms in use.	Firearm unintentionally discharged.	-Firearms only to be loaded immediately prior to use. -only one firearm at a time to be used. -while firearms in use all experiment participants to be behind shooter. -while in use firearms will only be loaded with a single round of ammunition, unless multiple shots are required in quick succession. -firearm safety mechanisms will be engaged at all times until shooter acquires confident sight picture on target, range is checked as clear and shot can be taken safely. -once all shots are fired weapon is to be checked as clear by shooter, this is to be confirmed by non-shooter and then the weapon is to be securely stored back in its case.	Catastrophic	Unlikely	Moderate	-only approved participants to be present during experiments. -approved participants to be licensed and experienced in handling weapons.	Catastrophic	Rare	Low	No
Excessive noise	Weapon discharged while person present is not wearing hearing protection	Hearing protection is to be worn at all times.	Minor	Unlikely	Low		Select a consequence	Select a probability	Select a Risk Level	No

Step 1 (cont)	Step 2	Step 2a	Step 3			Step 4				
Hazards: From step 1 or more if identified	**The Risk:** What can happen if exposed to the hazard with existing controls in place?	**Existing Controls:** What are the existing controls that are already in place?	**Risk Assessment:** (use the Risk Matrix on p3) Consequence x Probability = Risk Level			**Additional controls:** Enter additional controls if required to reduce the risk level	**Risk assessment with additional controls:** (use the Risk Matrix on p3 – has the consequence or probability changed?)			**Controls Implemented? Yes/No**
			Consequence	Probability	Risk Level		Consequence	Probability	Risk Level	
Example										
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	Regular breaks, chilled water available, loose clothing, fatigue management policy.	catastrophic	possible	high	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Flying debris	Fragments of projectile cause injury to experiment participants, particularly eye injury.	Participants to be shielded behind lexan polycarbonate screen at all times while firearms are in use.	Moderate	Unlikely	Moderate	Eye protection mandatory at all times that firearms are in use	Minor	Unlikely	Low	No
Weapon malfunction	Weapon malfunctions and causes injury to experiment participant through flying debris or sudden unexpected release of hot gas	All weapons to be inspected and cleared for use by licensed and qualified armourer prior to experiment beginning.	Major	Unlikely	Moderate	All ammunition used to be no more than 75% of the maximum recommended load power for each individual weapon. recommended ammunition loads freely available.	Major	Rare	Low	No
Exposure to sun	Sunburn, dehydration	long sleeves, hats and sunscreen to be required PPE for experiment in addition to eye and ear protection	Insignificant	Possible	Low		Select a consequence	Select a probability	Select a Risk Level	No
Unauthorised persons present during testing	Unauthorised persons interfering with experiment or exposing themselves to potential harm.	Testing to take place on a day when the range is not intended to be in use.	Major	Unlikely	Moderate	Approval from club executive to have exclusive use of range, preventing unexpected persons from having access to test area.	Major	Rare	Low	No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a consequence	Select a probability	Select a Risk Level		Select a consequence	Select a probability	Select a Risk Level	Yes or No
			Select a	Select a	Select a		Select a	Select a	Select a	Yes or No

Appendix C - Testing Equipment and Consumables

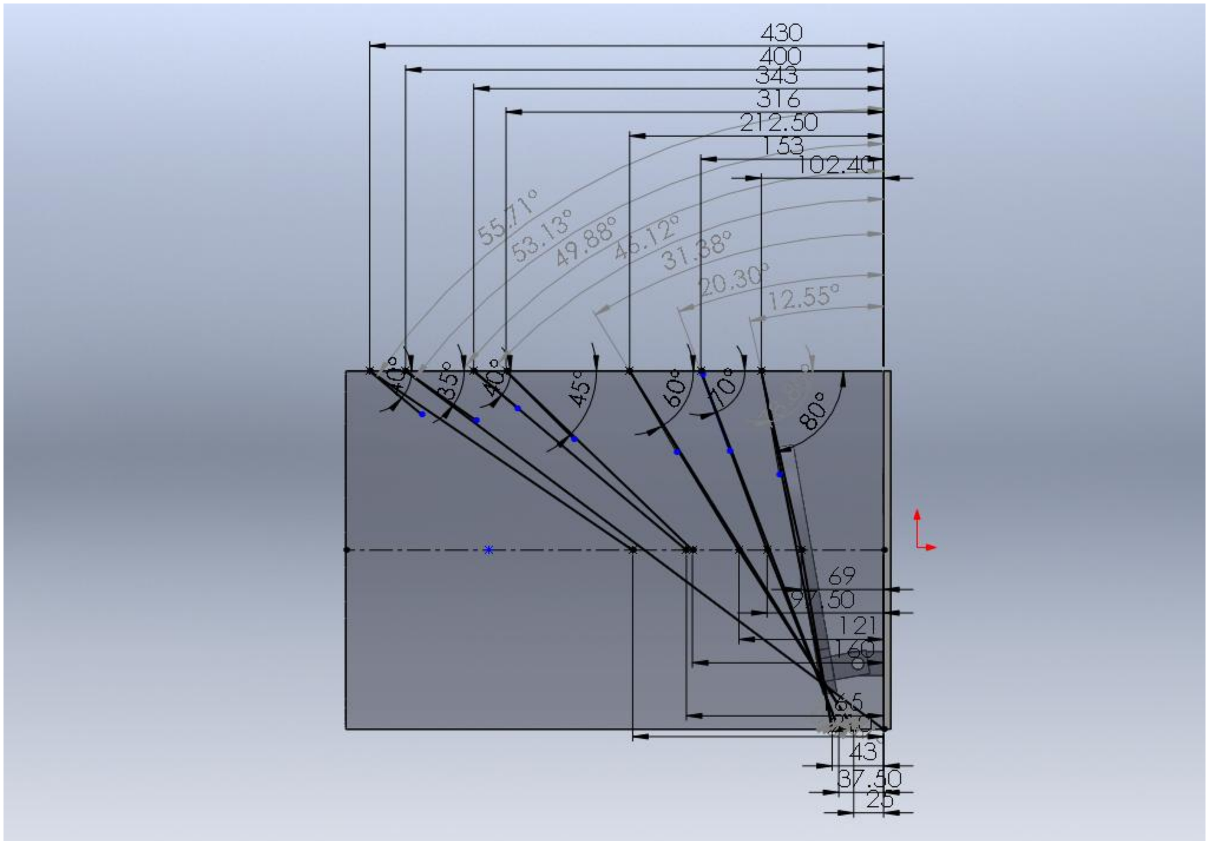
Equipment:

- RCBS Chronograph
- Target Support Frame
- Lithgow Rifle chambered in 32-20 Winchester
- Digital Protractor
- Vernier calipers
- Ø200mm Round Bisplate 500 Target Plate
- Portable Bench
- Lexan Polycarbonate Blast Screen
- Rifle Bracing Sandbags
- Earmuffs
- Digital Camera

Consumables:

- .32 Caliber 115gr Lead-Tin alloy projectiles
- ADI AR2208 Smokeless Gunpowder
- Remington Small Pistol Primers
- Single Side Cardboard (1.5m x 34m)
- Waxed Paper

Appendix D- Field Testing Data compiled in Solidworks



Screenshot showing the compilation of measurements taken during field testing using Solidworks to calculate angles.