Feasibility of Fin Stabilized Projectiles for Long Range Target Shooting

A THESIS SUBMITTED BY

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Abstract

Analyzing the feasibility of a fin stabilized projectile for long range target shooting applications. This application is for the sports of competitive shooting. The two projectiles that have been compared are a standard long range target shooting projectile and a fin stabilized projectile. The fin stabilized projectile was designed to have the same weight and velocity as a standard long-range projectile. The standard projectile had a known ballistic coefficient and weight. The manufacturer of the projectile had published a formula for minimum spin requirements to stabilize a given projectile at a selected muzzle velocity. The forces involved in stabilizing the standard projectile were calculated and summed to give an energy input. Similar calculations were done for a fin stabilized projectile and the two were compared.

Next there was a comparison of the drag of the two projectiles. The ballistic coefficient for the standard projectile was given by the manufacturer and the ballistic coefficient of the fin stabilized projectile was calculated using the same formula as that of the standard projectile. The ballistic coefficients were then used to calculate the velocity loss over distance from the muzzle to 2000 meters. The results showed that the fin stabilized projectile had a much lower ballistic coefficient than the standard projectile. The fin stabilized projectile also retained its velocity over distance better than the standard projectile. The fin stabilized projectile retained 85% of its original velocity whereas the standard projectile retained 53% of its original velocity. This revealed that a fin stabilized projectile is a design that shows great potential for long range target shooting applications.

CERTIFICATION OF THESIS

I, Rykent Joe Bezuidenhout, declare that the Honours Thesis entitled Projectiles Optimized for Long Distance Target Shooting is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This thesis is the work of Rykent Joe Bezuidenhout except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Signed: Date:

Endorsed by:

Professor David Buttsworth Principal Supervisor

ACKNOWLEDGEMENTS

I thank my parents and family for helping me talk to them and to share my ideas with them. I acknowledge my supervisor and the work he has done to assist me in my research.

DEDICATION

I have dedicated this paper to my family. They have done so much for me to help me get to where I am now and am grateful to have such a great family.

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Chapter 1: Introduction

Ballistics is the science of the flight and impact of a projectile, and as application example, we can cite Target shooting.

Target shooting includes categories like Action match, Air rifle field target, benchrest, big game rifle, combined services, field rifle three position, fly shoot, gallery rifle, handgun metallic silhouette international, junior sports shooting, law enforcement activities, lever action, long range precision, muzzle loading, practical shooting, precision rifle, rifle metallic shooting, shotgun, single action, target pistol and working gundogs (SPORTING SHOOTERS' ASSOCIATION OF AUSTRALIA, 2022).

The above categories require the skillful use of a firearm to engage a target of some kind. For example, in the case of an action match, it requires the use of a handgun in dynamic situations that could be quite contrasting. In one case, the shooter will engage two targets down range while the shooter moves from one distance to another. In another case the shooter will engage a moving target that will cover 60 feet (18.2 meters) in six seconds (SPORTING SHOOTERS' ASSOCIATION OF AUSTRALIA, 2023). In the long-range precision category, the competitor uses a rifle to engage a target up to 2000 meters. Competitors are scored on how accurately they put the shots (five) in the center of the target.

The action match category is based more around the shooter's skills. The accuracy of the firearm makes less of an impact as the targets are much closer than in the long- range precision category. The latter has three main contributing factors to accurately hit the targets. They are:

i. **Shooter.** The shooter must have the skill and technique to accurately aim the firearm.
ii. **Rifle**. The rifle must be able to fire the projectile consistently. The movement of the rifle during firing must be the same for each shot.
iii. **Ammunition.** The ammunition needs to be as consistent in dimensions, weights, and powder charges as possible. If the ammunition can produce the same projectile velocity for each shot, then the placement of the shot will be extremely consistent.

The importance of the three above factors instigated this research work. The ammunition that is being produced for the long-range precision category has reached a point where its accuracy is good, but the design hasn't changed since the 20^{th} century. The current ammunition has been optimized for its basic design but has not been redesigned to be optimal for its purpose. The current design of ammunition consists of a cylinder of high- density material that has one end turned to a sharp parabolic curve and the other into a truncated cone. Figure 1 displays an image of this design [reference? VLD Hunting brochure?]:

Figure 1 Berger 6mm 105gr VLD Hunting

This bullet design is the best commercially available. The flat end on the front of the bullet (the smaller flat section on the right-hand side of the image) is a 0.6mm hole that has been drilled into the bullet. This is for hunting reasons and improves the terminal ballistics of the projectile.

This research will therefore conduct simulations to improve the design of the bullet.

Chapter 2: Background Information

BALLISTICS

Ballistics is the science of the flight and impact of a projectile. The science is split into a few categories.

i. Internal ballistics, which deal with propulsion of the projectile.
ii. External ballistics, which delas with projectile's flight.
iii. Intermediate ballistics, which deals with the transition between the previous two categories.
iv. Terminal ballistics deals with the impact of the projectile.

Bullets / projectile do not have a form of propulsion once they have been fired and therefore internal ballistics do not apply to them.

Terminal ballistics are the effects of the bullet at the end of its flight when it hits a target (John A. Zool, 1992). The terminal ballistics of a bullet is of no concern when target shooting as the target is made of paper or steel.

External ballistics are about the projectile and its flight. If this is known, then the shooter will be capable of determining where the bullet is going to impact the target. The ballistics of a bullet are based on several factors. These factors include:

i. the initial/muzzle velocity,
ii. the ballistic coefficient,

iii. stability of the projectile in flight and
iv. the drag imparted on it. If the bullet is supersonic at the beginning of its flight and then sub-sonic when it reaches its target, then the stability of the projectile through this transition also impacts its trajectory.

Due to the likelihood that the bullet will be moving at both supersonic and sub-sonic speeds there will be two equations for the drag imparted on the projectile. This transonic and supersonic drag is called wave drag (EMANUEL, 2001). This is an increase in the drag force due to shockwaves being formed as the projectile passes the critical Mach speed (James W Purvis, 2012). The sub sonic drag will follow the standard drag model.

FIREARMS

The invention that was needed to bring about the development of firearms was black powder/gunpowder. This chemical mixture was discovered in China in the nineth century (E. Gray, 1982). This newly discovered material had the ability to burn without the need for oxygen in the atmosphere. This combined with its ability to increase the rate of the reaction if in a confined space made it perfect to inspire the invention of a firearm. The first firearms were invented in the tenth century in China (W.Y.Carman, 2016). The first firearms that were used consisted of a bamboo or metal pole with black powder in a container at the end of the pole. This was used to project fire and projectiles towards the enemy. The next evolution of the firearm was the musket. The design of a musket consisted of a barrel stock and ignition mechanism. Figure 2 shows the basic design of a musket (Springfield model 1822 Flintlock [wikipedia, 2009]).

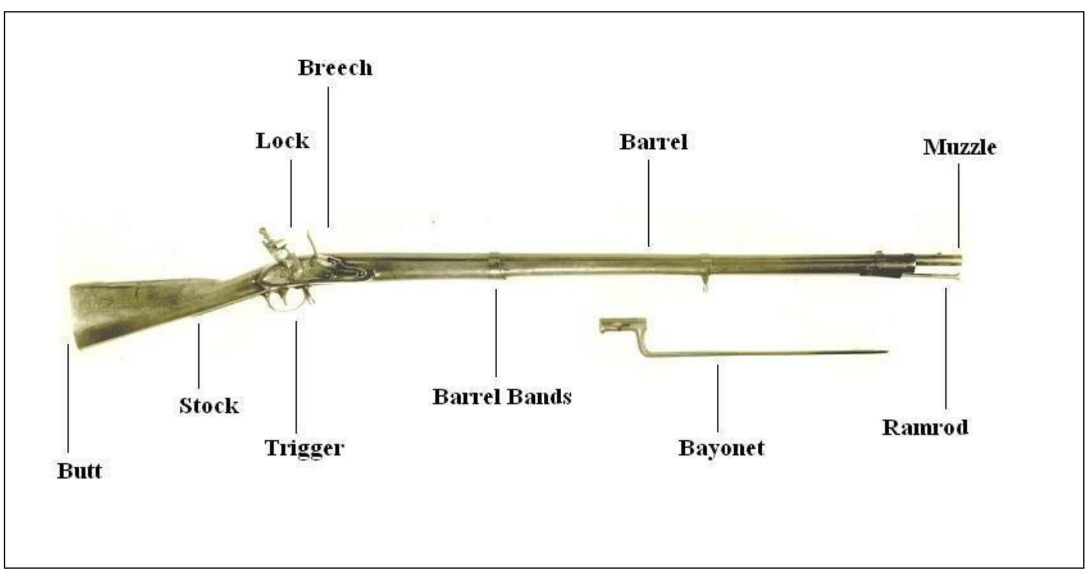


Figure 2 The parts of a musket

In this design of firearm, the lock contains a small piece of flint that when fired will strike a metal plate at the breech. This will ignite the black power within the breech. This will propel the projectile down the barrel and out the muzzle. This design of firearm is loaded from the muzzle as the breech cannot be opened. The ram rod is used to push the powder and projectile down the barrel.

This design of firearm is not called a rifle. This is due to it lacking rifling in the barrel. This design used any spherical object that fits down the barrel. The projectile can be made from stone or metal (Flatnes, 2013). These firearms were not accurate and that is why during the times they were used the standard military tactic was to have one line of shooters face another. The engagement distances were within two hundred meters.

The next major improvement of the firearm is a combination of two inventions. The invention of rifling and the Minié ball massively increased the accuracy of firearms. The Minié ball is not a ball and more resembles a modern bullet. The Minié ball is a hollow based conical nosed bullet designed by Claude-Étienne Minié (W.Y.Carman, 2016). This design was more stable than a standard ball as its design was self-righting. The center of mass of the Minié ball was in front of the center of drag. This creates a self-righting effect like that of a dart. This design, when combined with rifling, made for a very stable projectile that was capable of being accurate at great distances.

One rifle design to note of this period is the Whitworth rifle, which uses a polygonal rifling. This consisted of a helical polygonal spiral. The traditional and polygonal rifling is shown in Figure 3 (Wikipedia, 2008).

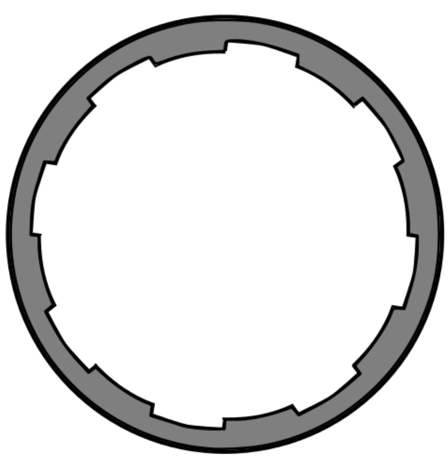
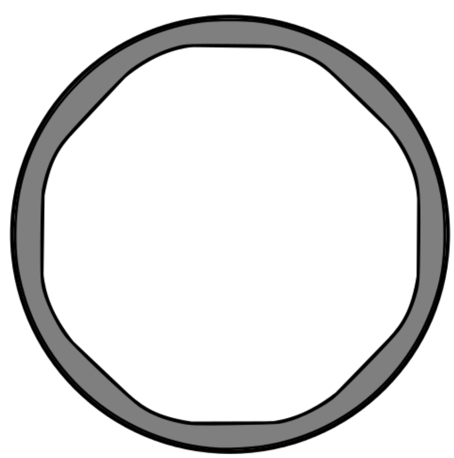
Traditional	**Polygonal (Whitworth)**
	

Figure 3 Rifling Comparison

This polygonal design is known for its exceptional accuracy. This rifle was tested by the British military and found to be within three minutes of angle accuracy at 500 yards (457 meters) (McCollum, 2017). This means that all the shots fired would fall within a 15-inch circle (Tim, 2023).This design also required the use of octagonal bullets to fit the bore of the barrel and take advantage of the rifling.

The next evolution of firearms is where modern firearms become prevalent - the use of self-contained metallic cartridges. In this case gunpowder, bullet and primer are held together by a metallic container. This allowed for a diversification in firearm design and a better standardization of cartridges. The image of a few popular modern cartridges is shown in Figure 4.

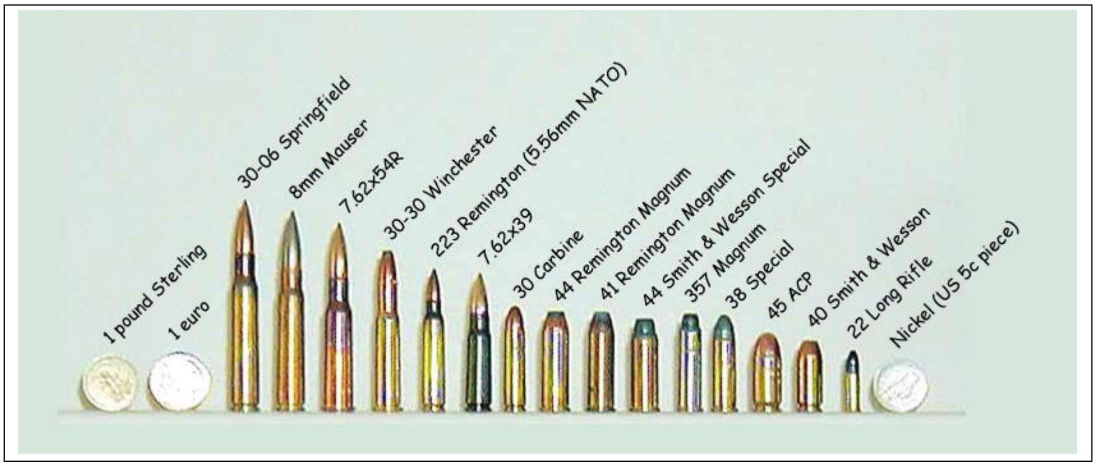


Figure 4 Cartridge sizes

The anatomy of a cartridge is displayed in Figure 5. A rimfire cartridge and a center fire cartridge are displayed on the left- and right-hand side respectively. The rime fire has the primer compound located in the rim whereas the centerfire has the primer compound located in the center (Quizlet, n.d.).

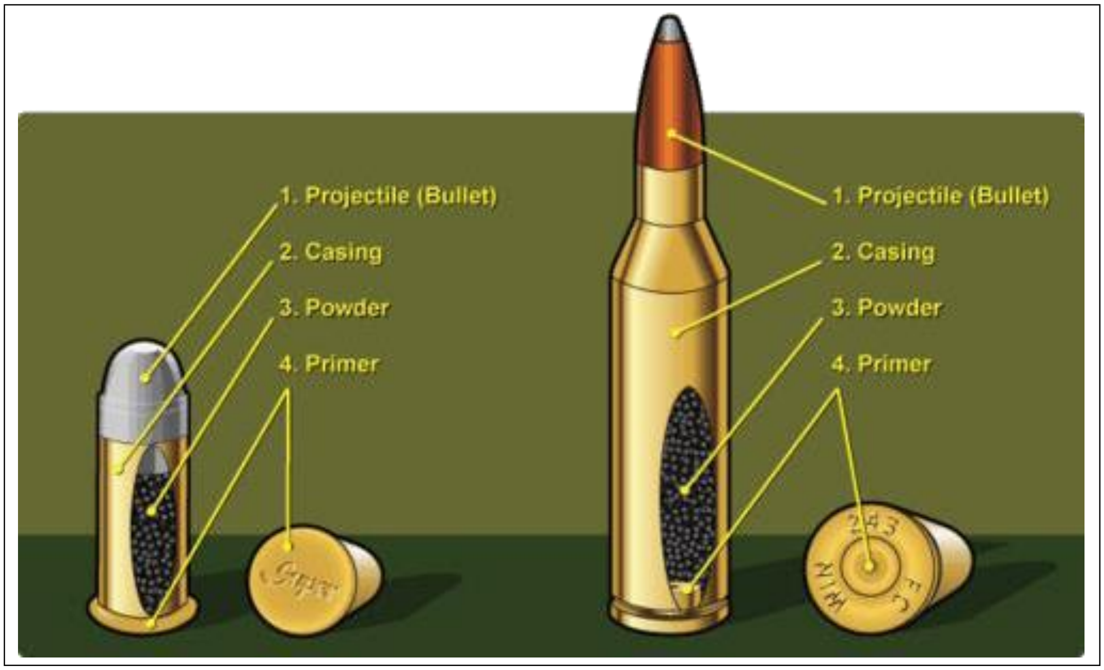


Figure 5 Cartridge anatomy

The 22 long rifle is the most produced and popular cartridge in the world and the 30-06 is a very popular all-round cartridge used mainly for long range shooting. (ammo and gun collector, n.d.).

The naming convention for ammunition is not standardized but follows similar rules. The first number of a cartridge is the diameter of the bullet/caliber. This can be in millimeters or in inches. For example, the .22 long rifle, the caliber is 0.22 inches in bullet diameter. Some cartridges have both the diameter of the bullet and the length of the brass case, an example of this is the 6.5x55 Swedish. This cartridge uses a 6.5mm bullet and has a case length of 55mm.

The self-contained metallic cartridge gave way to two major firearms designs. The single shot rifle and the Magazine/tube fed rifle. Both designs open the breach from the rear of the barrel and allow the cartridge to be loaded from the rear. The single shot rifle was designed to hold a single cartridge in the breech. These were popular when the transition from black powder to smokeless powder occurred as they offered a stronger breech. A magazine/tube fed rifle was designed to have a breech that was fed from a magazine or tube. This allowed for more secure storage of cartridges in the field and for faster successive shots.

Chapter 3: Literature Review

Lahti conducted work on the improvements on the design of bullets (Lahti, et al., 2019). In this work it was suggested that most of the high-density material should be as far away from the center of mass to have the best distribution of mass to maximize the rotational momentum of the projectile. This distribution of mass is very similar to that of a flywheel in principle.

The rotational momentum then creates a gyroscopic effect that will stabilize the bullet during flight. The gyroscopic effect keeps the bullet in the best orientation during its flight. If the gyroscopic motion was absent, then the bullet would tumble during its flight, which as a result creates an unstable and unpredictable flight path.

The one aspect that is not covered in the previous paper (Lahti, et al., 2019) is how the bullet's shape affects aerodynamics. The shape of the projectile plays a large role in how well it can retain its velocity over distance. Litz showed the effects of the bullet shape performance (Litz, 2021) between a round nose flat bottom projectile and a spitzer (German for pointed) point, boat tail projectile. It was found that the round nose flat bottom projectile has a higher drag coefficient at all speeds and therefore results in greater velocity loss and a greater vertical drop over distance.

In Weapon Employment Zone (WEZ) Analysis of the Optimize 300 Winchester Magnum (300MW) versus 338 Lapua Magnum (338LM) with Various Ammunition Types (Litz, 2021), a comparison is made between two different cartridges. The 300WM used a 230-grain projectile for all the testing. The 338LM used two designs of 250 grain projectiles and two designs of 300 grain projectile. The change in mass affected the muzzle velocity of the 338LM. There were two designs used for each mass. The first design had the ogive radius tangential from the body and a short boat tail. The second design had an offset ogive intersection and a longer boat tail. The two calibers tested are normally used for long range hunting and target shooting applications. The main difference between the two is the 300 Winchester magnum is 7.8mm (0.308") in bullet diameter and the 338 Lapua magnum is 8.61mm (0.339") in diameter.

The WEZ report compared the velocities of the two calibers at ranges from 0 meters (muzzle velocity) to 1500 meters. The results showed that for the similar weight bullets, the 230 grain for the 300WM and 250grain for the 338 LM; the velocities were very similar. At the muzzle, the 338LM was faster by 45 meters per second. When the projectiles reach 1500m, the difference has changed so that 300WM is 36m/s faster. This is due to the ability for 300WM to retain momentum over distance. This is attributed to the more aero dynamic shape. The bullet of the 300WM is smaller in diameter and therefore experiences less drag.

When the 300-grain projectile was used in the 338LM the muzzle velocity was 823m/s. This is 31m/s slower than the 230 grain 300WM. When the projectiles reach 1500 meters, the 338LM had a velocity of 366m/s and the 300WM had a velocity of 350m/s. The reason for the 338LM having a better velocity than the 300WM is due to the heavier projectile. The 338LM projectile had 70 grains (4.54 grams) more mass than the 300WM. This allowed the 338LM to retain more energy over 1500 meters. This shows that the relationship between mass and aerodynamic drag are very closely linked in long range accuracy.

Most of the documents mentioned have referred to the bullet shape. The bullet shapes that have been discussed have all been of a very similar design. A design consisting of a cylinder with an ogive nose and a boat tail end. This design is and has been very effective for a many years as many of these designs have been around for decades. The ogive nose was developed in 1898 by the French to replace the round nose. (Hawks, 2013). The ogive nose was found to be more accurate than the round nose.
This design has optimal aerodynamic characteristics that suit all calibers. The exact dimensions of the bullets change but the overall shape remains the same.

An area that has seen more development in projectiles is tank ammunition. This has been done for very similar reasons to that of the target shooting projectiles. A tank projectile is designed to retain as much energy down range as possible to be able to work effectively. A tank uses a projectile that has an extremely small diameter compared to its length. A tank projectile can be 33mm in diameter and up to 1320mm long (George E. Hauver, 2005). This reduces the cross-sectional area compared to the guns' bore diameter. This smaller cross-sectional area reduces the drag experienced. This also allows the projectile to have large amounts of mass, as some projectiles can be up to 1400mm long (MINISTRY OF DEFENCE ROYAL ARMAMENT RESEARCH AND
DEVELOPMENT ESTABLISHMENT, 1996). This shows that reducing the diameter of the projectile is one of the best options to increase long distance accuracy. The reduction in diameter reduces the cross-sectional area of the projectile which greatly reduces the drag experienced. This combined with the mass of such a long projectile, allows for a small loss of energy due to drag.

The major issue faced with reducing the diameter and increasing the length, is that the bullet becomes unstable during flight. The solution to this issue is the change of the stabilization method from spin stabilization to aerodynamic stabilization. This development is again shown in tank ammunition. Tanks have stopped using rifling to spin stabilize the projectile and have transitioned to fin stabilized. This is because as the ratio between the diameter and the length of the projectile increases, the required rotational speed becomes impractical. The rotational speeds are stated as the number of inches of travel per rotation. A standard twist rate is a 1 in 10, this means for every 10 inches of travel the bullet will rotate once. The highest commercially available twist rate is a 1 in 6 twist.

This twist rate will allow the shooter to stabilize longer heavier bullets capable of better energy retention over distance. The required twist rate for tank projectiles becomes less than a 1 in 1 twist rate. This high twist rate then starts to become more akin to a thread pitch than a rifle twist rate. With a twist rate this high, the rifling would no longer be able to spin the projectile. The rifling would act more like a thread and stop the projectile from traveling down the barrel.

Overall, the literature search found that there is a lack of information on the topic of projectile optimization. This is likely due to two main reasons, the first is that most of the information is proprietary. The research that has been done on this subject has mostly been completed by companies trying to develop a better product than their competitors. This makes the information very difficult to find and access. Secondly the information is difficult to find or access because the research is done by military researchers or contractors. This makes any of the research done classified and unable to be accessed by the public until it becomes declassified. During the literature search multiple documents were found where the access is less restricted but still requires military permission and login information to access.

Chapter 4: Research Objectives

The objective of this research document is to determine whether using a fin stabilized projectile is a feasible option for long range target shooting. The force of accelerating and stabilizing the two projectiles will be calculated and compared.

Chapter 4: Research Methodology

The following approach will be used:

i. A control bullet will be selected and compared to a projectile with fins.
ii. Calculation on the forces required to spin the bullets will be conducted. This will determine how much energy is then available for a fin-stabilized projectile. Calculations will be done to assess the amount of drag that is experienced between the projectiles and if there is an aerodynamic advantage to either design.
iii. Simulations, using a finite element analysis, will be performed to determine if the fin stabilized projectile has a lower drag coefficient than that of a standard spin stabilized projectile. A simulation will also be done on the fin stabilized projectile to determine if it will withstand the forces during acceleration. A calculation will be performed to determine the length of the projectile for a given body diameter and material.
iv. The findings of the simulation for the two designs will be discussed and, if found, a better design will be proposed.

v. Conclusions about the simulations and whether a better design was found, together with challenges found.
vi. Recommendation about further work will be given if required.

Chapter 5: Projectile design

Two projectile designs have been selected to be tested. The first design is a control design based on a commercially available bullet. The fin stabilized projectiles will be based off tank ammunition as it has been very well studied and designed. The number of fins start at the smallest number required to produce a stable aerodynamic shape.

CONTROL

The control bullet will be based off the Berger 7mm 190 grain Long Range Hybrid Target Rifle Bullet (Berger Bullets, 2023). The dimensions of the bullet are displayed in Table 1. The simulation was performed at sea level (one atmosphere/100Kpa) and at a velocity of 850 meters per second.

Table 1 Dimensions of Berger 7mm 190 grain Long Range Hybrid Target Rifle Bullet

Overall length [mm]	Boat tail length [mm]	Nose length [mm]	Base to ogive [mm]	Bearing surface [mm]
40.6654	5.2578	20.9042	21.1074	14.0716

The Ogive of the bullet selected as the control was not stated as that information is proprietary. Below is the schematic of how an ogive is created.

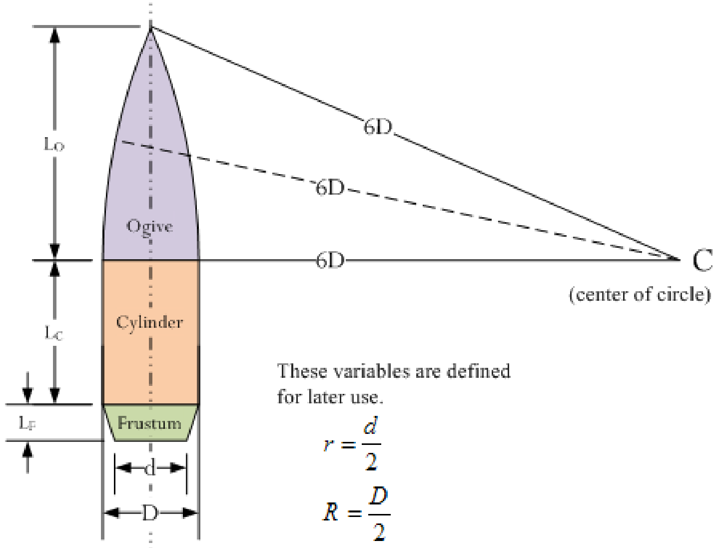


Figure 6 Bullet Schematic (Hornady Manufacturing Company, 2021)

This schematic shows a tangential ogive, A similar method is used to create a secant ogive. Figure 15 in the appendix shows the difference between the two designs.

An analysis of the bullet has been done to determine the rotational velocity and mass moment of inertia to gain an idea of the amount of spin stabilization required.

The rotational speed of the projectile is directly related to its velocity. The spin used to stabilize the projectile was found by using the miller twist rule (Wikipedia, 2022).
Equation 1 displays the formula used to determine the required twist rate for the control bullet.

Equation 1 Rotational Stability

$$t^2 = \frac{30m}{sd^3 l(1+l^2)}$$

T = bullet diameters per turn = 25.97

M = mass of bullet in grains = 190

S = stability factor (2 is recommended)

D = diameter in inches = 0.27559

L = bullet length in number of bullet diameters = 5.81

The twist rate given by the equations is then converted to inches per revolution. This combined with the velocity of the bullet gives revolutions per second. The revolutions per minute is 281664.15rpm.

Inches per revolution: $\frac{in}{r} = t * d = 25.97 * 0.7559 = 7.157$

Revolutions per second: $rps = \frac{in}{r} * v_{\frac{in}{s}} = 7.157 * \left(2800\frac{ft}{s} * 12\right) = 4694.402$

Revolutions per minute: $rpm = rps * 60 = 281664.15$

Radians per s: $\frac{rad}{s} = rps * 2\pi = 29495.8$

The twist rate given by the equations is then converted to inches per revolution. This combined with the velocity of the bullet gives revolutions per second. The revolutions per minute is 281664.15rpm.

The parallel mass moment of inertia was estimated using the solid cylinder equation and half of the radius (WolfRam Alpha, 2018). This gave a mass moment of inertia of 75.4 g-mm^2.

$$I = \left(\frac{m * d^2}{2}\right) = \frac{12.312 * 3.5^2}{2} = 74.411$$

The next item that was calculated was the energy associated with the bullet moving down the barrel. There are three items that were observed

The first was the frictional force of the bullet moving down the barrel. In this case, a formula for calculating the force to engage a press fit was used (MEADinfo, 2023). The energy found was 1410.00 J.

Equation 2 Obturation Force Equation

$$p = \frac{\delta}{\frac{d}{E_o}\left(\frac{d_o^2 + d^2}{d_o^2 - d^2} + v_o\right) + \frac{d}{E_i}\left(\frac{d^2 + d_i^2}{d^2 - d_i^2} - v_i\right)}$$

$$f = p * C_f * l$$

Table 2 Obturation Figures

Bullet	Barrel
Ei= Young's modulus Gpa= 110	Eo= Young's modulus Gpa = 210
Vi= Poisson's ratio = 0.34	Vo= Poisson's ratio =0.292
Di= Shaft internal diameter = 0	Do= Barrel outer diameter = 25mm
D= Shaft nominal diameter = 7.2mm	D=hole nominal diameter = 7
SM = bullet maximum diameter =7.23	BM = barrel minimum diameter =7

Ff= frictional force

Cf=coefficient of friction: 0.36

(Engineering Tool Box, 2023)

A= area of contact between bullet and barrel = 309.45mm^2 Force

overlength of barrel = $F_f * L$ = 1410.21J

L = length of barrel

The second was the force and energy in accelerating the bullet to its final speed. Using the initial and final speed, together with the length of the barrel, an acceleration of 592601.706m/s^2 (60408 g) was found (Wikipedia, 2023). The time the bullet spent accelerating was 0.001434 seconds. After this time, the bullet will be out the barrel and will only experience the force of drag.

Equation 3 Bullet Acceleration

$$t = \frac{\Delta x}{0.5(v_o - v_f)}$$

$$t = \frac{0.6096}{0.5 * (0 - 850)} = 0.001434353\ seconds$$

$$a = \frac{\Delta v}{\Delta t} = \frac{850}{0.001434} = 592601.706\ m/s^2$$

The third calculation was the required energy to spin the bullet. Using the time previously calculated the rotational acceleration can be calculated. The final speed of rotation was 20563837.44 radians per second (Wikipedia, 2023). Using this and the mass moment of inertia the energy required to accelerate the bullet was 5316.855J.

Equation 4 Rotational Acceleration

$$a_r = \frac{\Delta \omega}{\Delta t} = \frac{29495.58 \frac{rad}{s}}{0.0014343} = 20563837.44\ rad/s^2$$

Equation 5 Rotational force

$$w = f * r \Rightarrow f = a_r * m_i = 20563838.44 * (7.54115 * 10^{-5}) = 1550.74\ Nm$$

mi = mass moment of inertia for a solid cylinder with a diameter of 7mm

$w = 1550.74 * \frac{24\ in}{7.14746}$ The number of rotations is equal to the length of the barrel divided by the number of inches per revolution.

The total energy expended on the bullet is the sum of the force to push the bullet down the barrel and accelerate it both linearly and rotationally, totaling 11.175KJ. This shows that most of the force exerted when firing a bullet is in pushing it down the barrel and spinning it.

A calculation was done to determine the velocity change if only the rotational acceleration was removed, and the energy converted to linear acceleration. This would give the projectile an additional 5199.887 J of energy for acceleration (wikipedia, 2023). This will achieve a velocity of 1251.87m/s. This is an increase in velocity of 48%.

Equation 6 New velocity

$$f = \frac{1}{2} m * v^2 \Rightarrow v = \sqrt{\frac{2 * f}{m}}$$

$$v = \sqrt{\frac{2 * (4447.74 + 5199.887)}{0.01231}} = 1251.87\ m$$

An increase in velocity is one of the simplest methods of achieving better long-range accuracy. The higher the velocity of the projectile the less time there is for gravity to accelerate it towards the ground and the less time wind has to shift the point of impact.

FIN STABILISED DESIGN

To compare a fin stabilized projectile to the control projectile the mass must remain the same. This will allow the two projectiles to have the same kinetic energy for a given velocity. The mass of the fin stabilized projectile will need to be 12.312 grams to match that of the control projectile. If the design is assumed to be a cylinder, the length and diameter of the projectile can be determined. The optimal diameter of the projectile was found to be 4.15mm. This allows for a rod length of 101.6mm. This will allow the projectile to fit within a standard-length casing.

$$m = v * d$$

$$v = 12.31\ g * 8.96\ gr/cm^3$$

$$v = \pi r^2 * h = \pi * 4.15^2 * h \Rightarrow h = \frac{1374.12}{\pi * 4.15^2} = 101.587mm$$

The density of copper was used as lead is not suitable for this application. The density of copper is 8.96 grams per cubic centimeter (Wikipedia, 2023).

The next detail to determine is the design of the fins. The number of fins is the first design aspect. If only one fin is used the projectile will have an asymmetrical shape which will be unstable in flight. If two fins are used, it will produce a symmetrical shape if the fins are 180 degrees apart. This design will only provide stabilization in one plane. The projectile will be stable from rotating about the plane produced between the fins and the rod. The next option is to use three fins. This, like a tripod, will be sufficient to stabilize the projectile in the direction of flight. If the fins are 120 degrees apart it will produce a stable aerodynamic shape. More fins than three will only increase the cross-sectional area. This will increase the drag on the projectile with little to no benefit to the stability during flight.

The design of the fin stabilized projectile will consist of a long rod of 4.15mm in diameter and 101.6mm in length. There will be three fins placed at the rear of the projectile. The fins will have a triangular shape with a taper facing the direction of travel.

COMPARISON

A comparison between the properties of the control projectiles drag and the fin stabilized projectile will be made. This will use the drag force equation to determine the force on the projectiles. The projectiles will be kept at the same velocity and only the cross-sectional area and drag coefficients will be changed. The data for the comparison is displayed in Table 3 Drag force and inputs for the bullet comparison..

Table 3 Drag force and inputs for the bullet comparison.

	Control Bullet	Three-fin Dart	Units/comments
Drag Coefficient	0.04	0.029	Streamlined body for dart
Density of fluid	1.293	1.293	Kg/m^3
Velocity	850	850	m/s
Cross-sectional area	38.48451001	13.52651987	Mm^2
		1.4	Mm^2
Total area	3.84845 e-05	177265 e-05	M^2
Drag force	0.719038812	0.24011973	N

Looking at the force applied to the two projectiles, the fin stabilized projectile has 28.37% of the drag force on the control projectile. This is a large reduction in drag force. And will allow the fin-stabilized projectile to travel a greater distance before losing the same amount of speed as that of the control.

Using the industry standard methods of calculating velocity over time and distance a better comparison can be made. The industry method calculates a drag coefficient relative to a standard test piece. The two most common are the g1 and g7 test pieces. Below are the two designs that are used:

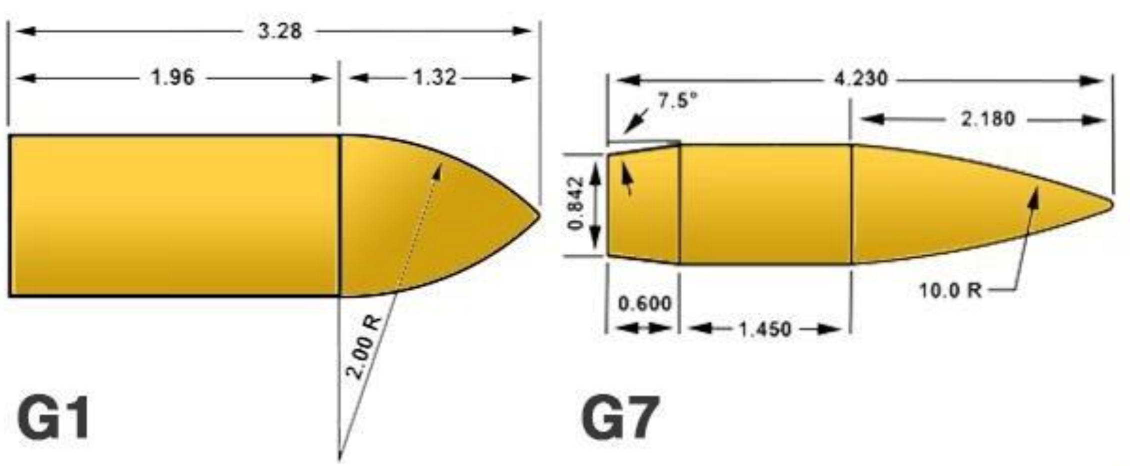


Figure 7 G1 and G7 Designs (Kestrel Meters, 2023)

The standard that will be used is the g7 design as this is an accurate representation to that of the control bullet design. To find the ballistic coefficient of the control bullet and the fin stabilized projectile the drag coefficient of the g7, control and fin stabilized projectiles are required. The ballistic coefficient can then be calculated (Litz, 2021).

Table 4 Ballistic Coefficients

Projectile	Drag Coefficient	Ballistic coefficient
G7	*0.24*	*1*
Control	*0.04*	*0.166*
Fin stabilized	*0.0225*	*0.09375*

$$B_c = \frac{d_c}{d_{c\,g7}}$$

With the ballistic coefficients for the projectiles calculated the velocity over distance can be calculated. This calculation approximates the velocity at a given distance and is the industry method (Physics forms, 2012). Using Equation 7 Velocity over time, the velocity at a given distance can be calculated (Physics Forums, 2012). The velocities for distances 0-2000 meters with 50-meter increments have been calculated.

The initial velocity for both projectiles was 850 meters per second, and both had a mass of 190 grains (12.3 grams). This was done to compare the force of drag between the two projectiles and not how weight or starting velocity affects the velocity at distance. The full set of results are in the appendix at table 5 control velocity over distance and table 7 Fin stabilized velocity over distance

Table 5 Section of Fin stabilized velocity over distance.

Distance	Control Velocity	Control Time passed	Fin-Stabilized velocity	Fin-Stabilized Time passed
50	836.5464001	0.059295281	846.4936	0.058945
100	823.3057406	0.119544167	843.0017	0.118135
150	810.2746511	0.180761994	839.5241	0.177569
200	797.4498147	0.242964346	836.061	0.23725
1900	463.5761297	3.073367803	726.4397614	2.420420042
1950	456.2387558	3.182089943	723.4430718	2.489391329
2000	449.0175162	3.292560585	720.4587441	2.558648313

Equation 7 Velocity over time

$$v_t = \frac{v_0}{1 + ktv_t}$$
$$t = \frac{e^{kd} - 1}{kv_o}$$
$$k = \frac{1}{2m}\rho B_c A$$

The table above shows the velocity of the two projectiles over 2000 meters of flight. Both projectiles are still above the speed of sound at sea level (346 meters per second) (Iowa State University, 2023). The velocity retention of the control is good for a conventional projectile and is what it has been designed for. The velocity retention of the Fin stabilized projectile is far greater than the control. The control has 52.83% of its original velocity and the fin stabilized projectile has 84.75% of its original velocity. This velocity retention will reduce the amount gravity affects the fin stabilized projectile at longer ranges. Below is a table that compares the percentage of velocity retention and the drop in elevation each projectile experiences.

Table 6 Section of percentage of velocity retained.

Distance in meters	Control velocity percentage	Fin-stabilized velocity percentage	Control projectile drop in cm	Fin-stabilized projectile drop in cm
50	98.42%	99.59%	0	0
100	96.86%	99.18%	-0.017245638	-0.017042646
150	95.33%	98.77%	-0.070096412	-0.068453258
200	93.82%	98.36%	-0.160270377	-0.154658922
1900	54.54%	85.46%	-43.16071445	-27.12783526
1950	53.68%	85.11%	-46.33061724	-28.73561475
2000	52.83%	84.76%	-49.66654085	-30.39662437

It can be seen that the fin stabilized projectile drops almost 20cm less than that of the control projectile. This is due to its ability to retain its velocity more effectively, which reduces the time it takes to reach the target. The only force that will cause a bullet to drop as it moves to the target is gravity. Gravity will affect both projectiles equally as both have no difference buoyancy force. The control bullet does have a force that, at extended ranges, will cause it to drop slower. This force is called Magnus effect and is caused by the bullets rotational motion. This is caused by the difference in ion pressure over the surface of a spinning object. This effect is very small and is difficult to calculate and will therefore be ignored.

Chapter 6: Discussion

CALCULATIONS

The calculations that have been done in this feasibility study are approximations. These equation results will be close to what the real world will produce. The equations have been created to be close approximations that will be accurate for use to determine the feasibility of a fin stabilized projectile.

The least accurate calculation will be the ballistic coefficients. The equation relates the drag coefficient of the control projectile referenced to a standard projectile. This works well for projectiles of similar shapes. There are two standards that get used for this propose. The one that has been used is the g7 standard and the other is the g1 standard. These two will cover all of the currently available factory ammunition. These however, are not good representations of a fin stabilized projectile.

ENERGY INPUTS

The energy requirements to accelerate the projectiles were calculated and the rotational acceleration of the standard projectile was also calculated. The fin stabilized projectile does not spin, and so no rotational acceleration was required. The force to accelerate the two projectiles from stationary to final velocity was the same as both had the same final velocity and mass. The rotational acceleration was found to be 47% of the total energy imparted on the standard projectile.

A simple calculation where the rotational acceleration energy was converted to linear velocity for the fin stabilized projectile was done. It was found that the new velocity would be 1250 meters per second, a 47% increase in the initial velocity. This is likely too high a velocity as modern propellants have a maximum achievable velocity of 1800 meters per second (wikipedia, 2023). This increase in velocity with the ability for the fin stabilized projectile to retain its velocity will be much better for long range target shooting applications.

FEASABILITY

The feasibility of using a fin stabilized projectile for long range target shooting is shown to be promising. The fin stabilized projectile has a smaller cross section, ballistic coefficient, and a potentially higher initial velocity. The fin stabilized projectile has been shown to have the potential to retain its velocity over distance due to its superior ballistic coefficient even at the same initial velocity.

The calculations have shown that the projectile can retain is velocity over distance. This is a very good start. This, combined with the potential to drastically increase the initial velocity, shows great potential. The higher velocity is beneficial to all projectiles as they will have less time while traveling to the target to be affected by gravity and any wind that may be present.

The material that is used will have to be looked at carefully. The predominant material used in bullets is lead due to its high density. This produces issues the higher the velocity for example with most modern cartridges it will have a copper shell. This is to stop the lead from depositing large amounts of material in the barrel.   With the fin stabilized projectile, the tensile strength of the material will need to be high enough to withstand the acceleration.

Chapter 7: Conclusions

The conclusion of the feasibility analysis is that this is a viable option to research. The drag imparted is smaller than the control and the initial speed is potentially higher. These are the two components that will affect long range target shooting most significantly. The calculations that have been done show that the fin stabilized projectiles ballistic coefficient is 24% of the control projectile.

The force to spin the control bullet was calculated and found to be 5.2KJ. If a fin stabilized projectile is used it does not need to be spun and can therefore use this energy for linear acceleration. The potential velocity increase is 47.3% due to the rotational velocity being converted to linear velocity. This amount of potential velocity increase would be a very large factor in long range accuracy.

Chapter 8: Further work

There is still lots of work that can be done on this project. Below is a list of actions that be taken with improved time and resources:

1. More calculations and analysis. Further calculation and analysis including reviews to ensure accuracy in equations.
2. Perform simulations in ANSYS. A simple two-dimensional simulation was completed. It has been placed in the appendix. The simulation performed will not work for the fin stabilized projectile as it is not symmetrical about its axis. A simulation would allow for analysis on how the flow around the projectile performs. The most interesting part of which is the Mach cone produced by a projectile moving faster than the speed of sound. This can be seen in the pictures in the appendix.
3. Physical testing. This would consist of two possible methods. The first would be to use the hypersonic had to do the in-flight testing. This would be useful to see how the projectile behaves during flight. The second would be to do full testing. This would involve firing the

projectile from a firearm. This will be more difficult as firing it safely will be the largest concern.

4. The final testing would be to do long range target shooting with the projectile and compare it to a comparable standard projectile.

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Appendixes

Figure 8 Tangent vs Secant

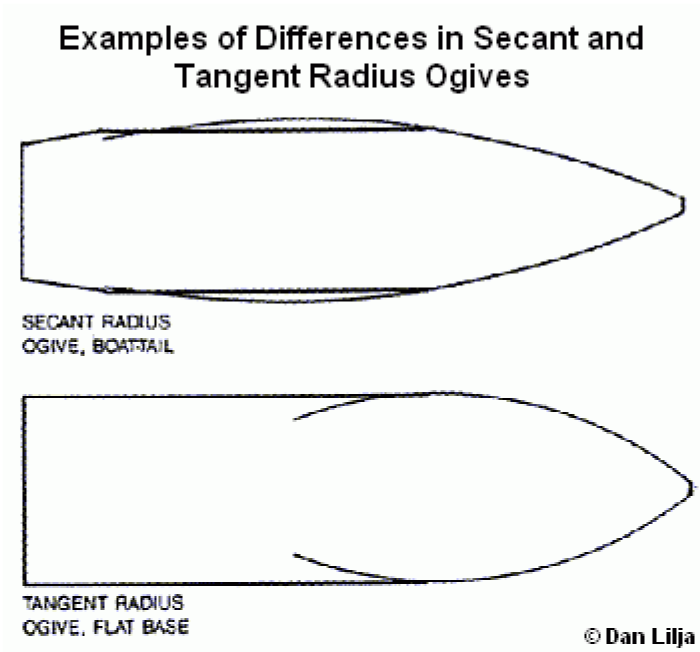

Table 7 Velocity variable

Variable	Control	Fin stabilized
M= mass	0.012312 kg	0.012312 kg
P= air density	1.225kg/m^3	1.225kg/m^3
Bc= ballistic coefficient	0.16666	0.09375
A= cross-sectional area	3.85*10^-5 m^2	1.773*10^-5 m^2
D=distance from muzzle	0-2000 m	0-2000 m
V0= initial velocity (muzzle velocity0	850 m/s	850 m/s

Table 8 Control Velocity over Distance

D	v(t)	t(d)	k
0	850	0	0.000319087
50	836.5464	0.05929528	
100	823.3057	0.11954417	
150	810.2747	0.18076199	
200	797.4498	0.24296435	

250	784.828	0.30616705
300	772.4059	0.37038621
350	760.1804	0.43563816
400	748.1485	0.50193951
450	736.307	0.56930713
500	724.6529	0.63775819
550	713.1832	0.7073101
600	701.8951	0.77798056
650	690.7857	0.84978757
700	679.8521	0.9227494
750	669.0916	0.99688462
800	658.5013	1.07221211
850	648.0787	1.14875104
900	637.8211	1.22652089
950	627.7258	1.30554146
1000	617.7903	1.38583287
1050	608.0121	1.46741555
1100	598.3886	1.55031026
1150	588.9175	1.63453812
1200	579.5962	1.72012055
1250	570.4225	1.80707934
1300	561.394	1.89543664
1350	552.5084	1.98521492
1400	543.7634	2.07643705
1450	535.1568	2.16912624
1500	526.6865	2.26330608
1550	518.3502	2.35900055
1600	510.1459	2.45623402
1650	502.0714	2.55503122
1700	494.1248	2.65541731
1750	486.3039	2.75741784
1800	478.6068	2.86105877
1850	471.0315	2.96636649
1900	463.5761	3.0733678
1950	456.2388	3.18208994
2000	449.0175	3.29256059

Table 9 Fin stabilized velocity over distance

D	v(t)	t(d)	k

0	850	0	8.27E-05
50	846.4936	0.058945	
100	843.0017	0.118135	
150	839.5241	0.177569	
200	836.061	0.23725	
250	832.6121	0.297178	
300	829.1774	0.357354	
350	825.7569	0.41778	
400	822.3505	0.478456	
450	818.9582	0.539383	
500	815.5798	0.600563	
550	812.2154	0.661995	
600	808.8649	0.723683	
650	805.5282	0.785626	
700	802.2052	0.847825	
750	798.896	0.910283	
800	795.6004	0.972999	
850	792.3184	1.035974	
900	789.05	1.099211	
950	785.795	1.162709	
1000	782.5535	1.226471	
1050	779.3253	1.290496	
1100	776.1104	1.354787	
1150	772.9089	1.419344	
1200	769.7205	1.484169	
1250	766.5452	1.549262	
1300	763.3831	1.614625	
1350	760.234	1.680258	
1400	757.0979	1.746164	
1450	753.9748	1.812342	
1500	750.8645	1.878794	
1550	747.767	1.945522	
1600	744.6824	2.012526	
1650	741.6104	2.079808	
1700	738.5512	2.147368	
1750	735.5045	2.215209	
1800	732.4704	2.28333	
1850	729.4489	2.351733	
1900	726.4398	2.42042	
1950	723.4431	2.489391	
2000	720.4587	2.558648	

Table 10 Velocity retention in percentage and drop in elevation in cm

	control	fin	drop cont	drop fin
50	98.41722354	99.58748	0	0
100	96.85949889	99.17667	-0.01725	-0.01704
150	95.32642954	98.76755	-0.0701	-0.06845
200	93.81762526	98.36011	-0.16027	-0.15466
250	92.33270197	97.95436	-0.28955	-0.27609
300	90.8712817	97.55028	-0.45979	-0.43318
350	89.43299244	97.14787	-0.6729	-0.62638
400	88.01746809	96.74712	-0.93087	-0.85612
450	86.62434832	96.34802	-1.23578	-1.12285
500	85.25327853	95.95057	-1.58976	-1.42703
550	83.90390971	95.55475	-1.99504	-1.76911
600	82.57589837	95.16057	-2.45391	-2.14956
650	81.26890649	94.76802	-2.96877	-2.56883
700	79.98260137	94.37709	-3.54209	-3.02741
750	78.71665558	93.98776	-4.17644	-3.52575
800	77.47074689	93.60005	-4.87449	-4.06435
850	76.24455814	93.21393	-5.63898	-4.64369
900	75.03777723	92.82941	-6.47278	-5.26425
950	73.85009695	92.44647	-7.37885	-5.92654
1000	72.681215	92.06511	-8.36027	-6.63103
1050	71.53083384	91.68533	-9.42021	-7.37825
1100	70.39866064	91.30711	-10.562	-8.16869
1150	69.28440721	90.93045	-11.789	-9.00287
1200	68.18778992	90.55535	-13.1048	-9.88131
1250	67.10852963	90.18179	-14.513	-10.8045
1300	66.04635163	89.80978	-16.0175	-11.773
1350	65.00098552	89.4393	-17.6221	-12.7874
1400	63.97216522	89.07034	-19.331	-13.8481
1450	62.95962885	88.70291	-21.1484	-14.9558
1500	61.96311866	88.337	-23.0786	-16.1109
1550	60.98238101	87.97259	-25.1261	-17.314
1600	60.01716624	87.60969	-27.2958	-18.5657
1650	59.06722866	87.24829	-29.5923	-19.8665
1700	58.13232647	86.88837	-32.0207	-21.2171
1750	57.21222169	86.52994	-34.5863	-22.6179
1800	56.30668011	86.17299	-37.2944	-24.0696
1850	55.41547123	85.81751	-40.1506	-25.5727
1900	54.5383682	85.4635	-43.1607	-27.1278
1950	53.67514774	85.11095	-46.3306	-28.7356
2000	52.82559014	84.75985	-49.6665	-30.3966

Work in progress ↓

The ogive shown has been created using an 88mm radius that is tangential to the body of the bullet. The bullet has been analyzed as a negative in a section of flow. Figure 9 displays the sketch of the negative and the flow area around the projectile:

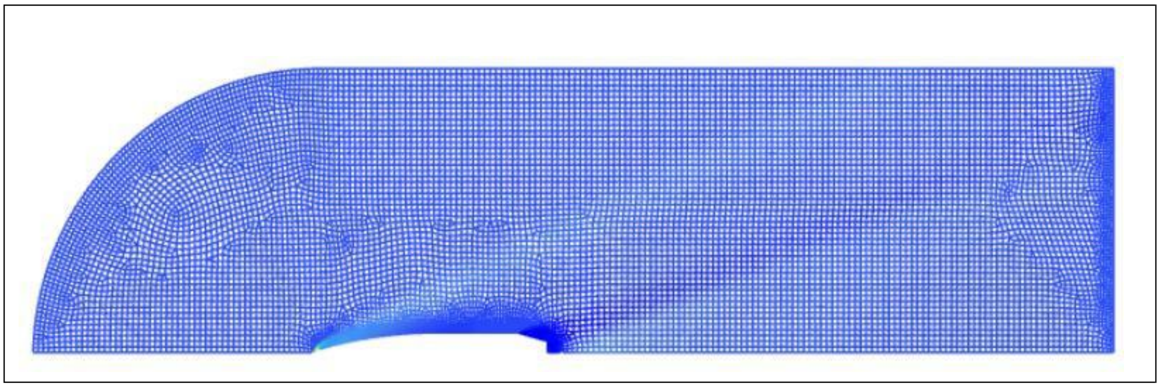

Figure 9 Control Sketch

The total flow section is 200mm in length with 140mm behind the bullet. This is done to allow the calculation of the flow behind the bullet. Because the bullet is symmetric about its axis only half of the bullet has been modeled. The next image is of the mesh that was generated. The mesh is used to run the calculations of fluid flow around the bullet. The dark band behind the bullet is a region of high-density meshing.

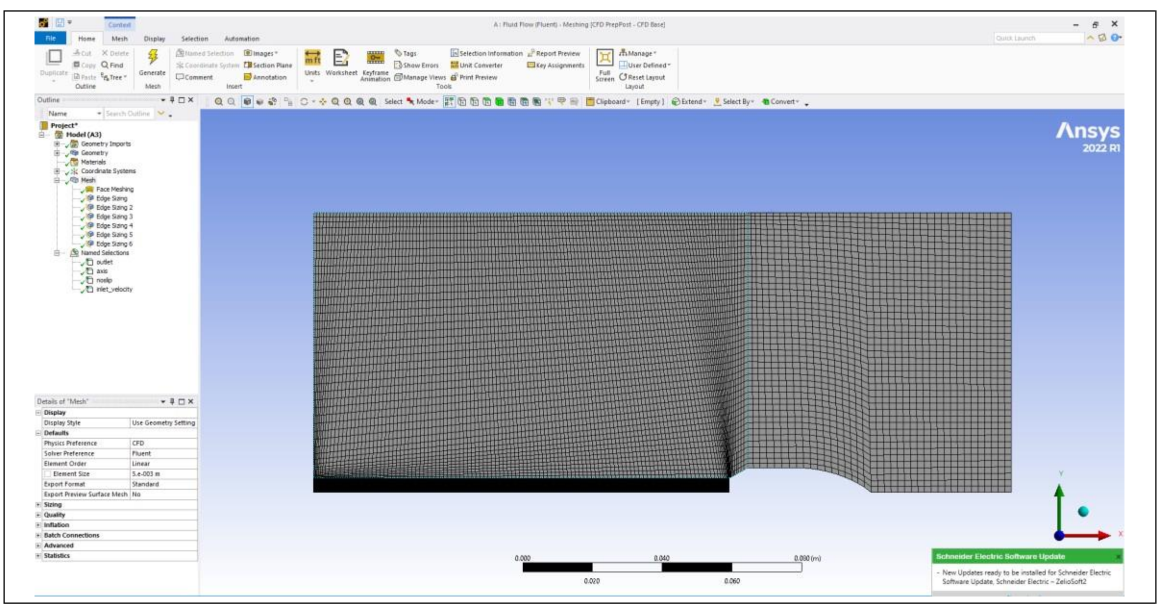

Figure 10 Control Meshing

The next step was to define all of the meshing sections. In the image below the blue arrows denote the inlet of the fluid flow. The red arrows denote the exit direction of the flow. The bullets profile has been set as to a no slip condition as this is the object the flow will be moving around.

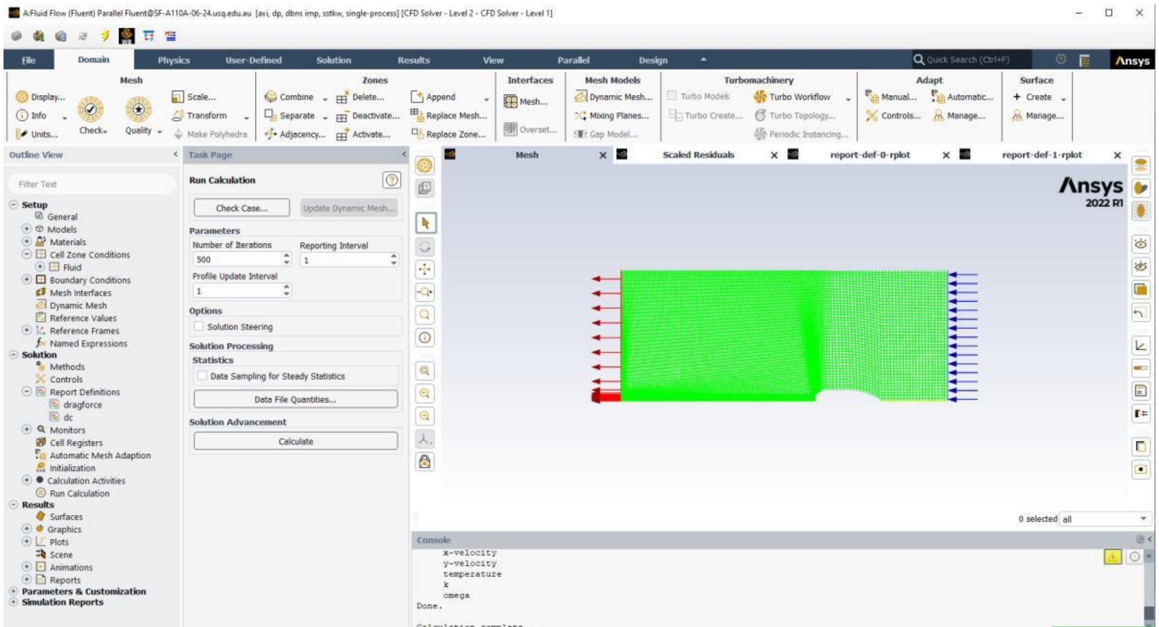

Figure 11 Control Set Up

The program was instructed to perform 500 iterations of the calculations. This was done as it would produce a stable output. After the calculations were done, two graphs of data and a graph of accuracy were created. The two data graphs show the drag coefficient of the bullet as the number of iterations progressed and the other the drag force. Both the drag coefficient and drag force stabilized as the iterations continued. Showing a stable simulation.

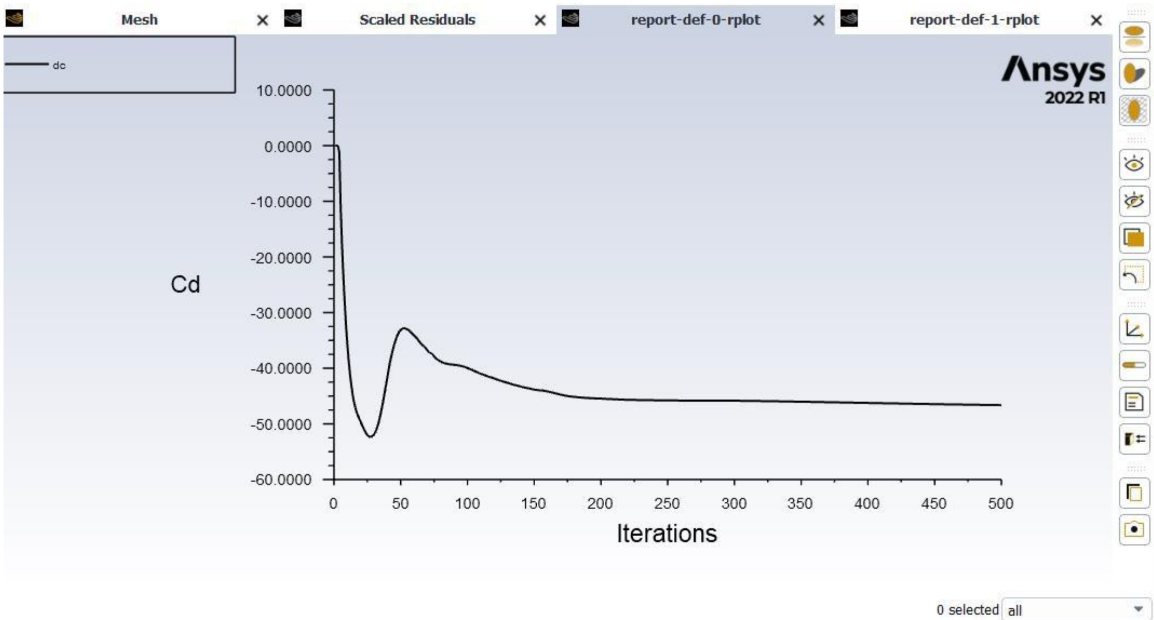

Figure 12 Control Drag Coefficient

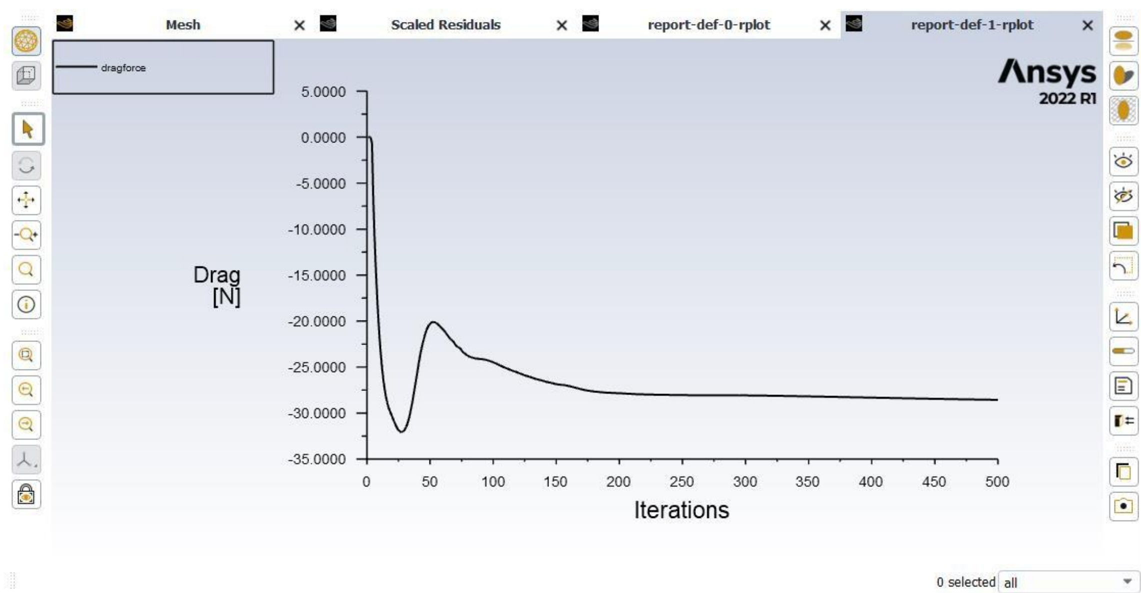

Figure 13 Control Drag Force

The accuracy graph that was produced show a semi stable simulation. The continuity and omega values showed a stable simulation. The k value began to increase after iteration 300 and continued until iteration 500. This shows that the simulation is stable but is inaccurate.

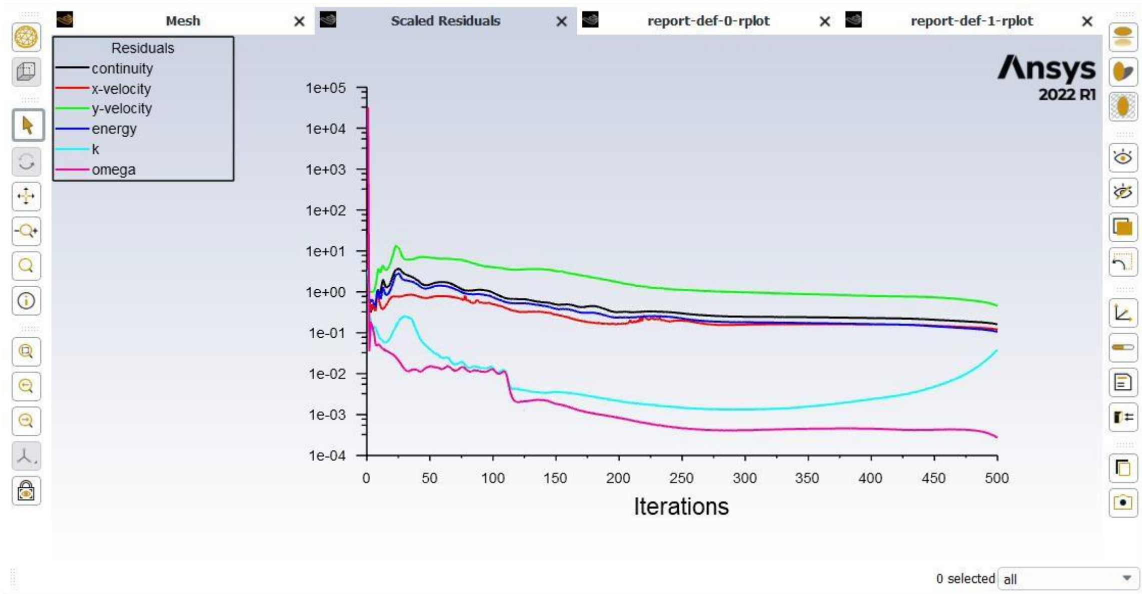

Figure 14 Control Accuracy

The image below shows the pressure contour from the simulation. The line running through the image is the line of symmetry. The simulation was completed using only half of the bullet as the flow will be symmetrical along the axis of the bullet.

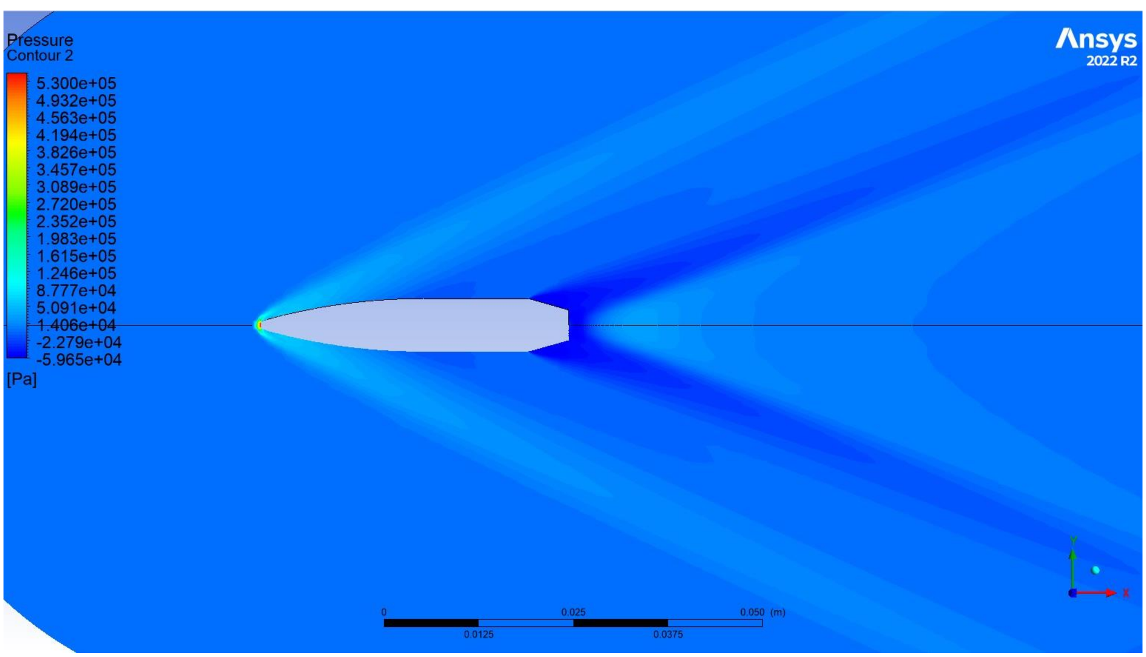

Figure 15 Pressure Contour Control

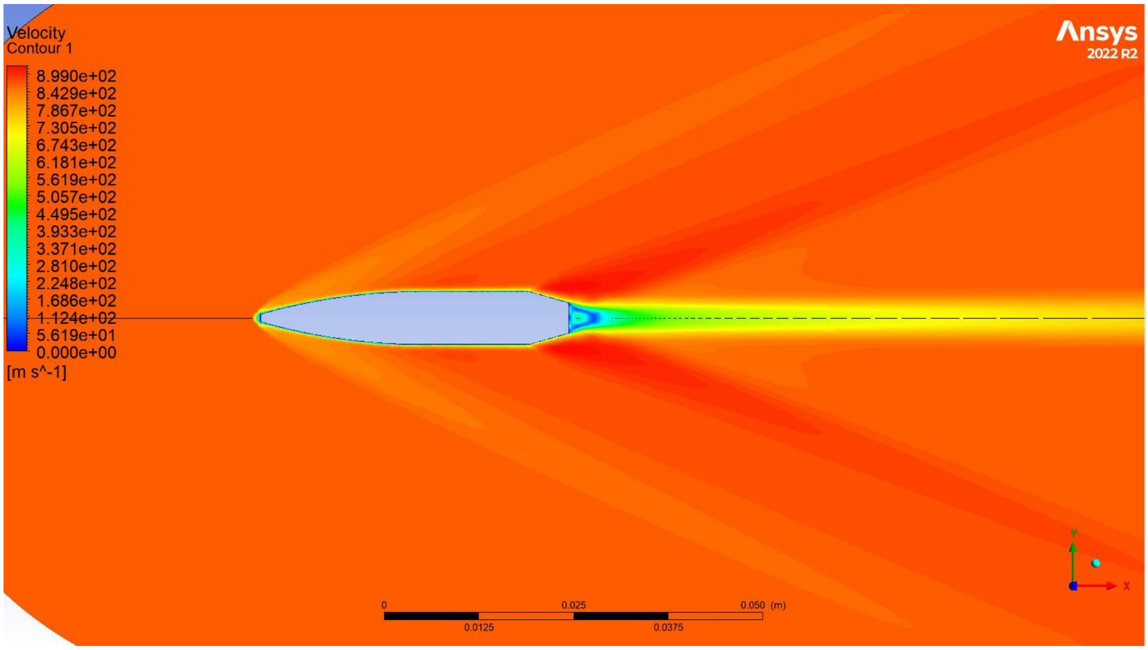

Figure 16 Velocity Contour Control

The velocity contour plot shows a very similar result to that of the pressure contour plot. Both plots show a wave that begins at the tip of the projectile. This wave is very likely the Mach cone that is created when a projectile is moving faster than the speed of sound.
This cone can be used to verify that the simulation has run correctly. This can be done by measuring the angle between the wave and the axis of flight.