IMMERSIVE FIREARM BALLISTICS SIMULATION IN VIRTUAL REALITY

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#PSCR2020

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TERMINOLOGY

BALLISTICS

The field of mechanics that concerns with the launching, flight behavior, and impact effects of projectiles

INTERNAL BALLISTICS

Sub-field of ballistics that concerns projectiles before they leave the firearm

EXTERNAL BALLISTICS

Sub-field of ballistics that concerns projectiles in flight

BULLET

Projectile that is launched from a firearm towards a target. The part of the cartridge that is launched

BARREL

Tube in the firearm that bullet travels through when fired. Bullet starts at “chamber” end, exits through “muzzle” end

SIGHT

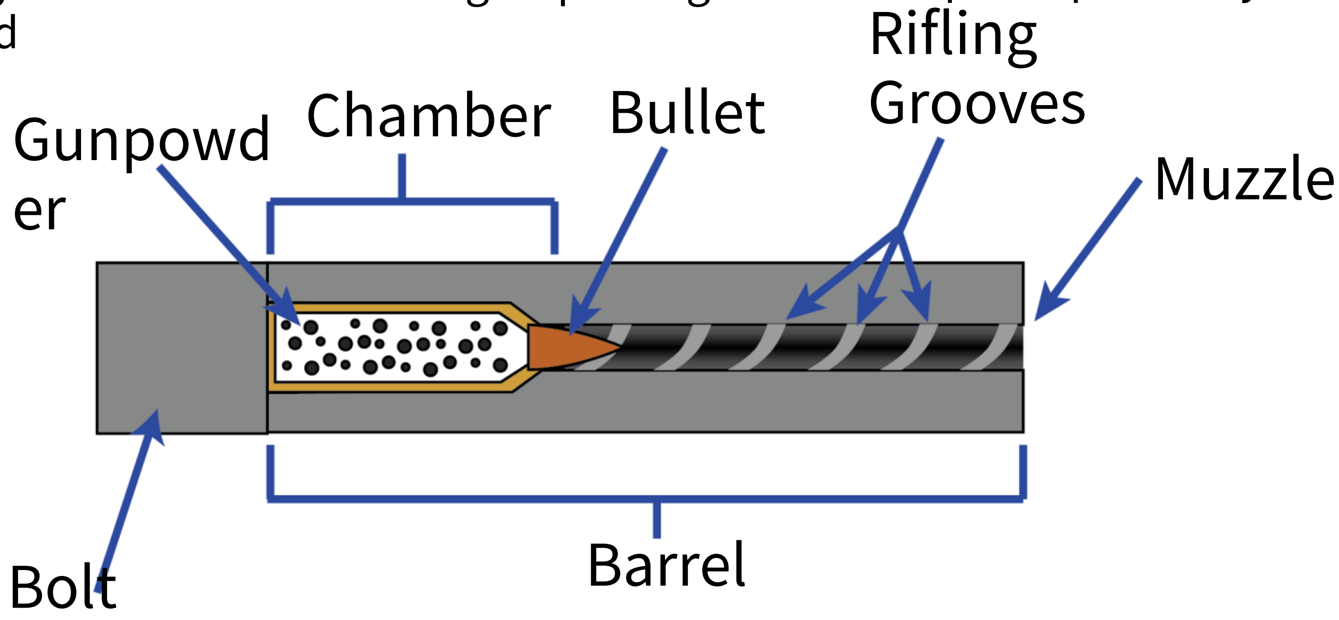
Aiming device that allows the user to point the firearm such that when fired, the bullet will hit the target

ZERO

To properly calibrate a sight. A verb, an adjective, and a noun

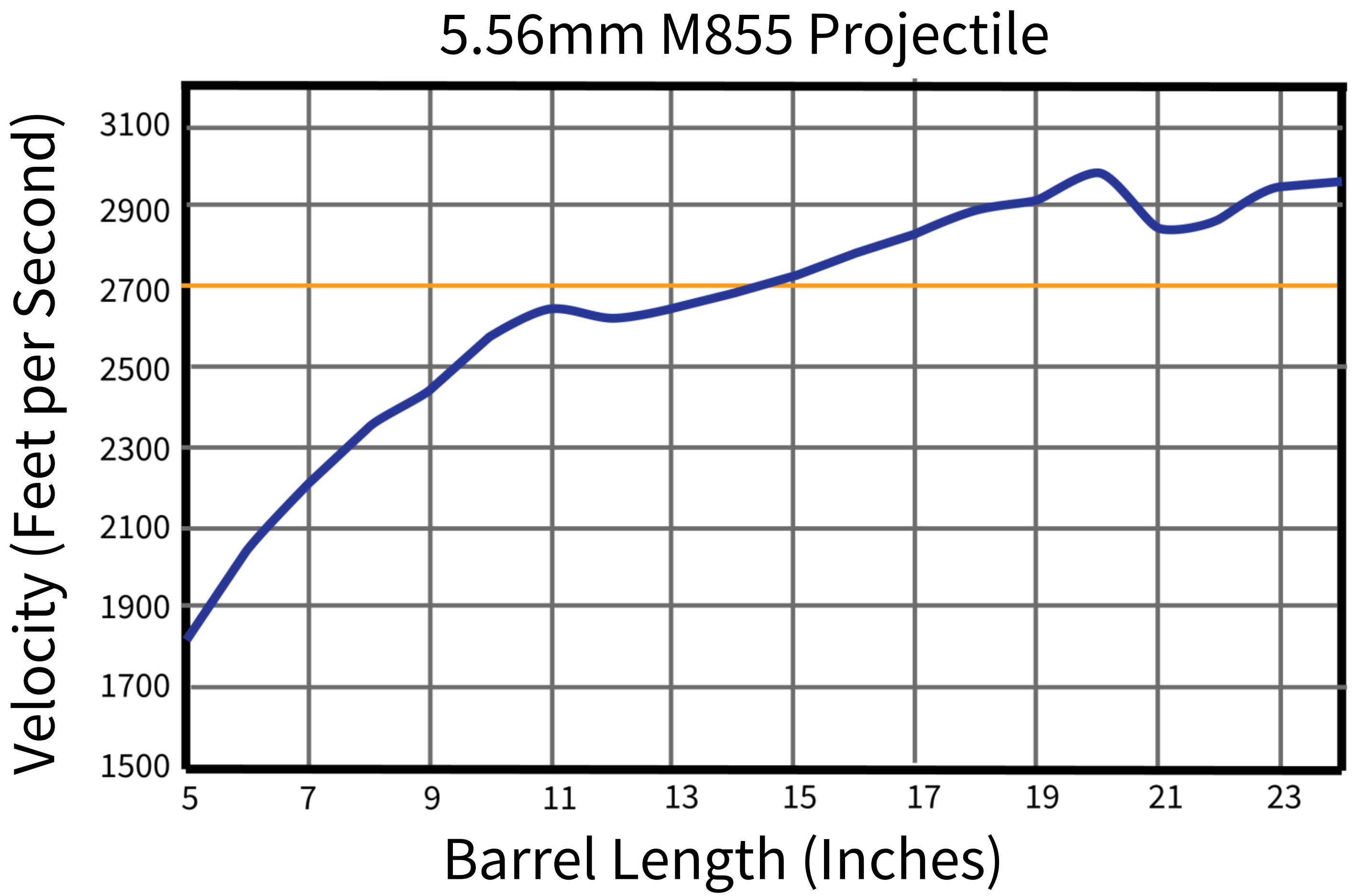
INTERNAL BALLISTICS: OVERVIEW

1. When the gun is fired, gunpowder behind the bullet is ignited, creating an expanding explosion in the chamber
2. The bullet seals the barrel, blocking the way to the muzzle. Expanding gas begins to push the bullet down the barrel
3. Spiral Grooves cut along the inside of the barrel called "rifling" cause the bullet to begin spinning as it is pushed
4. As the bullet travels down the barrel, it gains velocity
5. The bullet continues to gain velocity until it exits the muzzle. Now the barrel is no longer sealed, and the expanding gases escape into the air and dissipate
6. The bullet travels through the air, stabilized by the spin imparted by the rifling



INTERNAL BALLISTICS: CONCLUSIONS

1. Longer barrel = more muzzle velocity
2. Longer barrel =/= more mechanical accuracy



EXTERNAL BALLISTICS: OVERVIEW

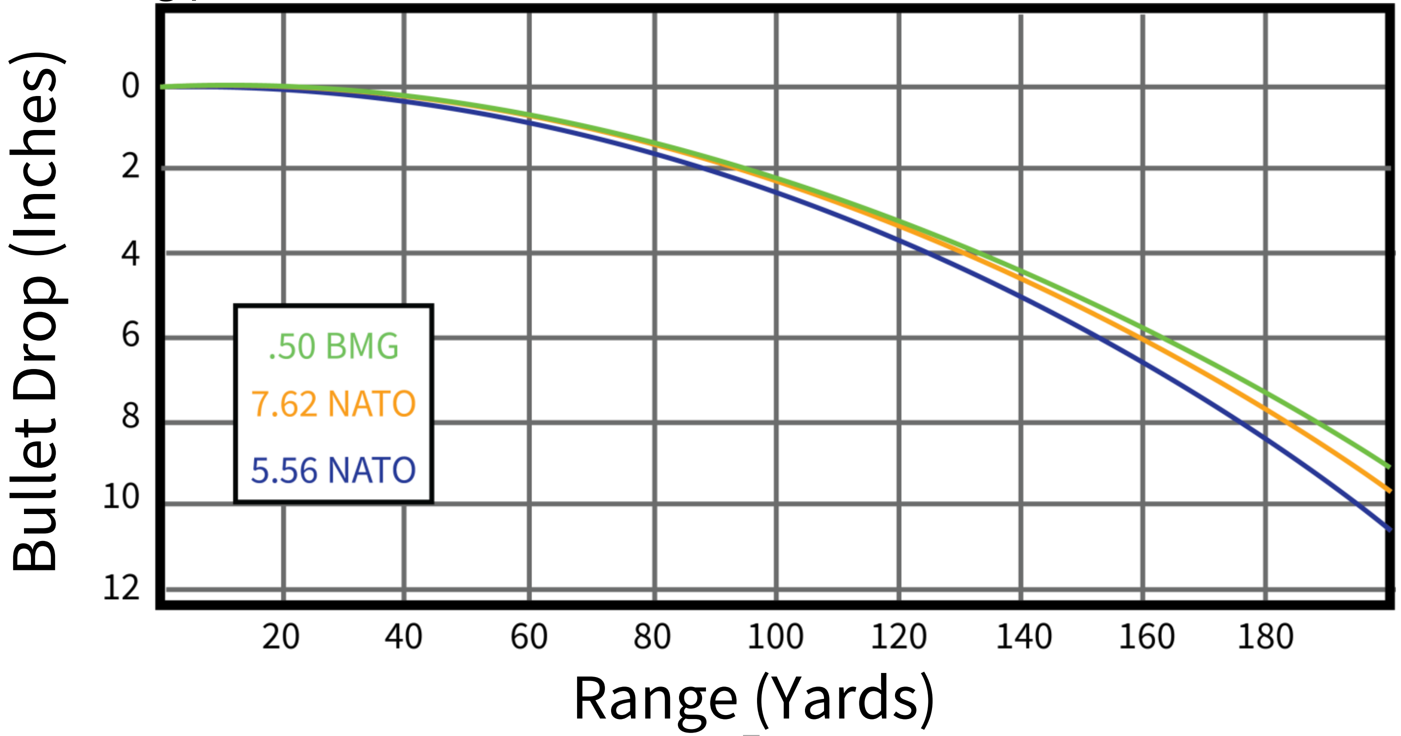
The bullet leaves the barrel traveling at the "muzzle velocity." This is the highest velocity the bullet will ever reach. It is a product of barrel length, bullet weight, and propellant composition.

Now external forces will begin to affect the bullet. The two most important are:

GRAVITY DRAG

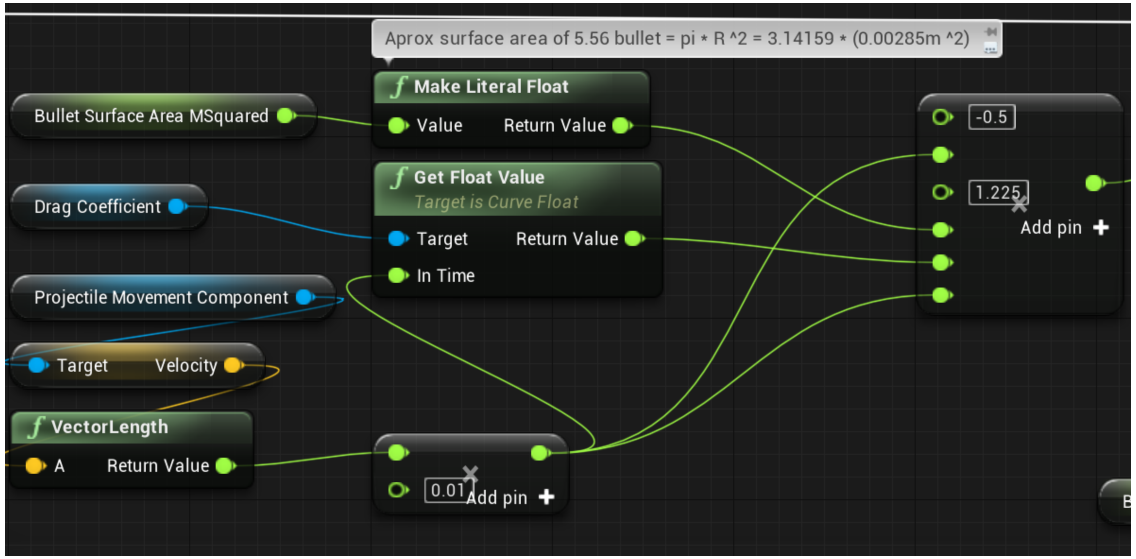
EXTERNAL BALLISTICS: GRAVITY

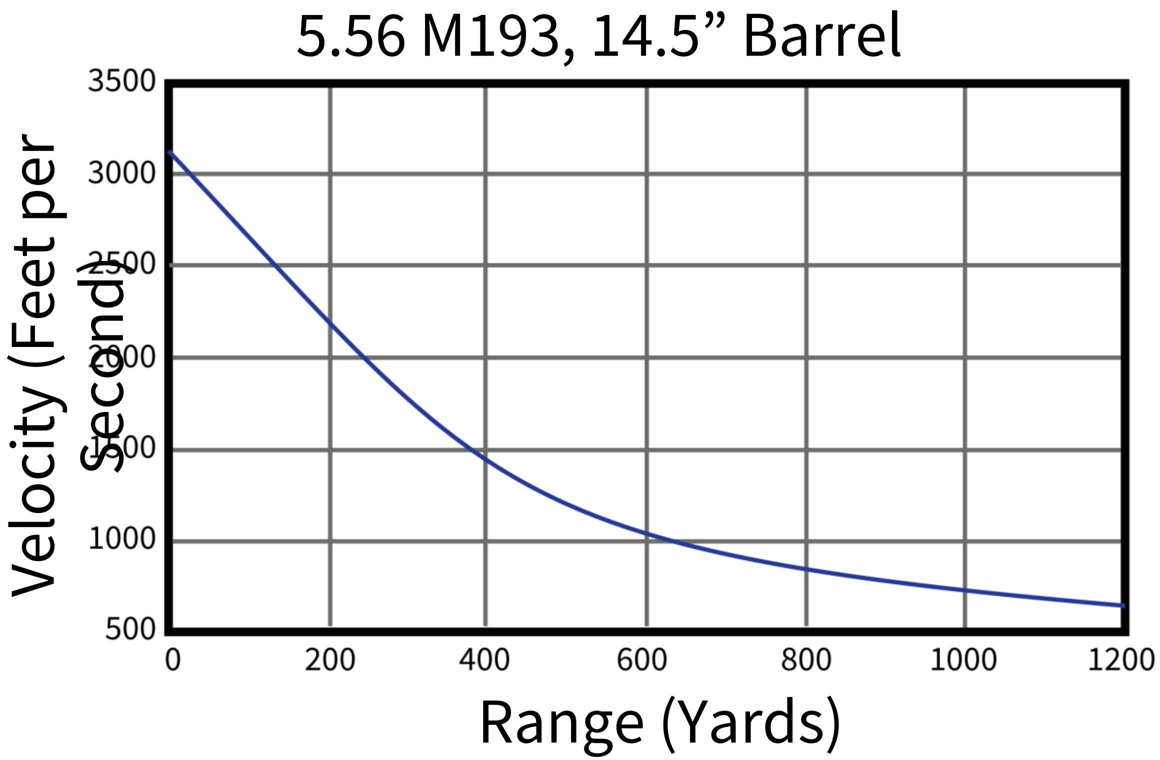
- Like all objects on earth, gravity will cause the bullet to accelerate towards the earth at $9.8 m/s^2$
- Though initially travelling along the axis of the barrel, gravity will cause the bullet to diverge from this axis in the direction of the earth's surface
- We call this divergence "bullet drop," and it increases as the bullet gets further from its starting point



EXTERNAL BALLISTICS: DRAG

- Air resistance on the bullet, known as drag, begins slowing the bullet's velocity the moment it leaves the muzzle of the barrel
- Our simulation uses the drag equation D = Cd * A * .5 * r * V^2, with approximated values for the drag coefficient (Cd) and the surface area (A) of our given bullet
- The effect of drag slowing the bullet exacerbates the effect of bullet drop





SIGHTS: OVERVIEW

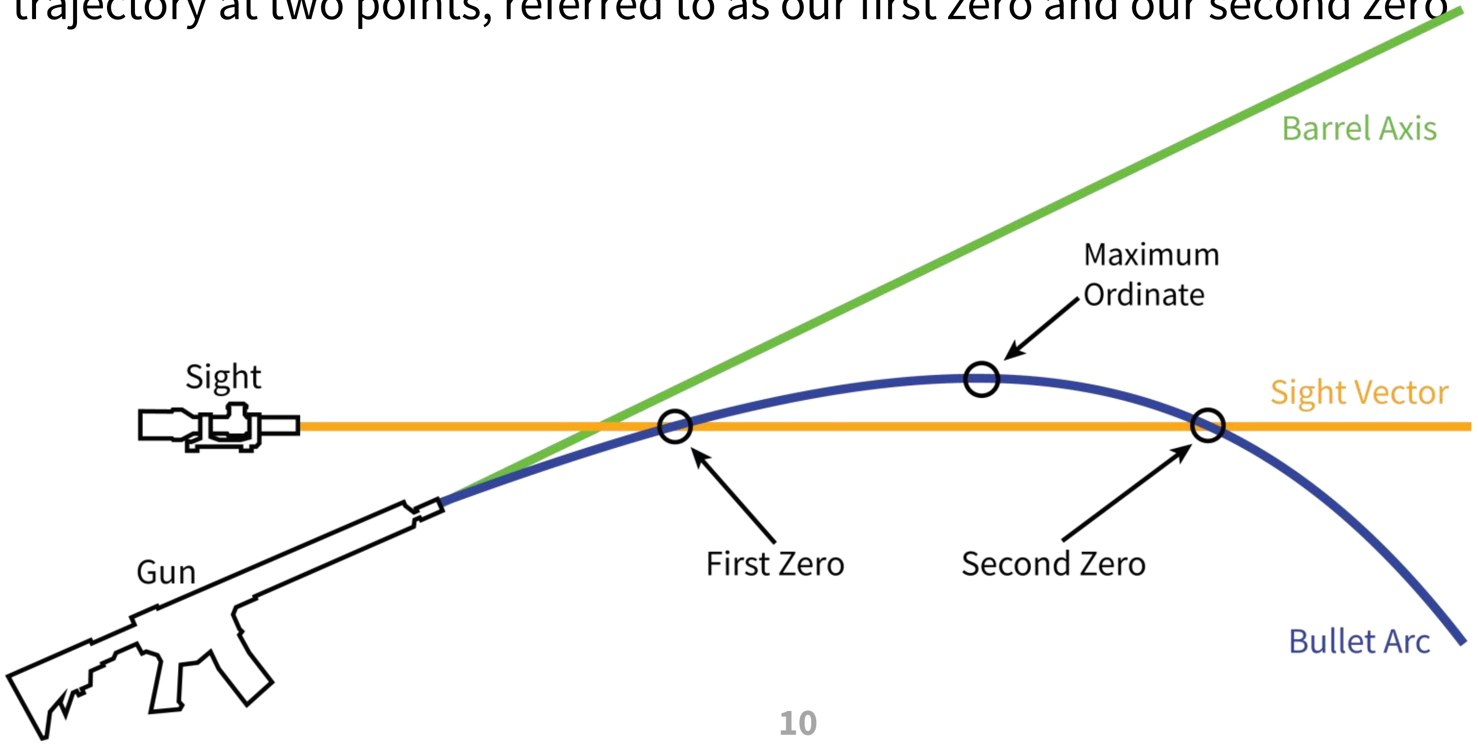
- We successfully hit our target by using a sight
- A sight does nothing more than provide us a precise, repeatable way to visualize a vector between our eye and the sight itself, and beyond
- If we zero our sight such that our sight vector is aligned parallel with the vector our bullet will travel on, we can easily visualize the path of the bullet
- Then, we can aim our firearm such that our sight vector is aligned with our target, and know that the bullet will follow a similar vector, and hit where our sights are aiming

Iron Sights

Red Dot Sight

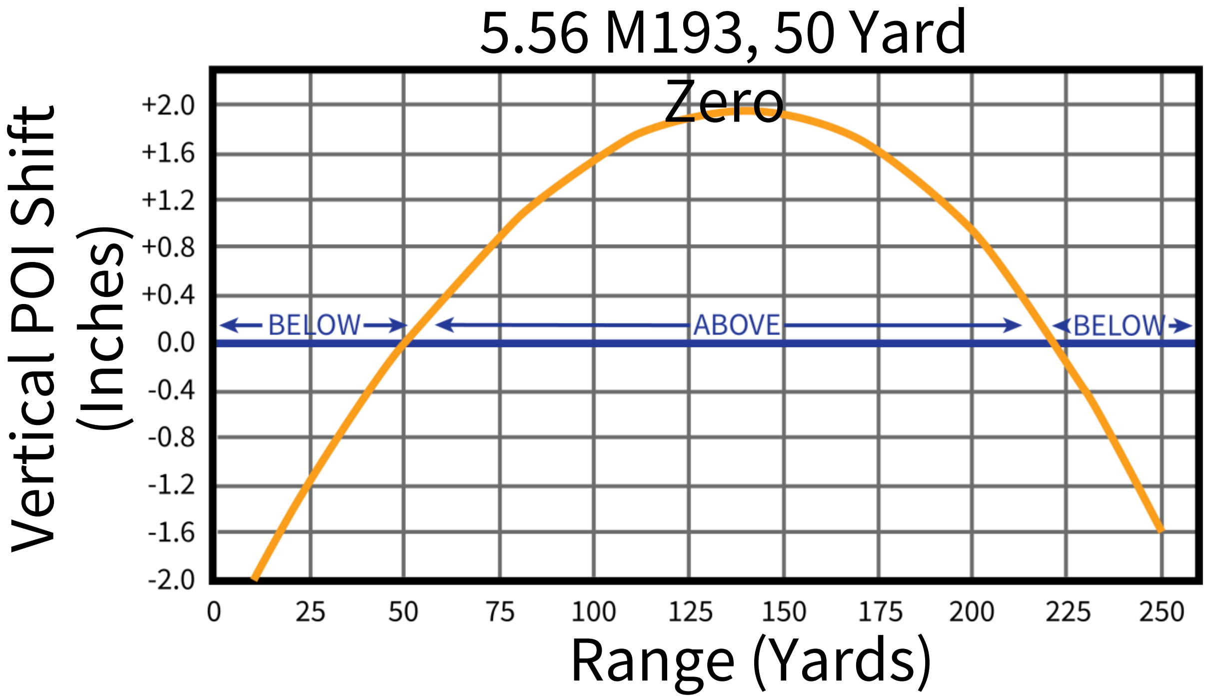
SIGHTS: ZEROING

- As we just learned, bullets do NOT travel in a straight-line vector. Gravity and drag causes them to move in an arc
- So instead of aligning our sight vector to be parallel with the VECTOR of our bullet, we have to align our sight vector so that it intersects the ARC of our bullet at a given range (preferably the range we expect to shoot targets at)
- So we zero our sight to align the sight vector to intersect the arc of the bullet trajectory at two points, referred to as our first zero and our second zero



SIGHTS: EFFECTS OF ZEROING

- At ranges closer than our first zero, the bullet will impact below our sights. Between the first and second zero, the bullet will impact ABOVE our sights. At ranges further than our second zero, the bullet will once again impact below our sights.
- Changing what range we zero our sight at will change not only where our sight vector intersects our bullet trajectory, but also how far our sight vector will diverge from the bullet trajectory between our first and second zero

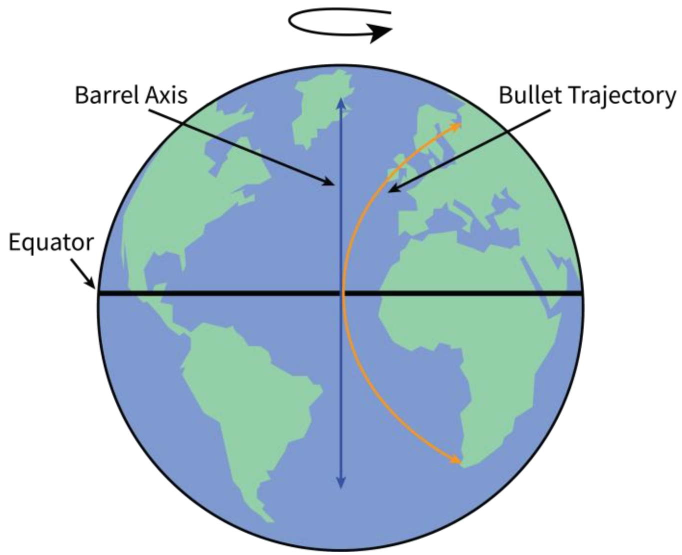


SIGHTS: COMPARING ZEROES

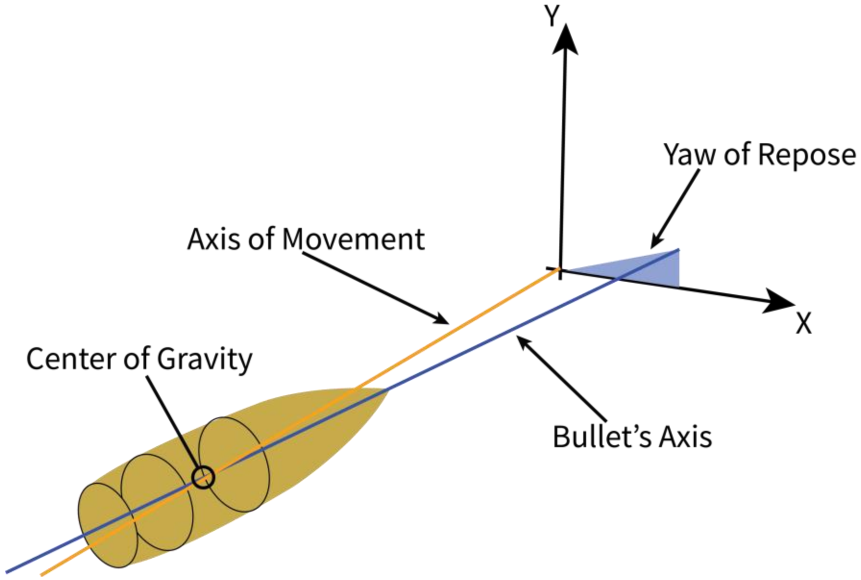
- There's no single right answer for what range to zero your firearm at. It depends on what you are shooting at, and what distance you are shooting it from
- With 5.56mm bullets used in the AR-15, there are several popular zeroes. From the 1960s until the 1990s-2000s, the US Military used a 25m/220m zero. This is what many SWAT teams use today. Currently, the US Army uses a 50y/200y zero, and the US Marine Corps uses a 36y/300y zero
- Zeroing a firearm in real life is an iterative (and tedious) process that involves turning dials on the sights to make minute internal adjustments within the sight. Sometimes violent jolts can misalign the internal components of the sight, ruining your zero
- In our simulation, zeroing a firearm is accomplished by placing an object representing our point of impact at a chosen range, and the sights reference it to adjust themselves automatically

OTHER EXTERNAL FORCES

- Gravity and drag may be the two most important external factors on a bullet's external ballistics, but they are by no means the only ones
- Other factors include ambient temperature, ambient air pressure, the Coriolis Effect, transonic destabilization, and gyroscopic (spin) drift
- Our simulation currently only supports gravity and drag. At the close ranges we shoot in VR, this suffices for an accurate simulation of real-world external ballistics, but perhaps other external factors may be simulated in future updates



The Coriolis Effect



Gyroscopic (Spin) Drift

TECHNICAL IMPLEMENTATION DETAILS

- Bullet is physics based (actually heavily modified projectile actor from Unreal First Person Content Example)
- Bullet drop “just works” since objects in UE4 that simulate physics are affected by gravity by default
- Bullet velocity is manually set each frame based on the drag equation
- Bullet actor also has a complex system for ricochets and barrier penetration (unfortunately beyond the scope of this presentation)

THANK YOU

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