. trajectory - the curved path of an object that has been fired, hit or thrown into the air.

The science of projectile & firearm

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(Unit-03) Internal & External Ballistics

1. Definition → firing up something
2. Ignition of propellants
3. Shape & size of propellants → acc. to grain size, the rate of burning is depended.
4. Manner of burning - constant, progressive, degressive
5. Energy considerations
6. Various factors affecting internal Ballistics: lock time, ignition time, Barrel time, errosion, corrosion & gas cutting
7. Vaccum trajectory
8. Effect of air resistance on trajectory ~~computation~~
9. Base drag, drop, drift, yaw → जो उसका पाथ है! वो चीज़ के दूसरी जगह ~~पर~~ चले जाना।
10. Shape of projectile & stability
11. Trajectory computation
12. Ballistics coefficient & limiting velocity

→ INTERNAL BALLISTICS : is a science of what goes on inside a gun

- It include lock time, the time from sear release until the primer is struck.
- Ignition time, the time from when the primer is struck until the projectile starts to move
- Barrel time, the time from when the projectile starts to move until it exits the barrel.

→ Internal ballistics (also interior ballistics) a subfield of ballistics is the study of propulsion of a projectile.

→ In guns internal ballistics covers the time from the propellants ignition until the projectile exits the gun barrel.

* what physically occurs inside the gun barrel once a projectile is fired.

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→ EXTERNAL BALLISTICS deals with motion of projectile or bullet from the muzzle end of the weapon, to the target or till it drops under the influence of gravity

* The period from when the projectile has left the muzzle until impact with the target.

* Internal ballistics is the study, which deals with the motion of projectile in the bore of the weapon whereas external ballistics deals with the fight from the muzzle of the weapon to the target.

→ Internal ballistic, which deals with the motion of projectiles, commences as soon as the first grain of the propellant is ignited & sustains till the projectile leaves the muzzle end of the weapon.

→ The study includes all details concerning the impulse, which makes the projectile move out from the muzzle in the air.

- This period can be divided under 3 main heads:

(1) Lock time - is the time interval between release of the sear & the impact of the striker on the percussion cap. lock time can measured in a number of ways, one such system the use of linear motion sensors & an oscilloscope is made.

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→ **Propellants** are an explosive particles which through combustion provides velocity to the projectile.

- generally 3 types of propellants are used in firearm (1) Smokeless powder
  (2) Semi-smoke powder
  (3) Black powder

→ Ignition time is the duration or interval between the striking of the firing pin to blow the ignition of the first grain of powder.

- The ignition, under the normal conditions, takes place at an interval of about 0.002 sec.

(2) Ignition time - is the duration or interval between the striking of the firing pin to blow the ignition of the first grain of powder.

- The ignition, under the normal conditions, takes place at an interval of about 0.002 sec.

(3) Barrel time - is the time interval from the pressing of trigger to the exit of bullet from muzzle end.

* In most of the weapons lock time + Ignition time + barrel time varies from 0.003 to 0.007 sec.

* Phenomenon of Internal Ballistics:-

→ Internal ballistics includes study of several phenomena:-

(1) Ignition
(2) Burning of propellants & geometry of gun powder

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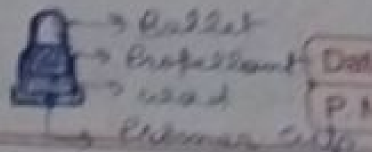
(3) Pressure & its measurement
(4) Atmospheric conditions like temperature etc.
(5) Shape of cartridges
(6) Density of loading
(7) Twist of rifling
(8) Bullet fit & velocity of bullet at muzzle
(9) Heat generation & problems
(10) Strenght of barrel
(11) Erosion
(12) Corossion or rusting of barrel
(13) Bullet of weapon
(14) Recoil of weapon
(15) Phenomenon of brushing of barrel

* Ignition - when the firing pin strikes the hammer, the priming compound explodes with great velocity causing jet of flames of an extremely high temperature to pass through the flash hole into propellant chamber

- This jet of flame ignites the propellant which burns at high speed to form a large volume of high pressure gas which accelerates the bullet down the barrel & out of muzzle end.



* Burning of propellant.

→ Nitrocellulose propellants, if ignited in open (unconfined) space, will burn gently.

→ The heat & pressure will increase the rate of burning if it is ignited in close (confined) space.

→ The products of combustion in case of nitroglycerine are detailed below:

Nitroglycerine ⟶ CO_2 + Water vapour + Oxides of nitrogen + nitrogen + ...

→ 1 gm of nitroglycerine produce 1000 cm^3 of gases at 0°C & 760 mm.

→ The temp. may cross 3000°C only a portion of this energy is converted into Kinetic energy of projectile most of it is wasted.

→ The pressure ~~built~~ built must be sufficient to overcome the inertia of the bullet so as to start its accelaration down the bore.

→ Heavier the bullet, greater the resistance & higher the pressure.

→ When the propellant burns, it gives rise to gases & they remain confined (close) completely with cartridge case & pressure is exerted equally on the base of the cartridge, it walls & the base of bullet.

→ Different types of powders namely progressive powders, degressive powders, & constant burning propellants as explained below:

① Progressive powder - for some weapons, particularly in respect of shoulder arms, it is desirable that pressure should not develop suddenly & the increase in pressure should be gradual (not sudden)

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eg: Perforated grain powder

→ No sudden development of pressure not only provides better velocities but also prevent quick wearing out of the barrel.
→ Progressive powder are manufactured to suit the needs of a particular weapon by controlling the shape & size of powder grains

(2) Degressive Powder - In this the shape & size of grains in powder are kept such that, as burning of propellant progresses, the rate of burning goes down.
eg: Non-perforated powder grain
to make holes or holes in something

(3) Constant Burning ~~Powder~~ Propellant - In this type of propellant, powder grains contain single perforation & the total surface area burning is consistant
eg: Single perforated grain.

* Geometry of gunpowder
→ Burning of propellants is function of geometry of gunpowder, certain terms are briefly explained:

(1) Combustion - It takes place when the reactn of burning propellant arise out of its contact with the air in an open space. If the reactn takes place in an enclosed space, the space should be large enough for the heat generated to dissipate & the gases produced will disperse without generating any significant increase in the pressure.

• Combustion - the process of burning something
• exothermic - producing heat
• endothermic - releasing heat

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③ ~~Detonation~~ ~~Deflagration~~ - shock waves are produced & excess amount of gases takes place while explosion.

② Deflagration - It includes rapid & violent burning & is intermediary step between gradual combustion & detonation.

* Combustion of Propellants & Barrel lenght

→ Combustion in propellants ∝ Barrel lenght

→ Combustion of gun powder is greater, then ~~Exp~~ Explosion of gun powder for bullet which ~~of~~ it will create pressure more & through an lenght of will easily help to pass barrel

→ Depends totally on type of gun powder used

* Temp. variations are substantial, they affect the ballistic aspects of the ammunition.

- In hot places the pressures developed may be excessive & the firearm may burst.

- In cold places the ammunition may develop low velocities.

- Indian Ordnance Factories manufacture most of their ammunition with a temperature tolerance of $-52°C$ to $72°C$.

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* Factors affecting internal Ballistics

① Chamber pressure - The pressure inside the cartridge case & the chamber of the firearm is a critical factor.

- It is influenced by the rate of burning of the propellant, the volume of the chamber & the resistance offered by bullet as it moves end of muzzle.

② Propellant type - Diffⁿ types of gunpowder or propellant have varying burn rates.

- The burn rate determines how quickly the powder combusts, affecting the pressure & the time over which that pressure is applied to the base of bullet.

③ Powder grain size & shape - The size & shape of the powder grains influence the burn rate.

- Fine grains generally burn more quickly, creating a rapid pressure rise.
- Powder with a consistent grain size is desirable for uniform ballistics.

④ Bullet weight & Design - The weight & design of the bullet influence its response to the pressure generated by the burning propellant.

- Heavier bullets generally require more pressure to achieve the same velocity as lighter bullet.

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(5) Barrel lenght - Longer barrels generally provide more time for the complete combustion of the propellant, resulting in higher projectile velocities.

(6) Barrel twist rate - The rifling inside the barrel imparts a spin to the bullet, stabilizing it in a flight.
- Too fast or too slow a twist rate can-vely impact accuracy.

(7) Bore & groove dimensions - The diameter & shape of the bore & grooves are critical for proper engagement of the bullet's surface.
- The bore diameter should match the bullet diameter & the groove dimensions should allow for effective stabilization.

(8) Casing Material Design - Cartridge cases are typically made of brass due to its ability to expand & seal the chamber under pressure.
- The design of the case, including its thickness & lenght, can affect the efficiency of powder combustion & the ease of extraction.

(9) Ignition System - It influences how quickly & uniformly the propellants ignites.
- Centre fire system are more precise than rimfire systems, allowing for greater control over ignition timing.

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(10) Temperature - The temp. at which the firearm is operated can affect the burn rate of the propellant.
- Cold temp. can slow down the burn rate, while high temp. can increase it.

(11) Bullet lubrication - Lubrication on the bullet reduces friction as it travels down the barrel
- This can influence the consistency of the internal ballistics & also aid in preventing fouling within the barrel.

(12) * Errosion - In internal ballistics refers to the gradual removal of material from the interior surfaces of the barrel due to the abrasive action of high-speed gases & particles generated during the firing of a cartridge.

→ * Causes (1) High-speed gases: The hot gases produced by the combustion of the propellant create a high-pressure environment inside the barrel, leading to erosion of the metal surfaces.

(2) Abrasive Particles: Particles, such as unburned powder & debris from the primer are accelerated down the barrel along with the projectile, contributing to erosion.

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→ Effects ① Throat erosion: The area near the chamber throat often experiences more erosion due to the intense pressure & temperature during the initial moments of firing.

② Altered dimension: Erosion can change the dimensions of the barrel, affecting the bore diameter & rifling. This, in turn can impact accuracy & velocity.

③ Reduced Barrel life: Excessive errosion shortens the lifespan of the barrel, requiring replacement after a certain number of rounds.

(13) * Corrosion - It is the chemical deterioration of metal surfaces inside the barrel, typically caused by the presence of corrosive elements.

→ Causes ① Hygroscopic Propellant: Some propellants are hygroscopic, meaning they absorb moisture from the air. When these residues mix with moisture, they can lead to corrosive reactions on the barrel surface.

② Residue Buildup: Residues from combustion, such as salts & acids can remain in the barrel if not adequately cleaned. Over time, these residues contribute to corrosion.

→ Effects ① Pitting: corrosion can result in the formation of pits or small holes on the interior surface of the barrel.

(2) Roughening of Barrel Surface: Corrosion can lead to a roughened surface, affecting the bullet & trajectory & potentially reducing accuracy

(3) Maintenance Issues: Regular cleaning is crucial to preventing & mitigating corrosion. Failure to clean the barrel properly can accelarate corrosion.

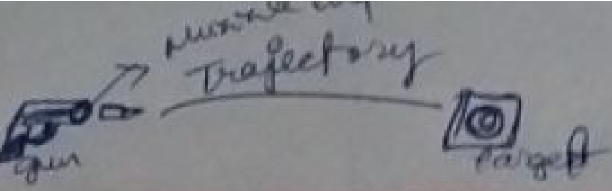
(14) * Gas cutting - It involves the erosive action caused by high-velocity gases escaping past the base & sides of the moving projectile

→ Causes (1) Insufficient Bullet Seal: If the bullet does not create a proper gas seal with the barrel, hot gases can escape around the sides of the bullet, cutting into the metal surfaces.

(2) Bullet fit: The fit of the bullet within the barrel is crucial. A loose fit can allow gases to escape, contributing to gas cutting

→ Effects (1) Increased Wear: Gas cutting exacerbates wear on the barrel, particularly in the throat area.

(2) Fouling: Gas cutting contributes to fouling as the escaping gases carry with them particles & residues that can accumulate in the barrel.



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(8) Accuracy Issues: Gas cutting can affect the consistency of the internal ballistics, leading to accurate problems over time.

→ External Ballistics - It deals with flight of projectile from the muzzle end of the weapon to the target.

- This is complicated subject involving parameters such as the shape of bullet, sectional density, atmospheric conclusions & even rotation of the earth in larger caliber weapons etc.

- It deals with the flight of the bullet from the muzzle of the weapon to the target.

- It would be more appropriate if it is said that the external ballistic deals with the motion of projectiles / bullets exiting from the muzzle end of weapon to target or till it drops under the influence of gravity.

* Trajectory means the path of the bullet from the muzzle to the striking point on the target. It is in a form of parabola.

→ The exact shape of this trajectory can be predetermin by knowing.

1. Gravitational effect
2. Muzzle velocity
3. The angle of elevation of the barrel
4. The sectional density of the bullet
5. Bullet shape

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6. Factors affecting external ballistic
7. Trajectory
8. Range
9. Drop of fall
10. Angle of fall
11. Remaining velocity
12. Maximum range or extreme range
13. Spin & drift
14. Structure of projectiles
15. Sectional ~~of~~ density
16. Gravitational pull
17. Air resistance
18. Weather condition
19. Muzzle velocity
20. Muzzle energy
21. Momentum
22. Trajectory formation.

* Vaccum Trajectories & Air trajectories

→ Both vaccum trajectories & air trajectories are imp. in external ballistics.

→ Vaccum trajectories have great importance in space travel

→ But, derivations & formulations applicable to vaccum trajectories cannot be applied to the real trajectories in air & for small arms ammunition

→ At best it could be a rough estimate in the case of extremely low - velocity project

* Range Determination

→ Determination of range for vacuum trajectory is based upon the fact that in absence of air resistance, the horizontal component of velocity of projectile does not change & the force of gravity remains constant. The [illegible] measured along the line of sight.

→ Effective range is a range of a projectile trajectory at which it damages the target effectively or the minimum range at which a projectile causes maximum damage to the target.

→ Extreme range is the maximum range or maximum distance for a projectile at which it reaches the target whether it causes damage to target or not.

* Since the velocity of the projectile is the most imp factor affecting the shape of the trajectory, it is accordingly adjusted suitably to make the trajectory flatter.

Flatter trajectories are very valuable for several reasons & an increase in the velocity of the projectiles helps make them flatter, because the greater the velocity, the flatter will the trajectory become.

* Bullet Spin - The spin of bullet is its revolving around its longitudinal axis. The rifling in the barrel of a firearm called a rifled weapon gives a spin to the bullet resulting in a reduction of air resistance because

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it disperses the air. In addition, it keeps the bullet in the line of fire & reduces the loss of velocity. If the spin of the bullet is not available, several problems which have been solved by it would appear including inaccurate aims

* Drift

→ Drift takes place, due to following reasons:

① If wind direction from left of bullet, the bullet will get drift to right (& same vice versa for other direction)

② If the motion of the wind is the same direction as that of bullet, it adds velocity of the projectile, but if direction of wind is opposite of bullet then the velocity will be decreased.

• Behaviour of Bullet

* Yaw

→ Yaw is something, which only has relevance to rifled ammunition.

This is due to slight destablization of the bullet as it leaves the barrel & is probably the result of excessive spin on the bullet.

This causes the bullet to describe an air spiral while at the same time having a spin around its tail axis.

* Drift - gyroscopic drift is the gradual deviation of bullet from its intended path due to its spinning motion imparted by rifling of barrel.

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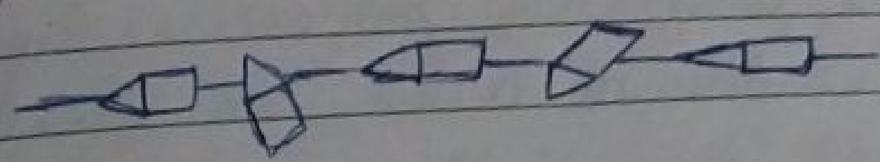
→ As the range becomes greater the effect disappears & the target groups return to their normal expected dimensions.

→ The deviation between the longitudinal axis of the bullet & the axis of the path of the bullet is known as Yaw & the between it is termed angle of yaw.



Yaw

* Effect of Air resistance on trajectory

→ Air resistance is also known as drag, significantly affects the trajectory of projectiles in ballistic.

→ When an object, such as bullet or a projectile is fired or thrown, its trajectory is initially influenced by various factors, including the force applied & the angle of launch.

* Factors linking projectile shape to stability :-

- Aerodynamics : (a) Streamlined design
  (b) Pointed or tapered design
- Spin stabilization : (a) Rotational motion
  (b) Rifling in Barrels
- Center of pressure & centre of gravity
  Balanced distribution
- Fins or stabilizers - Aid in stability
- Impact on performance - Accuracy, Range
- Engineering consideration : • Design optimization
  • Material & weight distribution

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* Drag force

- Nature of drag - when a projectile moves through the air, it encounters resistance known as drag.
- This forces opposes the motion of the object & is influenced by its shape, speed & air density.
- The faster the projectile moves or the larger its cross-sectional area, the greater the drag force

- Base drag - type of aerodynamic resistance encountered by projectiles particularly at the rear or base of object.
- It occurs due to the disrupted airflow behind a projectile, affecting its trajectory & overall flight characteristics.

→ Characteristic of Base drag

① Shape Impact - Projectiles with non-aerodynamic or blunt bases disturb the airflow as they move through the air.

② Formation of wake - As the projectile advances, the air flow separates from the surfaces at the rear, forming a turbulent wake. / the wake leads to a low-pressure area behind the projectile.

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(3) Pressure differential- The low-pressure region behind the projectile creates a difference in pressure between the front & back. (this pressure difference generates a force that opposes the projectile's motion, contributing to base drag.

* Shape of projectile & stability

→ Shape of projectile is fundamental in determining its stability during flight in ballistics.

→ Stability refers to the ability of a projectile to maintain its intended orientation & trajectory, minimizing deviations caused by external forces like air resistance or wind.

• Factors linking Projectile shape to stability:

(1) Aerodynamics- (a) Streamlined design: Projectiles with sleek & aerodynamic shapes encounter less air resistance.

(b) Pointed or tapered tips: These shapes help in cutting through the air more efficiently, reducing drag & maintaining stability.

(2) Spin Stabilization: (a) Rotational Motion: Many projectiles, like bullets are designed to spin.

(b) Rifling in Barrels: Firearms use rifling in the barrel to impart spin to bullets, ensuring a stable flight path.

(3) Centre of Pressure & centre of gravity
- A well-designed shape balances the centre of pressure with the centre of gravity.

(4) Fins or Stabilizers
- Some projectile have fins, tail configurations or stabilizers. These elements manipulate airflow to counteract disruptive forces at the rear, enhancing stability & maintaining proper orientation.

* Ballistic Coefficient
→ It is usually represented by 'c' & indicates the ability of the projectile to overcome air resistance & its efficiency in flight.
→ The Sectional density is not only factor affecting the retardation (the degree of velocity loss due to the air) of a bullet, as a shape of the bullet also plays a very large part.
→ If form factor is taken in to consideration & sectional density is divided by it, the term so obtained is called ballistic coefficient.

Ballistic coefficient $(c) = w / i d^2$

c = Ballistic coefficient

w = Weight of bullet

i = Form factor

 Yaw

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d = diameter of bullet

→ Form factor is basically a measure of how streamlined a bullet

→ Thus, the bullet coefficient, the better will retain its velocity & lower the bullet drop for any given distance

* Different behaviour of bullets in flight -:

→ Different behaviour of bullets in flight.

- These behaviour are observed in terminal ballistic.
- Terminal ballistic is a part of ballistic where we observe motion of bullet from muzzle end to the target.
- Few example here in bullet behaviour in flight are
- Drag - It is the backward movement of firearms on firing bullet.
- The backward pressure changes the bullets directⁿ of flight
- Yaw - Here the bullet spin in greater number of time as compare to normal which changes its direction of flight.
- Swing type moment is observed
- Drift - Here the bullet changes the direction due to the pressure of wind.
- If the velocity of projectile is in right direction, but air pressure is in left directⁿ then bullet will move towards left (& vice versa)

* Effect of air resistance on trajectory

→ ~~Also~~ known as drag significantly affect the trajectory of projectile in ballistics.

- such as a bullet or a projectile, its trajectory is initially influenced by various factors, including the force applied & the angle of launch. However, as the object moves through the air, air resistance comes into play & alters its path.

* Drag force - When a projectile moves through the air, it encounters resistance known as drag. This force opposes the motion of the object & is influenced by its shape, speed & air density.

→ Trajectory alteration -
a) Deviation from ideal path - Use of air resistance, projectiles follow a parabolic trajectory.
b) Flattening of trajectory - Drag causes the trajectory to flatten out over distⁿ

→ Velocity reduction :-
- loss of speed
- Terminal velocity

→ Environmental factors
- air density & temp.

→ Range & accuracy :-
- Reduced range
- Accuracy issues

→ Computational models
- Ballistic calculation

→ Projectile design considerations
- Aerodynamics
- Stability enhancement