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Ballistics Study of Mortar Weapon Technology

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Abstract— Internal ballistic, external ballistic, and terminal ballistic studies on mortar weapons play an important role in improving the performance and effectiveness of these weapons in modern combat. This study involves an in-depth understanding of the behavior of the projectile from the moment it is fired until it reaches the target. This review utilizes a qualitative method using the Systematic Literature Review (SLR) approach which involves the identification, assessment and interpretation of all findings related to the topic of discussion from various relevant sources. This review aims to explore various aspects of mortar weapon ballistic performance, both internal ballistics, external ballistics and terminal ballistics as well as developments related to the latest mortar technology, such as precision guidance systems, automatic charging capabilities, use in combat vehicles, and others. The results of this study provide an understanding of the three aspects of ballistics to improve understanding of mortar weapon performance, improve accuracy, range and maximize effectiveness in various terrain conditions and combat situations that can provide tactical advantages for the troops who use them so as to make a reference for the development of mortars at this time.

Keywords—component; Mortar; Internal Ballistics; External Ballistics; Terminal Ballistics.

I. INTRODUCTION

Mortar weapons are a type of artillery weapon that plays an important role in modern military strategy. Mortars have been used for hundreds of years and are also found in the inventory of almost all state armed forces, as well as most non-state armed groups. Although they have been used since the World War I era, in fact, technological developments have helped maintain the existence of mortars as an element of infantry fire support that is quite reliable until now[1] (Utomo, S., 2019). They are relatively easy to operate and are often used in current and recent conflict zones. Mortars are key assets in support of infantry operations used to provide fire support to ground troops. Mortars have the ability to quickly shift and engage multiple targets simultaneously and through obscuration with great flexibility and the ability to engage targets at medium to long ranges. The optimal performance of a mortar weapon relies heavily on a deep understanding of its ballistic aspects.

In this context, ballistic studies on mortar weapons are the main focus in an effort to improve the effectiveness and accuracy of fire. An in-depth understanding of how mortar projectiles move in space and time, as well as the factors that affect their trajectory, is essential to optimize their use in the battlefield.

This study aims to explore various aspects in the ballistic performance of mortar weapons, such as internal ballistics, external ballistics and terminal ballistics. From the physical properties of the projectile to environmental influences such as wind and altitude, a thorough understanding of these factors will provide a solid foundation for further development in this field. The development of mortar weapons continues in line with technological advancements and the tactical needs of modern militaries, such as precision guidance systems, autoloading capabilities, use on combat vehicles, and others. As such, ballistic studies on

mortar weapons are not only relevant for theoretical understanding, but also have great practical implications in their use in the field of battle.

II. METHODOLOGY

This study uses a qualitative method using the Systematic Literature Review (SLR) approach. This approach involves the identification, assessment and interpretation of all findings related to the topic of discussion from various sources. Systematic review is a term used to refer to mixed research methodology because it uses a variety of sources, both qualitative and quantitative sources. It is developed to locate, collect and then evaluate research related to a specific topic focus. The stages of the SLR approach are broadly divided into three stages, namely: 1) Planning, in writing refers to the problem formulation described in the introduction, the data used in this research is secondary data which can be obtained through literature studies, books and related scientific articles; 2) Implementation, the application of the SLR method can help find sources. At the stage of searching for reference sources as a review of relevant literature, using both national and international scientific articles; 3). Reporting, the final stage in the SLR approach where analyzing the results of the reference articles that have been searched will be made in the form of writing which is then continued in the discussion of the literature review.

III. RESULTS AND DISCUSSION

A. Mortar

Mortar is one type of assistance weapon used by infantry units that can be used to shoot targets that cannot be seen by the eye directly or indirect fire. Indirect fire is a method of aiming and shooting without relying on directing the muzzle of the weapon directly at the target. The indirect fire method is used in field artillery, mortars, anti-tank cannons and anti-air cannons, such as targets behind hills / mountains. In general, mortars are fired at a large angle, so that the trajectory of the bullet forms a parabolic shape and uses a smooth / grooved barrel [2]. Most mortars have height limitations, and are only capable of firing at high angle trajectories (above 45°), which means they cannot be used as direct fire support (Jenzen-Jones, 2015). Mortars fall into three main groups: light mortars (51-60 mm); medium mortars (61-99 mm); and heavy mortars (100-120 mm+). Light mortars can be carried by a single soldier, and are found at company level of some infantry units, the inherent limitations of light mortars (short range and small explosive charge) can be minimized with careful planning and thorough knowledge of their capabilities. Medium mortars have been the most commonly used since World War II as they are more lethal than light mortars but they remain easy to carry for light infantry battalions and can fire at distances of 100 m to 5,500 m, whereas heavy mortars are gaining considerable popularity worldwide given the changing nature of operations. Many operators believe that heavy mortars have greater utility both in terms of lethality potential due to their higher explosive power and the ability to fire newer ammunition properties. Heavy mortars have a range of approximately 500 m to 7,000 m but require a truck or mortar carrier to move them (Gander & Hogg, 1993; Isby, 1988).

Mortars are smooth-barreled weapons (without grooves and galleries). Grenade loading is done from the mouth of the barrel using the drop system, i.e. the grenade is loaded directly into the mortar. When the grenade enters the mortar, the grenade digger will touch the striking pen, so that the grenade filling burns and pushes the grenade out of the barrel towards the target. In the implementation of 60 mm mortar firing at the target, it is always preceded by a review shot which aims to determine whether there is a deviation in direction and distance from the target. This deviation always occurs in every mortar shooting even though it uses the firing table data from the mortar [3]. Mortar weapons consist of several large parts, namely the barrel, base plate, bipod and aiming device which can be seen in Figure 1.

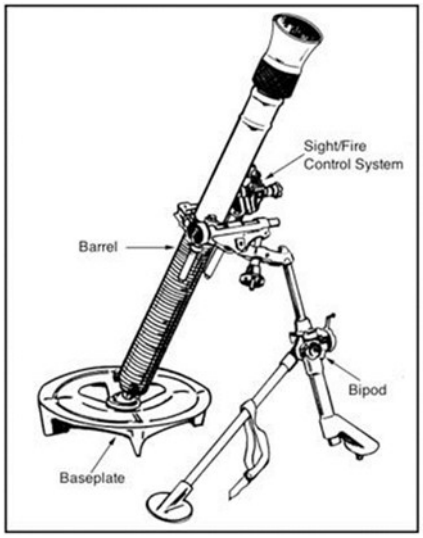

Fig. 1. Parts of a mortar (source: Wood, M. M. J.)

These parts have their own functions, for example, the barrel is the most important part of the weapon in the form of a straight tube usually made of rigid high-strength metal, where the rapid expansion of high-pressure gas is used to push the projectile out of the front end at high speed. The mortar's base plate stabilizes the system, and helps prevent the barrel from being driven into the ground by the recoil of the shot. The bipod serves to help stabilize the mortar, and acts as a simple sighting arrangement. There is generally a thread that allows the barrel to be moved left or right to adjust the azimuth, and a screw adjuster that allows the firing angle to be moved up or down, to adjust the range. Modern mortars typically range in caliber from 60 mm (2.36 in) to 120 mm (4.72 in). Modern mortars are muzzle-loading, relatively easy-to-operate weapons that consist of a barrel into which the shooter drops bullets. As the bullet reaches the bottom of the barrel, it strikes a fixed firing pin that fires the bullet. The barrel is generally set at an angle of between 45 and 85 degrees (800 to 1500 mils), with higher angles resulting in shorter horizontal trajectories. Some mortars have movable striking pens and can be operated by a lanyard or trigger mechanism. In modern warfare, mortars up to 81 mm can be carried by infantry troops and used in place of small-scale short-range artillery. Mortars have advantages in terms of portability due to their size, freedom of movement without the need for logistical support, and the ability to be fired from trenches or defilades (combat positions that protect the operator from direct return fire). Due to its high trajectory, mortar fire can be used against enemy positions such as trench lines, gun pits, and other locations not protected by overhead cover. Mortar projectiles often hit targets at very steep angles, making the mortar an ideal weapon to fire from, into, or out of defilade. Sometimes referred to as 'poor man's artillery', they are easy to build and operate, rugged, portable, cheap, and versatile, although generally less accurate than artillery (Dullum et al., 2016).

B. Ballistics

Ballistics is the science of the motion, properties, and effects of projectiles, especially bullets, gravity bombs, rockets, and others. Ballistics science is divided into several parts studying the peroyectil from being fired until it hits the target and the effect on the target. In this study, it is related to the acceleration of the projectile in the mortar barrel, the behavior of the projectile at the end of the mortar barrel and during the trajectory, and its effect on the target. Ballistics is separated into three branches, namely internal ballistics, external ballistics and terminal ballistics, which can be seen in Figure 2.

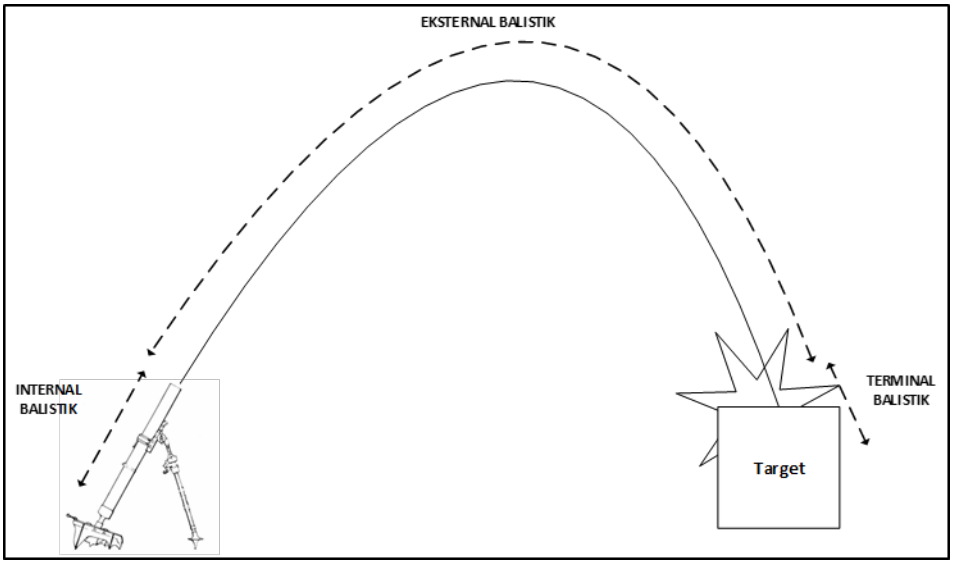

Fig. 2. Internal, External, and Terminal Mortar Ballistics. (source: Processed by the author)

C. Internal Ballistics

Internal ballistics is defined as the science that deals with the events that occur inside the barrel from the time the propellant charge is ignited until the projectile leaves the muzzle. Ballistic internals are also concerned with the factors that affect the rotary motion of the mortar before it leaves the muzzle of the barrel. The total effect of all ballistic internal factors determines the speed at which the projectile leaves the muzzle. This speed is called muzzle velocity and is expressed in meters per second (MPS)[4]. Gas pressure peaks quickly and subsides gradually once the projectile starts moving. The peak pressure, together with the travel of the projectile in the bore, determines the speed at which the projectile leaves the barrel. The factors that affect the speed of the mortar-ammunition combination are as follows:

1. An increase or decrease in the burning rate of the propellant can increase or decrease the gas pressure.
2. An increase in the size of the weapon chamber, without an increase in the amount of propellant, will decrease the gas pressure.
3. Gas escaping around the projectile inside the barrel lowers the pressure.
4. Increased bore resistance to projectile movement, prior to peak pressure, further increases pressure.
5. Increasing the resistance of the bore at any time has the effect of dragging the projectile and decreasing the velocity.

Temporary variations in bore resistance are caused by carbon buildup in the barrel.

The science of ballistic internals has been defined to evaluate the ignition and combustion process of the propellant, the pressure changes in the barrel, the onset of projectile motion inside the barrel, the friction between the projectile and the barrel, the dynamics of the projectile inside the bore, and the barrel dynamics (wave propagation, thermal expansion, etc.) during launch. The internal physical foundation of ballistics can be established based on gas laws that explain how the chemical energy of the propellant is converted into the kinetic energy of the projectile [5].

D. External Ballistics

External ballistics means the study of bullet behavior and influencing factors in free air after exiting the barrel mouth. The factors are; Muzzle Velocity; Departure Angle; Gravity; Air resistance; Projectile weight and shape; Projectile rotation; Earth rotation. In external ballistics, mainly gravity and air affect the movement of the projectile after it leaves the muzzle of the barrel. Gravity causes the projectile to fall due to air resistance. The shape of the front part of the mortar (nose cone) is the main end of the aerodynamic surface, this part which greatly affects the drag force of a mortar. Generally, the shape of the mortar tip is made in various forms, including long ellipses, short ellipses, cones, parabolics and others [6]. When projectiles are fired into the air, their paths differ because projectiles of different sizes and weights respond differently to the same atmospheric conditions. In addition, a given altitude and muzzle velocity can result in a wide variety of trajectories, depending on the combined properties of the

projectile and the atmosphere. The distance between the center of pressure (CP) and the center of gravity (CG) plays an important role in mortar stability. During mortar launch, the propellant burns to produce thrust. As the propellant mass is ejected as combustion products, the center of gravity moves from the initial location. But the center of pressure remains constant as there is no reduction in cross-sectional area. This makes the distance between CG and CP change and the stability changes [7]. The mass, shape, and drag coefficient of the projectile affect the trajectory path and accuracy of the shot. The initial velocity of the projectile provides the energy required to pass through the battlefield and reach the target. The firing angle affects the maximum range and accuracy rate of fire. First, changing the angle of the mortar barrel will affect how far the projectile can travel. A higher angle will result in a shorter distance, and a lower angle will have the opposite effect. In addition, many mortar projectiles can be fired with adjustable propellant loads. An increase in the amount of propellant will result in an increase in range. The maximum range of a mortar projectile is directly affected by the model of mortar used to fire it, as well as the amount of additional propellant charge. The length of the mortar barrel has the most significant influence on the range of the fired projectile, with longer barrels tending to allow for a longer range. Factors such as wind, temperature and altitude can affect the movement of the projectile and the accuracy of the shot.

E. Terminal Ballistics

Terminal ballistics covers the phase where the projectile reaches the target and interacts with it or is a branch of ballistics that studies the interaction between the projectile and the target material [8]. Terminal ballistic studies take into account factors such as the speed and angle of attack of the projectile, the type of warhead, and the effect of damage on the target. It helps in evaluating the effectiveness of mortar weapons in combat situations. Based on the law of conservation of energy, the total energy of the projectile is equal to the energy absorbed in the perforation and the residual kinetic energy of the projectile. The residual velocity of the projectile is used to find the energy absorbed in the perforation [9].

Mortars can provide effects on targets depending on the type of munition used. These effects are: destruction, neutralization, suppression, and obscuration [10].

1. Destruction, making enemy combat ineffective. Since only direct hits with High Explosive rounds can destroy hard targets, such as armored vehicles or bunkers, mortars are not often used against them to achieve destruction. Against soft targets, such as trucks or frame buildings, mortars can be used for destruction, but even then the amount of ammunition expended is large.
2. Neutralization, knocking the target out of action temporarily. Against hard targets, it is difficult to achieve neutralization with mortar fire. Against some targets it can be achieved, especially dismounted infantry or wheeled vehicles. Experience has shown that it takes about 10 percent casualties to neutralize a unit. A higher percentage may be required, depending on how experienced and strong the enemy is. Neutralization usually lasts no more than a few hours
3. Suppression, limiting or preventing enemies in the target area from firing back or performing other combat tasks. The effects of suppressive fires are immediate, but they only last as long as the fire continues. The key to a successful infantry attack is to apply suppressive fire correctly. The mortar platoon's high rate of fire and organizational response make it an excellent suppressor. Suppressive fire plays a huge role in generating combat power by infantry troops. Suppressive mortar fire, along with other weapons, allows infantry to close in range for the final assault. Effective suppressive fire increases infantry mobility. The more effective suppressive fire is, the less infantry troops rely on stealth, cover and concealment. Mortar fire can continue to suppress the enemy until the attacking troops are close enough to use their hand-carried weapons for suppression. Suppressive fire carries the attack for the last 200 meters and into the enemy's defensive positions. At that point, the enemy chooses to stop resistance by surrendering or retreating, or he is killed or wounded.
4. Obscuration interferes with the enemy's ability to observe the actions of friendly forces or prevent them altogether. Obscuration fire does not neutralize or suppress the enemy, as he can still use his weapons, but it reduces the effectiveness of enemy fire. Mortars can fire WP rounds that explode directly at enemy positions to suppress and obscure, or they can fire WP rounds or smoke to obscure observation. Mortar obscuration is effective for direct response missions with limited scope and for a short time. Smoke munitions are used during rapid advances to increase obstacles created by debris generated from previous fires. They reduce the enemy's ability to acquire targets or react to force movements.

F. Development of Mortar Weapon Technology

The most revolutionary development in mortar systems is the introduction of precision guidance systems. Guided mortar systems claim to enable precise targeting and increase the likelihood of a first-round hit. The claim of many militaries is that they greatly reduce the potential for collateral damage and reduce the logistical burden. Modern mortars may also utilize a fire control system (FCS) to help improve accuracy, set-up time, and accelerate rate of fire (Jenzen-Jones, 2015). Modern guided mortars can be relatively accurate. The 81-mm and 120mm Roll Controlled Guided Mortar (RCGM) has a circular probability of error (CEP-the radius of a circle in which half of all fired weapons are expected to fall or explode) of less than 10 meters. But these mortars are not the mortars that most armaments have. And accuracy means little in preventing civilian harm if such weapons are used in densely populated areas.

AMOS (Advanced Mortar System) represents the latest technology in turret systems. The system is capable of operating autonomously with impressive firepower, including direct and indirect fire capabilities along with Multiple Rounds Simultaneous Impact (MRSI), up to a range of 10 km [11]. The AMOS turret consists of a double-barreled 120 mm mortar with automatic ammunition handling and an electronic target engagement/firing system. AMOS is designed to have the flexibility to be integrated into various wheeled platforms as well as on fast combat ships which can be seen in Figure 3.

Fig. 3. AMOS on a combat vehicle (source: BAE systems)

AMOS is equipped with an automatic mechanism for loading bullets, enabling a high rate of fire without significant manual intervention, also equipped with the MRSI (Multiple Rounds Simultaneous Impact) moode which allows the firing of multiple bullets with different trajectories so that they arrive at the target at the same time giving maximum surprise effect. The development of vehicle-mounted launch platforms also provides high mobility and the ability to fire from multiple locations.

In addition, mortar developments were also seen by the manufacturer Rheinmetall, namely the 120 mm Ragnarok mortar, and the trail ragnarok which can be seen in Figure 4. The ragnarok mortar where a fully motorized weapon system with a weapon elevation angle of 0 -1.530mils (vehicle delayed) on a relative mounting surface designed to be as compact as possible to allow integration also in smaller spaces. Manual loading of the loader platform ensures an uncomplicated system with few moving mechanical parts. The fully automatic aiming system is supported by the highly intuitive Vingpos software, featuring a precise graphical aiming dialog.

Fig. 4. Ragnarok Mortar and Trail (source: European Security & Defense)

Mortars are a key asset in support of infantry operations. Mortars have the ability to quickly shift and fire at multiple targets simultaneously and through obscuration[13].The Ragnarok trailer can be easily attached to any vehicle equipped with a suitable trailer coupling and towed to the respective firing position. Once in the firing position, the vehicle is parked roughly opposite to the direction of fire and the loading platform is lowered to the ground. This is done hydraulically, but can also be done manually in emergency mode in a process that takes only a few seconds. A weapon system that is towed rather than carried by the vehicle offers the possibility to concentrate a complete mortar squad, which usually consists of four soldiers, along with equipment and ammunition on a single vehicle. In addition, the ragnarok trailer offers the advantage that it can be towed by almost any vehicle. For example, if a high level of protection is required, the vehicle can be attached to a 4×4, 6×6, or 8×8 armored vehicle. The development of domestic mortars was also carried out by PT Hariff Daya Tunggal Engineering, which made a computer-based mortar firing system on 81 mm caliber mortars that makes it easier for mortar shooters to determine the coordinates and distance of the target so that it is faster and more accurate.

IV. CONCLUSION

This study provides an understanding of mortar weapon ballistics, which includes three main aspects: internal ballistics, external ballistics and terminal ballistics. These three aspects of ballistics are essential to improve the user's understanding of the overall performance of mortar weapons, as well as to improve their accuracy, range and effectiveness in different terrain conditions and combat situations. A better and detailed understanding of mortar weapon ballistics can provide a significant tactical advantage to the forces using them. Internal ballistics focuses on the processes that occur inside a mortar weapon from the time the munition is fired until it leaves the barrel, including the chemical reactions of combustion, the pressure and temperature inside the barrel, and the barrel design that affects the initial velocity of the bullet. External ballistics includes the study of the behavior of the munition after it leaves the barrel until it reaches the target, including the trajectory of the bullet, the influence of wind, rotation and stability, and weather conditions that affect the shot. Meanwhile, terminal ballistics deals with the behavior of the bullet as it reaches and hits the target, including impact effects, penetration of target material, fragmentation, and the effectiveness of different types of warheads.

In addition, this study can also enrich the technical and theoretical knowledge of mortar weapon ballistics and be used as a solid foundation for the development of more advanced and effective mortar weapons in support of military operations on the battlefield. The development of mortar weapon technology provides significant benefits, including improved accuracy, operational efficiency, tactical advantage, and increased safety for troops. By continuing to utilize advanced materials and modern technologies, future mortar weapons are expected to make greater contributions to military mission success and adaptability in various combat situations. Through in-depth understanding and practical application of these ballistic concepts, significant improvements in the performance and effectiveness of mortar weapons in various combat situations are expected.

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