Determination of the Speed of Sound to Calculate Distances Through Firing a Rifle at 22°C at the Sea Level

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Abstract. The purpose of this research is to analyze the speed of sound variations based on firing a rifle at a distance of 1240 meters at 22 ° C at the sea level in the province of Santa Elena, Ecuador. This is a non-experimental cross-sectional study based on the data collected from 45 students, in addition, it has a descriptive design, and the measurements were taken using a chronometer during the 8 attempts each participant had. The main focus was the variation of time from the sparks ignition until the sound produced by the gunpowder explosion during each attempt. Instruments to establish meteorological conditions were used in order to measure wind time, distance, temperature, speed and direction. The data analysis was aimed at determining the individual and general median time of shooting flight, having as a result 351,27 m/s. This value is close to the 350 m/s presented by Galileo Galilei and it remarkably differs from the 372 m/s claimed by Donoso (2013) or the 330 m/s stated by the Military Education and Doctrine Command (2018). This research also aims at contributing to the military field to calculate distances which allow the determination of the enemy´s position or the location of a missing combatant through firing a rifle. Since precision is a key factor in military operations, this investigation may be considered to design a battling field simulator in which distances and direction are calculated through a gun shot.

Keywords: speed of sound, rifle, calculate distances, simulador, tools

1 Introduction

The military training process requires not only academic or physical preparation but also a solid commitment to serve the country which includes an adequate aptitude as a combatant. For these reasons, it is imperative that future officers know how to apply practical methods that involve simple calculations to determine distances and directions using all the instruments available. One example of military tools are rifles, these are part of shooting practices as well as real situation drillings against an adversary.

The FAL rifle is a Belgian battle weapon, it is chambered for the 7.62×51mm NATO cartridge. The word FAL comes from the French acronym "Fusil Automatique Léger" which is translated in English as Light Automatic Rifle [1]. It is illustrated in Fig. 1, and it is used during the military training at the Air Force Academy.

Fig. 1. FAL Rifle used during military training

According to the Military Education and Doctrine Command of Ecuador [2], to appreciate a distance means to be able to calculate it with the lowest possibility of a mistake from the observer to the target or between two points on the ground, which means that weapons could be used to measure indirectly the distance between two points on the ground. A military officer must be able to know how to optimize resources, especially because of transportation issues, that is why distances can be determined through devices or by plain sight [2].

Taking into consideration the wide range of natural phenomena that may occur, Aristotle stated that the propagation of sound in the air is generated by a source, a vibrating body, whose movement disturbs the air causing its spread [3]. The trajectory of this movement can only be considered through the geometric distance commonly known as slope, which is the distance between two points measured as a straight line [4]. It is considered as a reference for sound spread, Aristotle produced sounds that under some conditions generated scattered sounds creating an echo, this is considered as the reflection of sound, and for this reason horizontal and vertical distances are discarded, as it is illustrated in Fig. 2 [3].

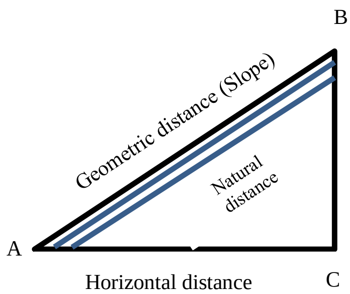

Fig. 2. Types of distance

The interval measure of geometric distance is calculated based on the flight system, taking into consideration the time between the transmission and the reception of the echo [5]. This means that time continues during the emission of short pulses train of ultrasonic waves and their reception after been reflected by some object which is around [6]. According to the Military Education and Doctrine Command of Ecuador (2018), distances are classified as: proximate (100 mts), short (400 mts), median (800 mts) and long (more than 800 mts) and their calculation is a fundamental fact to optimize weapon transportation during combat.

There have been several attempts to calculate distances, Galileo Galilei measured the speed of sound in the air through a simple and precise form with the help of a colleague, who was an Artillery Captain. They fired a cannon (loaded with gunpowder) and placed themselves at a distance of 3500 meters away on a nearby mount, they used a “pulsilogium”, an invent of Galileo to measure time by counting the oscillations of a small pendulum [3].

After firing the cannon, Galileo saw the gunpowder blaze and counted the oscillations up to ten, until he heard the shot sound and stated that 350 m/s was the speed of sound in the air [7], nevertheless, further research in the same field have determined that the speed of sound is 372 m/s [8]. It can also be confirmed that the sound travels through the air at a speed of 330 m/s, this enables the distance calculation if you can see and hear the action [2].

Another practical method to calculate the speed of sound, is to determine the time from the moment the sparks caused by the shot ignite until the hearing the sound produced by the explosive expansion of gas. The number of seconds which are counted could be considered as the distance in hundreds of meters. For instance, if it stops to the count of three, the possible distance is 300 meters [2]. It is important to mention that the acoustic waves that come from a whisper or from a scream travel at the same speed and it is called the “*a*” (acoustic) speed of sound. It depends on the air temperature, yet its propagation is from about 340 m/s under ordinary circumstances [9].

Navarro, Rios & Parra [5], stated that the speed of sound in the air at 0° centigrade is 331 m/s, therefore, the approximate speed in an environment which is at 20° centigrade is 343 m/s. This value is similar to the reference value which is 343 m/s in dry air at 20° centigrade. The state of art of this research takes into consideration the existence of shooting range simulators, yet there was none related to the calculation and determination of sound speed through firing a rifle.

2 Methodology and procedures

This is a non-experimental cross-sectional research, the data were collected once, and the participants were 45 students and an expert rifle shooter. The objective of the experiment was to measure the time from the sparks ignition until the sound produced by the gunpowder explosion during each shot to calculate distances. This study took place in the province of Santa Elena, in the city of Salinas, at the Military Aviation School which is located in the parish of Chipipe. It was used a FAL rifle, which was chambered for the 7.62×51mm NATO cartridge, each student had 8 attempts at a temperature of 22° C at 7:30 in the evening, as it is illustrated in Fig. 3.

Fig. 3. Each student had 8 attempts.

The speed of light (c) is faster in a vacuum which is equivalent to:

$$c = 2.998 \times 10^{8} \text{ m/s} \tag{1}$$

The sparks ignition is immediate and it can be seen by the human eye, it represents the reference to start timing using the chronometer, it stops once the gunpowder explosion is heard. The distance is determined in exact coordinates using a topographic map and a GPS which measured 1240 mts; there were collected eight samples per student and, as result, it was gathered 357 measurements and only 3 shots were dismissed. It is important to mention that the speed of sound is independent from the pressure, the frequency and the length of the waves [10], that is why these factors did not interfere with this research.

The measuring instruments used for this study were: topographical map, chronometers (CASIO), GPS (GARMIN Etrex), meteorological measuring equipment (VAISALA), which are illustrated in Fig. 4, Fig. 5, Fig. 6 and Fig. 7.

Fig. 4. Topographic Map, which is used to measure distances through scales.

Fig. 5. GPS, it was used to measure distances.

Fig. 6. Instrument applied to determine meteorological conditions, in this case, the temperature.

Fig. 7. A Casio chronometer

3 Results and discussion

The objective of the experiment was to measure the time from the sparks ignition until the sound produced by the gunpowder explosion during each shot to calculate distances. The results gathered after measuring all the shots are listed in table 1.

Table 1. Results collected

The speed of sound at 1240 meters									
Participants	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Median**
Student 1	3,87	3,74	3,66	3,70	3,56	3,55	3,60	3,53	**3,63**
Student 2	3,50	3,56	3,51	3,50	3,49	3,42	3,50	3,48	**3,50**
Student 3	3,67	3,71	3,66	3,47	3,51	3,57	3,41	3,59	**3,58**
Student 4	3,84	3,59	3,61	3,57	3,39	3,45	3,34	3,40	**3,51**
Student 5	3,83	3,64	3,66	3,50	3,46	3,39	3,41	3,50	**3,50**
Student 6	3,74	3,71	3,60	3,56	3,48	3,44	3,56	3,45	**3,56**
Student 7	3,80	3,82	3,64	3,44	3,50	3,49	3,41	3,54	**3,52**
Student 8	3,84	3,85	3,55	3,49	3,45	3,51	3,39	3,44	**3,50**
Student 9	3,80	3,73	3,68	3,64	3,70	3,65	3,72	3,70	**3,70**
Student 10	3,85	3,78	3,66	3,44	3,47	3,58	3,41	3,39	**3,53**
Student 11	3,62	3,43	3,64	3,58	3,62	3,20	3,50	3,57	**3,58**
Student 12	3,58	3,51	3,56	3,57	3,56	3,58	3,53	3,55	**3,56**
Student 13	3,85	3,85	3,69	3,47	3,40	3,44	3,40	3,47	**3,47**
Student 14	3,79	3,71	3,66	3,49	3,56	3,56	3,52	3,50	**3,56**
Student 15	3,73	3,58	3,63	3,54	3,45	3,54	3,46	3,53	**3,54**
Student 16	3,81	3,57	3,61	3,49	3,59	3,56	3,59	3,58	**3,59**
Student 17	3,78	3,68	3,60	3,62	3,55	3,57	3,57	3,54	**3,59**
Student 18	3,57	3,79	3,53	3,63	3,53	3,32	3,42	3,60	**3,55**
Student 19	3,40	3,55	3,60	3,50	3,60	3,38	3,44	3,50	**3,50**
Student 20	3,76	3,65	3,71	3,53	3,82	3,47	3,42	3,51	**3,59**
Student 21	3,65	3,65	3,65	3,65	3,60	3,66	3,70	3,72	**3,65**
Student 22	3,63	3,55	3,71	3,52	3,64	3,58	3,52	3,49	**3,57**
Student 23	4,00	3,80	3,61	3,40	3,37	3,20	3,50	3,40	**3,45**
Student 24	3,52	3,60	3,45	3,44	3,50	3,54	3,49	3,51	**3,51**
Student 25	3,61	3,54	3,44	NA	3,59	3,39	3,60	3,40	**3,54**
Student 26	3,80	3,70	3,76	3,50	3,56	3,46	3,41	3,40	**3,53**
Student 27	3,74	3,63	3,67	3,50	3,46	3,41	3,45	3,53	**3,52**
Student 28	3,53	3,53	3,55	3,51	3,57	3,50	3,53	3,58	**3,53**
Student 29	3,64	3,78	3,58	3,50	3,50	3,48	3,70	3,45	**3,54**
Student 30	3,47	3,43	3,47	3,53	3,55	3,53	3,47	3,58	**3,50**
Student 31	3,80	3,60	3,53	3,55	3,55	3,60	3,50	3,54	**3,55**
Student 32	3,65	3,63	3,59	3,47	3,47	3,54	3,55	3,50	**3,55**

Student 33	3,57	3,56	3,64	3,65	3,49	3,40	3,45	3,40	**3,53**
Student 34	NA	3,79	3,52	3,51	3,58	3,53	3,51	3,69	**3,53**
Student 35	3,61	3,66	3,60	3,47	3,51	3,50	3,52	3,62	**3,56**
Student 36	3,75	3,59	3,50	3,46	3,37	3,37	3,35	3,50	**3,48**
Student 37	3,90	3,81	3,82	3,54	3,42	3,63	3,45	3,42	**3,59**
Student 38	3,75	3,54	3,58	3,52	3,43	3,42	3,62	3,29	**3,53**
Student 39	3,73	3,43	3,50	3,56	3,59	3,59	3,53	3,48	**3,55**
Student 40	3,43	3,44	3,52	3,67	3,60	3,41	3,50	3,50	**3,50**
Student 41	3,64	3,65	3,64	3,54	3,63	3,64	3,64	3,64	**3,64**
Student 42	3,44	3,53	3,46	3,54	3,52	3,40	3,41	3,51	**3,49**
Student 43	3,75	3,67	3,60	3,40	3,56	3,43	3,41	3,48	**3,52**
Student 44	3,56	3,53	3,44	3,64	3,47	3,50	3,44	3,56	**3,52**
Student 45	NA	3,79	3,65	3,46	3,39	3,39	3,47	3,58	**3,47**
Final result									**3,53**

The time in seconds of the speed of sound in the air at 1240 meters was determined through the calculation of the individual median based on the eight attempts that each student had, afterwards, it was established the group average having as a result 3,53 seconds. The formula for the calculation of the average speed was taken from the time and total distance. According to Bueche & Hecht [11] *Vprom* is a measure that indicates how fast an object travels in space and it is also a scalar value quantity, for instance, the speed of an object that takes the time *t* to travel a distance *l* is obtained by the formula:

$$v\ prom = \frac{l}{t}. \tag{2}$$

Once the formula was completed with the research values, *l:* 1240 mts and *t:* 3,53 sec, the result was:

$$v\ prom = \frac{1240\ mts.}{3{,}53\ seg.} \tag{3}$$

This allowed the researchers to establish that the speed of sound at 22° C was 351,27 m/s.

In the case of the studies of Donoso [8], Sancho [7], Settles [9] and the Military Education and Doctrine Command of Ecuador [2], the calculation of the speed of sound was: 372 m/s, 350 m/s, 340 m/s and 330 m/s respectively. Nevertheless, it is important to mention that these investigations do not specify the temperature in which the shots took place. On the other hand, it was determined by Ríos, & Parra [5] and Cros & Ferrer-Roca [12] that the speed of sound in the air at 0° C is 331 m/s, therefore, within an environment which is at 20° C, it is 343 m/s. Bueche & Hecht [10], also described that the speed of sound a 0° C is 331 m/s, and that it increases along with the temperature in approximately 0.61 m/s per centigrade. Based on the data of the last two studies and according to the meteorological conditions of this research (22°C), it is added 1,22 m/s, having as a result 344,22 m/s. All the information related to these studies is explained in Fig. 8.

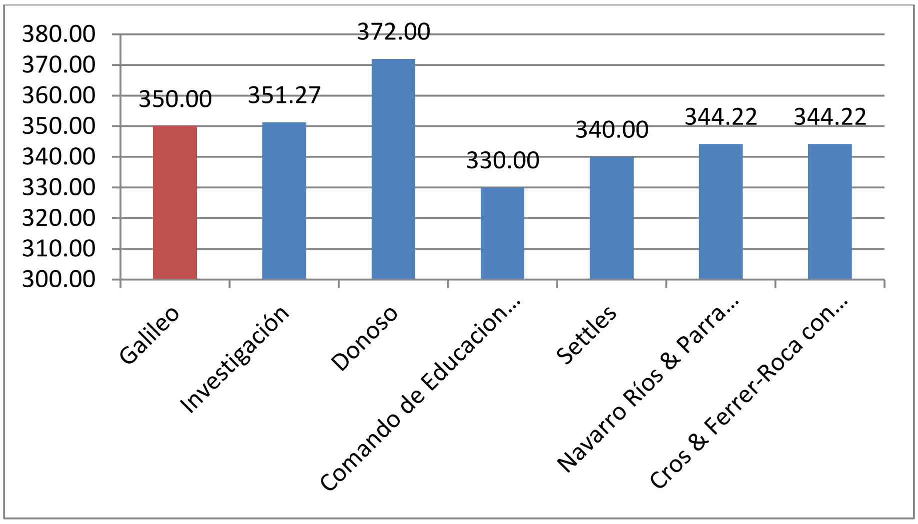

Fig. 8. Studies related to the speed of sound

4 Conclusion

During this research, the speed of sound was determined by firing a rifle at 22° C at the sea level, from a distance of 1240 meters and taking into consideration the 3,52 seconds from the sparks ignition to the sound caused by the gunpowder explosion, the result was 351 m/s. The studies conducted by Sancho (2014) and Galileo Galilei did not include the temperature when determining the speed of sound, however, it could be said that both experiments took place approximately at a temperature of 20° C based on the results of the current research.

The Military Education and Doctrine Command of Ecuador [2] stated that the speed of sound travels at 330 m/s, yet Navarro, Ríos, & Parra [5], Bueche & Hecht [10] and Cros & Ferrer-Roca [12] described in their studies, that this speed may occur at a temperature below 0° C. Likewise, after firing a rifle the distance could be determined by counting the seconds until the gunshot is heard by considering each second as 100 meters, this means that if the count stops after 3 to 8 seconds, the approximate distance is 300 or 800 meters.

Donoso [8] determined in his field studies that the median speed of sound in Chile is 372 m/s. After comparing the data presented in his research with the constant of 0.61

m/s per centigrade proposed by Bueche & Hecht [10], and in relation with the temperature in which this research took place, it could be said that Donoso´s investigation was at 68° C, therefore, this relation is discarded. On the other hand, Settles [9] claimed that the speed of sound of acoustic waves that come from a whisper or a scream travels at the same speed depending on the air temperature. Accordingly to the data provided by Bueche & Hecht [11], it could be defined that the approximate temperature in this experimentation was 15° C.

The speed of sound determined in this research was 351,27 m/s which differs from in some of the studies previously cited. However, it is convenient to consider the value obtained under this specific meteorological condition (22° C at the sea level), especially in the military field, since precision is a determining factor in all operations. By applying this procedure to calculate distance by using a rifle, it would be easier to intercept enemy forces or locate a missing combatant. Finally, this research could be taken as part of the basis to create simulators for virtual battling fields, in which users may be able to calculate distances by using a firearm.

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