

Handgun Accuracy Problem

Problem Presenter

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Problem Statement

A laboratory test, aimed to check the compliance of the model with demand, indicates that consecutive fires of about 10 centers around a circular region with a radius of 10cm. The fact that the fires, though performed at the same conditions, do not target at the same point is called focusing uncertainty of the handgun. Furthermore, it is observed, by myself also, that bullet velocity measured 10 meters from gun varies up to about 7m/s(around 340m/s) among the firing set of 10. There are about ten different models and each model seems to display a different magnitude of uncertainty and velocity deviation from the expected average. The company, being willing to produce more data at request, asks to see if the focusing uncertainty and variation in bullet velocities can some how be corelated. And with some help from other disciplines, the fact behind such uncertainties..? Experiment apparatus or manufacturing process. If latter, which manufacturing unit contributes more?

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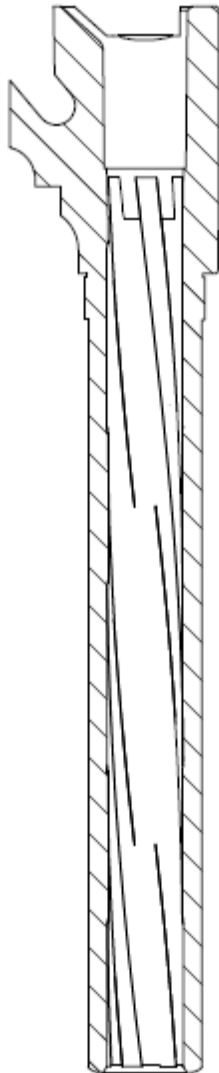
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The problem statement submitted read as follows

1.A handgun problem

A handgun manufacturer located in Trabzon aims to meet demands of people of Blacksea and abroad with a variety of models such as Kanuni, named after Kanuni Sultan Süleyman or better known Suleyman the Magnificent who was born in Trabzon, and Zigana, named after high mountains nearby Trabzon. The company would like to optimize its



production reinvestigating the models at hand: a statistical and a modelling approach seems to be needed for their request initially.

A laboratory test, aimed to check the compliance of the model with demand, indicates that consecutive fires of about 10 centers around a circular region with a radius of 10cm. The fact that the fires, though performed at the same conditions, do not target at the same point is called focusing uncertainty of the handgun. Furthermore, it is observed, by myself also, that bullet velocity measured 10 meters from gun varies up to about 7m/s(around 340m/s) among the firing set of 10. There are about ten different models and each model seems to display a different magnitude of uncertainty and velocity deviation from the expected average. The company, being willing to produce more data at request, asks to see if the focusing uncertainty and variation in bullet velocities can some how be correlated. And with some help from other disciplines, the fact behind such uncertainties...? Experiment apparatus or manufacturing process. If latter, which manufacturing unit contributes more?

2. Introduction

The problem described by the manufacturer's presenter concerned the accuracy of the standard handgun. This accuracy was measured in the company's firing range, which was visited twice by workshop participants. The gun is held in a vice, ten bullets are fired in a test, each bullet being manually placed in the chamber and the hole it makes in a paper target 25 meters away marked by an operative. The bullet's speed 3 meters from the muzzle is also measured. Bullet holes on the paper target can be up to 15cm apart (with no preferred axis) and the speed can vary by 18 m/sec. (Example: 355 +_ 9 m/sec.)

Comparison of a number of 10-shot tests did not suggest any particular trends, or correlations, between speed variations and angle dispersion. (See Figure 2.) The only noticeable feature was that the first shot fired tended to be on the outside region of the ten on the target paper. The workshop problem was to identify possible mechanisms that give rise to the dispersion of speed and angle and to model those mechanisms so that corrective design changes could be implemented.

In the following sections we provide the specifications of the gun that was used in the test firings and that was analyzed. Then we list the various mechanisms involved in firing the bullet, their likelihood of causing dispersion both in speed and angle of bullet trajectory, and suggestions for tests that could narrow the choice of causes.

3. Gun Specification

The standard handgun has the following technical specifications: 9×19 mm. caliber, simple recoil system, semi-automatic, magazine Capacity:15/18/20, triggering system: double action, total pistol weight (Empty Magazine):942 gr. (± 10 gr.), operating temperature:-35 °C / +60 °C, barrel rifling: right hand twist, 6 lands and grooves, length of twist:250 mm. The gun is shown in Figure 1.



Figure 1. The standard handgun. 9×19 mm calibre

Rifling refers to the helical grooves on the interior surface of the barrel. As the bullet is forced into the barrel by the high pressure created by the gunpowder explosion, the soft metal on the outer surface of the bullet is forced to conform to the cross-sectional shape of the barrel. The helical rotation of this shape on the inside of the barrel then causes the bullet to spin, and in its trajectory in free flight the spin improves its aerodynamic stability.

The internet provides numerous references to rifling, e.g. <http://en.wikipedia.org/wiki/Rifling>. Some rifling patterns are shown in Figures 9 and 10. There was no time during the workshop for the helical motion of the bullet inside the barrel to be considered.

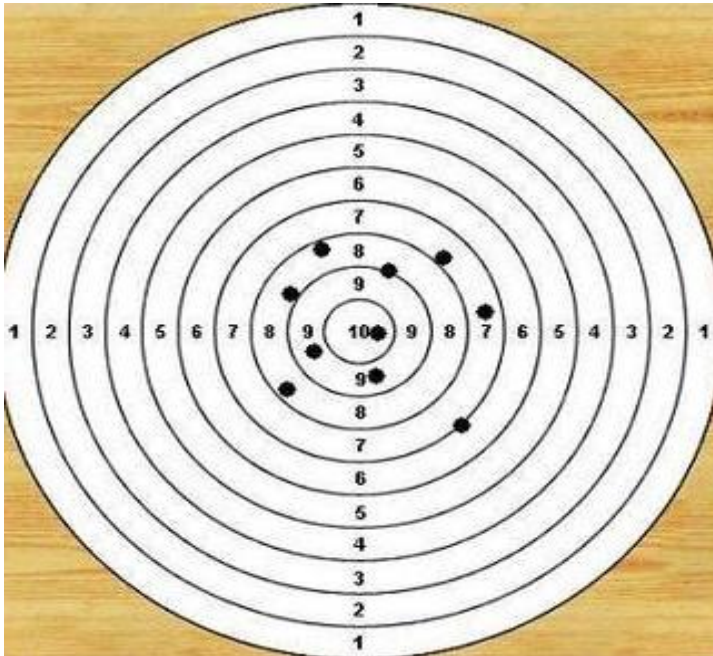


Figure 2. An example paper shot ten times successively.

4. Problem Approach

On the afternoon of the first day interested participants became acquainted with the gun's components and mechanisms (few of us had any experience in these.) The components of the handgun are shown in Figure 3 and the bullet/cartridge in Figure 4.

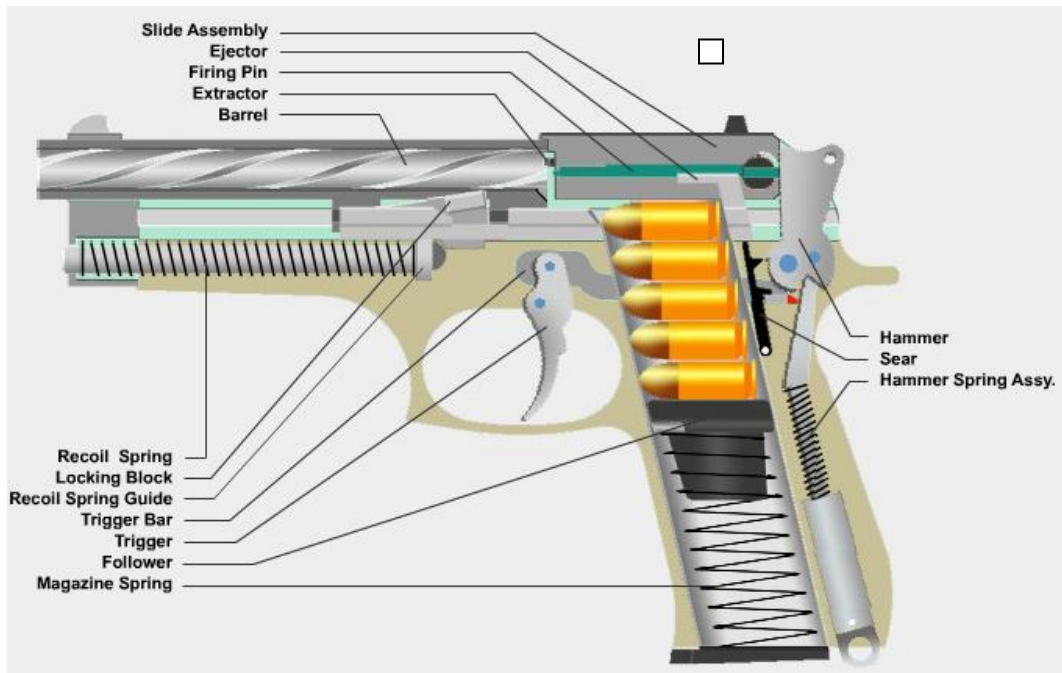
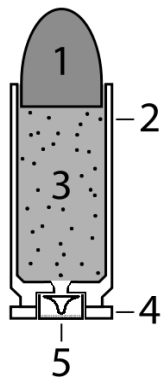


Figure 3. Primary components of the standard handgun



- A modern [cartridge](#) consists of the following:
1. the bullet itself, which serves as the [projectile](#);
 2. the [case](#), which holds all parts together;
 3. the propellant, for example [gunpowder](#) or [cordite](#);
 4. the [rim](#), part of the casing used for loading;
 5. the [primer](#), which ignites the propellant.

Figure 4. A modern [cartridge](#)

Activating the trigger allows the hammer to hit the primer which then ignites the gunpowder, causing an explosion and a large rise in pressure which forces the bullet down the barrel. The cartridge, being of large diameter than the barrel interior, remains in the firing chamber to be ejected subsequently. The bullet accelerates down the barrel and leaves the muzzle followed by the hot explosion gases. A new bullet may be inserted manually into the chamber; if there is a magazine clip, housed in the gun handle, each bullet in the clip is pushed into the chamber by force of a spring. The momentum of the bullet imposes a force in the opposite direction on the gun. This is partially absorbed by the recoil spring, to be released later as the assembly returns to its former state.

For the test firings, no bullet clip is inserted into the handle. The gun is held in a large, heavy, cast-iron vice, whose shaft fits through the handle. The faces of the vice clamp the gun on its handle just below the barrel/recoil spring assembly. On firing the vice slides slowly backwards on rails, approximately 2 cm., reacting to the recoil. The vice/ rail assembly is very stable and secure, with no visible vibration at a firing.

During the initial introduction to the mechanics involved in the firing of a bullet, and subsequently, a number of possible causes for angle and speed scatter were suggested. The primary ones that were discussed are listed below:

1. Differential heating (in space and time) of the gun barrel caused by the heat of explosion from each of the ten firings.
2. Recoil spring motion.
3. Interaction between the firing explosion and the motion of the vice.
4. Motion of the barrel assembly during firing.
5. Variability of bullets. The gun manufacturer is supplied with bullets by an outside manufacturer and there did not seem to be any data on their variability. (The latter is restricted in some manner by Turkish government regulations.) Variability in gun powder quality and in the amount inserted in each cartridge is clearly a possible cause of speed scatter, as is variability in manufacture of the bullet casing causing weight changes or distribution. The workshop had no resources to assess these and these aspects are left to the gun manufacturer to research. The other four possible causes above are now analyzed.

5. Analysis

5.1 Heating

This effect was discounted during the first visit to the firing range. Neither the ejected cartridge nor the gun barrel registered any substantial change in temperature after a firing, nor after ten firings. A fired cartridge was slightly warm to the touch. We had anticipated quantifying the amount of heat generated during a firing. This is possible from general information regarding the physics of firearms (see http://en.wikipedia.org/wiki/Physics_of_firearms#Firearm_energy_efficiency) that provides an energy distribution into approximately equal parts between bullet motion, temperature rise in the barrel and bullet, and heat content in the exhaust gases. Since we can deduce the bullet energy, the other two can be estimated. Temperature effects were not pursued subsequently.

5.2 Recoil spring motion

No exhaustive analysis was attempted for this effect. However, in order to give some partial information on the effects of the recoil spring (a mechanism to bring the barrel back to its rest position) on speed and angle control, we tried two different recoil springs in a standard handgun, that are called soft and hard springs. For tests consisting of two successive firing sets of 10, the diameters of bullet holes on the target sheets were 9.5cm and 9cm, respectively, not indicative of any major change different from the scatter on other tests. The recoil spring developed for a superior design and functionality called a "frame saver dual action recoil buffer spring system" is shown in Figure 5. It has several advantages such as preserving the structures of the handgun from the slide impacting the frame at high speed, gaining more control after the shot, better stability of the barrel and so on.

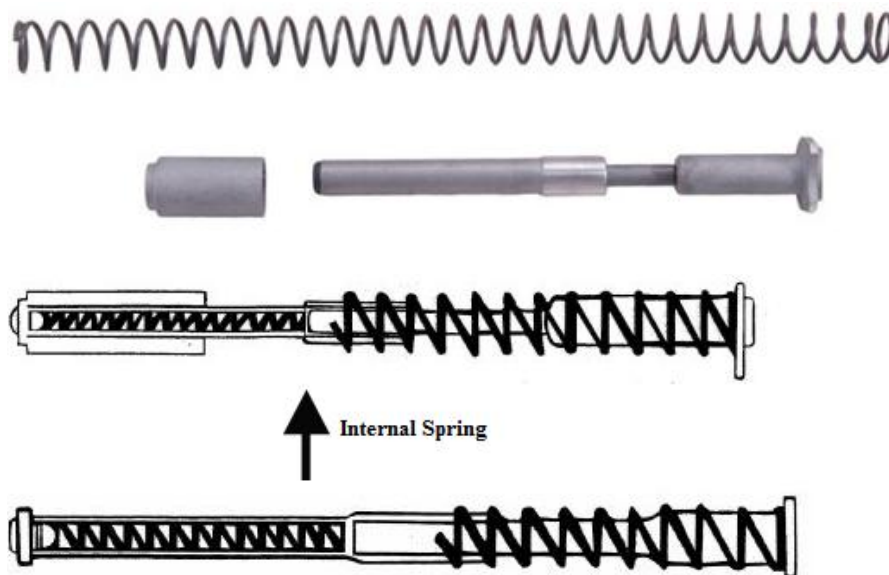


Figure 5. A frame saver dual action recoil buffer spring system and its structure.

5.3 Vice motion.

It was conjectured that the explosion could give rise to a vibration of the vice that in turn would cause movement in the gun position thereby affecting the bullet trajectory. This was discounted as a result of the **sugar cube experiments**, now described.



Figure 7. Sugar cube test, before, during and after firing:

Sugar Cube Experiments. In order to take into consideration the movement of the handgun and vice generated by the explosion during the firing, we placed sugar cubes at various positions on the barrel and vice, watched their motions and took video recordings. The sugar cubes, available in restaurants, were light and were wrapped in a waxy paper so that there was little friction between the cube and the surface on which it is placed. In Figure 7 some frames from the videos illustrate placement of the cubes and their subsequent motion during firing. There was upwards movement of the sugar cubes placed on the barrel, about 10 cm. into the air for a cube placed near the muzzle, half that for a cube placed mid-way from muzzle to chamber. The video frames in Figure 7 show that the movement of the cube takes place after bullet has left the barrel and that cubes placed on the vice do not move.

The sugar cube experiments for cubes placed at various locations on the barrel and vice showed no motion at all of those placed on the vice even though the cubes on the gun barrel exhibited a substantial jump. The vice has a slow rear-wards recoil motion which had no effect on the cubes. As a consequence of this it was decided that the vice played no role in the bullet trajectory scatter.

5.4 Barrel assembly motion during firing

The sugar cube experiment indicates that the explosion causes a reaction in the barrel assembly and this results in an impulsive moment to the assembly. Possible causes are now discussed.

(a) The gun powder explosion causes elastic wave motions in the gun material: here the discussion will be restricted to the barrel assembly. Longitudinal, transverse (shear), surface and toroidal waves are all possible. In steel, the wave speeds of the first three of these are 5,900, 2,300, 2,100 m/sec, respectively. (Toroidal wave speeds depend on the cross-sectional shape of the barrel, and since the cross-section is not a simple structure, this will not be considered.) The bullet speed at the muzzle is approximately 350 m/sec, and since the acceleration to this speed has been from rest, the average speed along the barrel is less than this. (If the bullet mechanics down the barrel are approximated by a constant acceleration, the average speed is $2/3$ the final speed.) It is evident from the large ratio of the elastic wave speeds to the average bullet speed that the elastic waves have had time to reflect eight or ten times back and forward along the gun barrel before the bullet exits and the sugar cube jumps. So attributing the phenomenon exhibited by the sugar cube experiment to elastic waves of the gun barrel is very unlikely. However we now conjecture a related mechanism of the elastic wave motions:

(b) A close examination of the barrel assembly revealed that the gun barrel fits in a cylindrical, concentric sleeve, the barrel assembly moves along rails on the mainstructure of the gun (to facilitate recoil and to open up the chamber) and there was play in each of these fittings. It is possible, then, that both or either of the alignments of the barrel/recoil assembly relative to the gun's main structure (fixed by the vice), and the gun barrel relative to the assembly, could be altered due to the set of elastic waves generated at each firing. An estimate of the angle shift related to scatter at the target is $10 \text{ cm} / 25 \text{ m} = 0.004$ radians. This angle shift of a barrel assembly 10cm in length will be accomplished if the play in the fittings is of order 0.4 mm end-to-end, a not unreasonable amount. Suggestions have been made to the gun manufacturer that firing tests be repeated with the play reduced or eliminated by shims inserted at convenient places.

(c) Since the sugar cubes placed on the barrel jump just after the bullet and exhaust gases have left the barrel, it is appealing to attribute their motion to the response of the barrel to the release of pressure in the barrel.

6. Rifling

Although we did not pursue any analysis with respect to rifling, we include a short description. The grooves inside the barrel seems (Figure 8 provides an example), give the bullet speed and rotation. Since the inside of the barrel is of a smaller diameter than the bullet, when the cartridge is fired, the bullet is forced into the barrel and the rifling engages the bullet, deforming it somewhat. Then, as the bullet is propelled down the barrel, it follows the shape of the interior surface and is forced to spin.

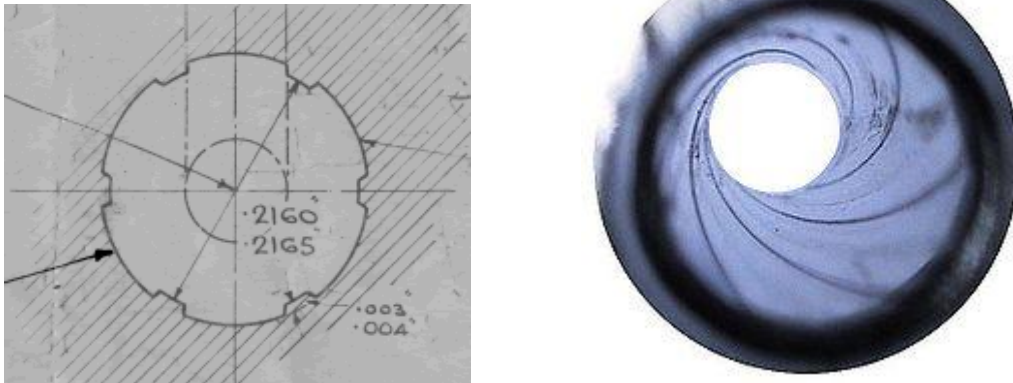


Figure 8. Cross section of the barrel and a view down the barrel.

The grooves used in standard handgun have fairly sharp edges. The sharply edged surface inside of the barrel as seen in Figure 8, only causes friction in the level at approximately 2% of the whole energy. To reduce this friction, and possibly for easier manufacture, there has been interest in other geometries of the grooves. Instead of standard rifling, octagonal rifling has been developed, as it seems to produce better accuracy due to the fact that it does not damage the bullet as badly as conventional rifling. See Figure 9.

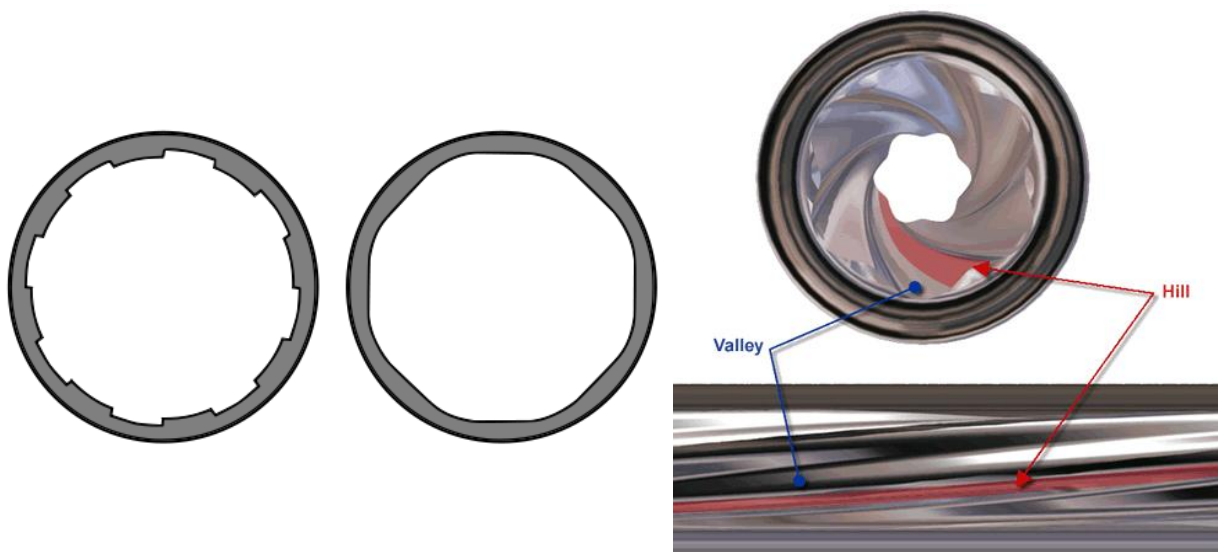


Figure 9. Conventional rifling pattern, polygonal rifling pattern and hammer forged 6-right polygonal rifling pattern

7. Conclusions

Various causes for angle and speed scatter were suggested in Section 3. The analysis presented in Section 4 discounts most of these. The causes remaining consist of bullet variability, and play in the fit of the barrel in its housing and the barrel/ recoil assembly in its slides. There were no available resources to test the former. Slight play in the gun examined and tested was estimated as a possible cause for angle scatter in terms of angle variations due to a misaligned barrel. Speed scatter is harder to attribute to this cause. It has been suggested to the gun manufacturer to repeat the test firings with the play reduced, and to compare results with the previous ones.

8. Acknowledgements

The study group acknowledges the contribution by the problem presenter Murat Alemdaroglu for his efforts through the study group and the organizers of the study group and other contributors of the study group whose names could not be identified.

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