# Proximity interlock firearm safety system (MuzzleSafe™ PATENT PENDING):

A safety system for certain firearms that will greatly reduce
the likelihood of injury or death from accidental discharge.

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2016-04-23

## ABSTRACT

Presented is a new technology that severely mitigates the likelihood of injury or death from accidental discharge of target firearms, competition firearms, hunting firearms, airguns, and other non-defensive types of firearms. The interlock system creates a “safe zone” near the muzzle of the firearm, disabling the firearm when any object enters this predefined space. Through active sonar, LiDAR, radar, or other rangefinding sensor, the interlock determines whether an object resides within the safe zone or not. If an object is present, the firearm is disabled. If an object is not present, the interlock may allow the shooter to manually disable the safety, or alternately, the interlock may simply allow the shooter to fire. This technology will save lives, because the likelihood of being shot by an accidental discharge is greatest within the first few feet of the firearm's muzzle. The system will also make it nearly impossible to accidentally shoot oneself.

## PROBLEM

According to the Centers for Disease Control, in 2013 there were 505 deaths from accidental discharge of firearms in the United States. Although this figure does not compare with the 130,557 total accidental deaths; the 38,851 deaths from accidental poisoning; or even the 3,391 deaths from accidental drowning, each of these firearms-related deaths is undeniably tragic. We who are responsible gun owners share an obligation to mitigate the likelihood that our firearms will inflict similar tragedies. This is more than simply a legal obligation; it is a moral obligation.

## BACKGROUND

Not all firearms are designed or optimized to fill the same role. Plinking, target shooting, clay pigeon shooting, exhibition shooting, cowboy action shooting, and defensive shooting are just a few examples of very different roles. For each, there are specialized firearms built or modified for that purpose.

- A target firearm is a gun whose sole purpose is to deliver shots accurately on inanimate targets. Such firearms are often chambered to fire relatively low-energy rounds, such as .22 Long Rifle, and may be ill suited for self-defense for that reason. Target firearms are also often heavier and bulkier than defense-oriented firearms, making them less suitable for defensive carry.
- A competition firearm is a gun that has been optimized for speed and accuracy, with the express purpose of engaging in competition with fellow shooters. Although such firearms are sometimes chambered in powerful rounds suitable for self-defense, the addition of bulky accessories such as reflex sights, compensators, barricade shrouds, and flared magazine wells often makes competition guns poorly suited for defensive carry.
- A hunting firearm is a gun that is optimized for accuracy and manageable carry weight, while delivering a shot that's adequately powerful to kill a particular type of animal humanely. Like any firearm, a hunting firearm can be used for self-defense, but the low capacity and slow rate of fire of many hunting guns makes them less than ideal for this purpose.

- Airguns are guns that propel projectiles via compressed air, carbon dioxide, or other gas. They are mostly for plinking, target shooting, and small game hunting, and are often a means to introduce children to the responsibilities of firearm ownership. Rarely are airguns used for any defensive application.

Common to most firearms that have *no defensive role* is the lack of necessity to deliver shots on a target from extremely close range. This is very useful information, because according to my calculations, **the likelihood of an accidental discharge resulting in striking a bystander decreases rapidly with distance**. The inverse square law dictates that if the probability of a shot fired at a random azimuth and zenith striking a particular target of interest is $p$, then doubling the distance between the shooter and target will result in a hit probability of $p$ / 4. Likewise, if the distance between shooter and target is quadrupled, the probability of a hit decreases even further to $p$ / 16, or about 6.3% of the original probability. Note that this applies *only* to shots discharged in a *random direction* (as an accidental discharge would presumably be); *not* shots that are deliberately aimed at a target.

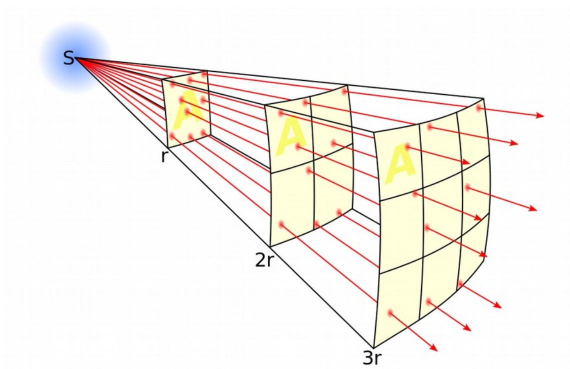


Fig. 1: An illustration of the inverse square law (source: Wikipedia).

Computing the likelihood that a random accidental discharge would strike a person at a given distance requires formulating an estimation of the cross-sectional area (or silhouette area) of a human subject. For my human subject model, I chose the illustration of a man that Carl Sagan inscribed on the Pioneer plaque:

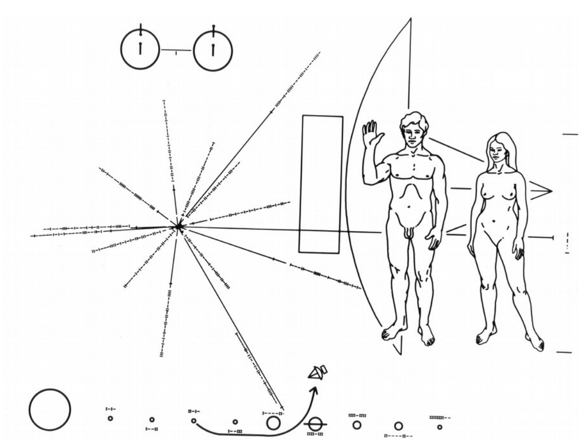

Fig. 2: Pioneer plaque inscription (source: NASA).

The subject of interest was cropped from the larger illustration, extraneous lines were removed, and finally the resulting image was converted into a silhouette:

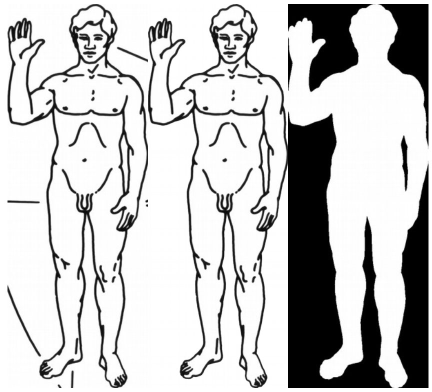

Fig. 3: Male subject image manipulation steps, from left to right.

The resulting image is 447 pixels wide, and 1225 pixels tall, for a total of 547,575 pixels. A software program was written in the [Processing](Processing) language to count the number of white pixels in the silhouette image. The number of white pixels was found to be 283,285. This represents a fraction of approximately 0.517 relative to the total number of pixels. So, the man's silhouette consumes a little over half the area of his bounding box rectangle.

If we assume the distance between the top of the man's head, and the tip of his left toe, is about six feet, that implies a pixel resolution of about 204.17 pixels per foot (1225 pixels / 6' = 204.17). Dividing the image width of 447 pixels by 204.17 pixels per foot yields an actual bounding box width of 2.19 feet. The product of the two bounding box dimensions (2.19' width times 6' height) yields a bounding box area of 13.14 square feet.

Since we know from the silhouette pixel count that the man's silhouette consumes 0.517 of the bounding box area, it stands to reason that the man's *actual* silhouette area (given the chosen bounding box height of 6 feet) is 6.79 square feet.

Now that an estimate of our subject's silhouette area has been made, it is easy to compute his probability of getting shot by a random firearm discharge. If we imagine the firearm floating in space, enclosed within an imaginary sphere, it is apparent that discharging the firearm will result in striking the surface of the sphere *at some point*.

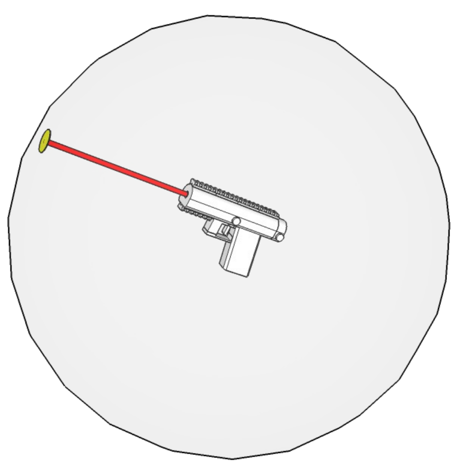

Fig. 4: An illustration of a handgun firing within an imaginary sphere, propelling a projectile along a given trajectory (red), and ultimately striking an area of interest on the surface of the sphere (yellow).

To compute the probability of hitting a particular area of the sphere, we may divide the area of interest by the total surface area of the sphere.

$$p_{impact} = \frac{A_{interest}}{A_{sphere}}$$

So, for example, if the area of interest is one square foot, and the area of the sphere's surface is five square feet, the probability of striking the area of interest is one in five, or 0.2.

In the case of the matter under research, the *area of interest* is a fixed value of 6.79 square feet, corresponding to the area of an average adult male silhouette. The sphere's surface area is a variable; a function of the radius *r* of the sphere, which corresponds to the distance between the gun and the potential accident victim.

$$A_{sphere} = 4\pi r^2$$

$$p_{impact} = \frac{6.79}{4\pi r^2}$$

A simple MATLAB script was written to generate graphs and tables of impact probabilities as a function of variable distance:

```
% shot_probability.m
R = linspace(1.05, 10, 200)
sphere_surface_area = 4 * pi * R.^2
human_surface_area = 6.79
hit_probability = human_surface_area ./ sphere_surface_area
figure();
plot(R, hit_probability);
xlabel('distance from accidental discharge (feet)');
ylabel('probability of getting shot (1=100%)');
```

The above script generated the following graph of impact probability as a function of distance from the muzzle of a firearm that is discharged at a random azimuth and zenith:

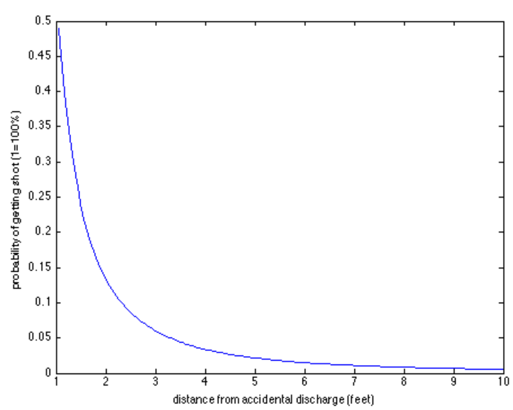


Fig. 5: Graph of impact probability as a function of distance from muzzle.

From this plot, it is readily apparent that the most dangerous place to be is within the first few feet of the muzzle of a firearm that is being accidentally discharged.

## SOLUTION

The combined realizations that:

1. Some types of firearms do not require the ability to fire on targets at extremely close range.
2. Being very near the muzzle of an accidentally discharging firearm increases a person's risk of being struck by the bullet drastically.

I realized that a potential way to greatly mitigate the statistical likelihood of injury from accidental firearm discharge would be to create a new type of safety interlock system that renders the firearm inoperable when an object is detected within a predefined range of the muzzle.

The exact details of how the interlock interfaces with the gun's fire control system are not relevant to understanding the concept of how the system will operate. The interlock could mechanically switch a firearm's existing safety lever. The interlock could introduce an additional safety, capable of preventing the firearm from discharging even when the manual safety is disengaged. An electronic fire control system may be used, in which the proximity interlock informs a logic circuit, which in turn takes input from other sensors (e.g. a trigger switch, a manual safety, etc.), and ultimately makes a decision about whether or not to fire the gun. The important thing to consider is the functionality of the system, which may be examined using the following flowcharts:

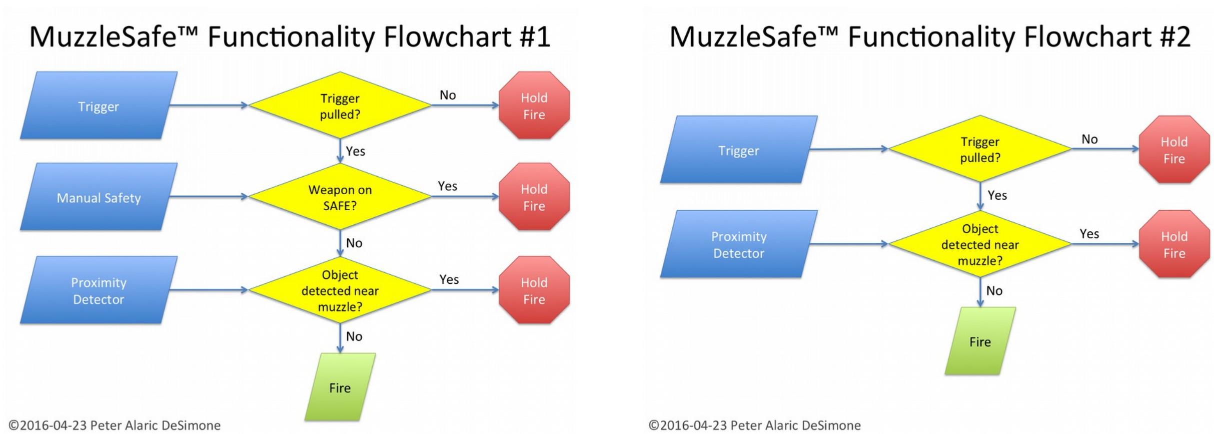


Fig. 6: Functionality flowcharts for a system with a manual safety (left), and no manual safety (right).

## IMPLEMENTATION

There are many possible implementations of the system. The choice of proximity detector could include sonar, ultrasonic sonar, LiDAR, radar, capacitance, structured light 3D scanning, stereoscopic/multiscopic photogrammetry, or some as-yet-unimagined form of rangefinding. The logic system (which makes the decision as to whether to fire or not) could be as simple as a mechanical safety actuated by an electromagnetic solenoid, servo, or motor. Or, it could be as complex as an electronic logic gate, microcontroller, or even a neural network.

For demonstration purposes, work has begun on a “proof of concept” prototype built around an airsoft AEP (automatic electric pistol), retrofitted with a Maxbotix LV-EZ series ultrasonic sonar rangefinder. The rangefinder module provides input to a microcontroller running an original firmware program. The microcontroller makes a decision to enable fire if no object is detected within the specified threshold range, or to disable fire if an object is detected within that range.

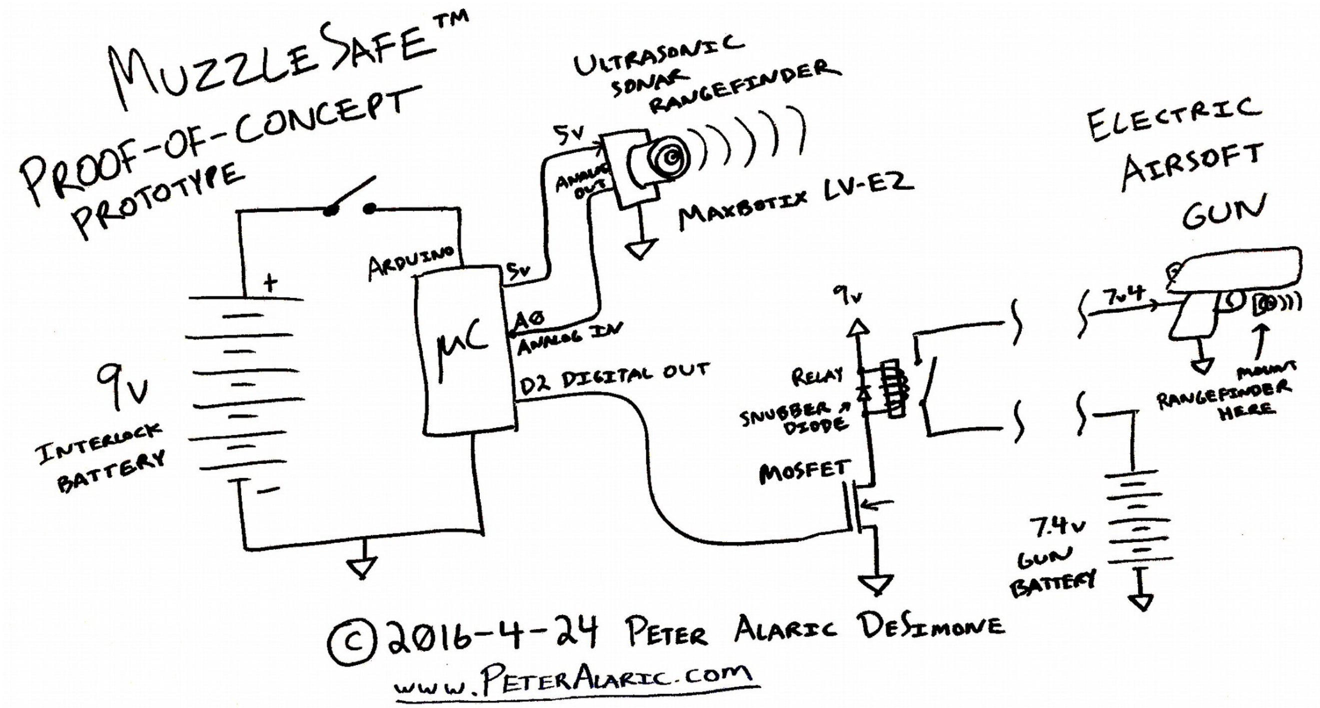


Fig. 7: Electrical schematic for MuzzleSafe proof-of-concept prototype.

To enable fire, the microcontroller switches a power transistor to the closed circuit condition, which allows current to flow through a relay coil, connecting the normally open output terminals of the relay. These output terminals have been spliced in series with the gun's battery, thereby allowing current to flow from the battery into the gun. To disable fire, the microcontroller switches the power transistor to the open circuit condition. This de-energizes the coil of the relay, which causes the relay's normally open contacts to default to the open circuit condition. Since these contacts are in series with the battery, the battery is effectively disconnected from the gun, disabling all of the gun's onboard systems, including its ability to fire. The MuzzleSafe module, however, remains powered and continues to perform ranging of whatever objects are downrange of the muzzle.

Fig. 8: CYMA CM121 Magnum Airsoft Electric Pistol (prototype testbed).

The rangefinder will reside beneath the barrel on a MIL-STD-1913 accessory rail. It will emit a beam of ultrasonic sonar pulses along an axis closely aligned with the barrel's point of aim. Whatever object the barrel is aligned to shoot will be the object being ranged by the ultrasonic sonar.

An integrated electronic fire control system would allow for more battery-efficient operation, since it would be possible to selectively perform ranging:

- Only when the trigger is pulled.
- Only when the gun is being held (indicated by a grip switch or similar sensor).
- Only when the gun is pointed horizontally (indicated by an accelerometer, mercury switch, or other similar orientation sensor).
- Or only when all of the above conditions are met.

Making ranging contingent on trigger pull would unfortunately introduce a “lock time” lag into the system, which would not normally be present, and would be annoying to experienced shooters. However, any scheme that avoids continuous ranging would greatly extend battery life, since ultrasonic sonar ranging is an active process that expends energy in order to range targets.

## APPLICATIONS

MuzzleSafe™ is currently for target firearms, plinking firearms, training firearms, competition firearms, airguns, and hunting firearms *only*. **<u>Under no circumstances should it be used in a firearm that is being relied upon for personal or home defense!</u>** All an assailant would have to do is quickly close the distance to the weapon and enter the “safe zone”, and the gun would become useless as a defensive tool. For this reason, militaries, law enforcement agencies, and legally armed citizens will rightly reject this technology for defensive applications. However, there are many reasons to embrace it for other applications:

- Firearms instructors can issue MuzzleSafe-equipped firearms to their students, and stand right next to them on the firing line with a drastically reduced concern of getting shot by an inexperienced shooter.
- Target shooters, rangemasters, and competition organizers can engage in shooting events with an added layer of safety.
- Since **MuzzleSafe makes it virtually impossible to shoot oneself**, this is a desirable safety feature for anyone who is concerned about children accessing their firearms.
- Many common types of firearm accidents (such as shooting oneself in the leg on drawing or holstering a sidearm) will be virtually eliminated by MuzzleSafe.
- Militaries and law enforcement agencies can use MuzzleSafe for live fire training exercises to reduce the risk of training accidents.

## ALTERNATE MODE

It is possible to configure the system to only permit fire when the rangefinder aligned with the barrel's point of aim reads a distance that is *less* than a predefined limit, or only when the distance lies within a specified range. This would prevent firing up into the air, which is also potentially dangerous.

## CONCLUSION

This technology will *dramatically* reduce the risk associated with handling certain types of firearms. While it is not a panacea – nor a substitute for proper firearm handling procedures (e.g. muzzle control discipline) – developing it further is a necessary step toward the future of firearm safety. The fact that lives will be saved by this technology is virtually guaranteed.

## ADDENDA

### 2016-05-09: Revised mathematical model, CAD simulation, and prototype field tests

The equation for bullet impact probability as a function of distance from the muzzle given in the BACKGROUND section holds exactly true only for shapes that conform to the surface of the imaginary sphere. The error is trivial for large values of $r$, but at very short range, the given formula will significantly overestimate the impact probability (unless the subject's body happens to be curled up around the gun).

The following revised formula is presented, which should hold true for a gun fired at either floor level, or top-of-head level, and a subject who is standing perfectly upright:

$$p_{impact} = c \cdot \frac{\arctan\left(\frac{h}{r}\right) \cdot \arctan\left(\frac{w}{r}\right)}{4 \cdot \pi^2}$$

Where:

- $c$ is the coefficient of the silhouette's bounding box fraction (0.517 for our purposes).
- $h$ is the height of our bounding box (approximately 6' from toe tip to top of head).
- $w$ is the width of our bounding box (about 2.19').
- $r$ is the horizontal distance between muzzle and subject.

This equation can be described as the product of the bounding box's horizontal and vertical angular subtends, normalized over the product of the two maximum possible angles $(2\pi)^2$, multiplied by the coefficient representing the subject silhouette's fractional area of his bounding box.

The formula originally given was easier to conceptualize, easier to implement, and fairly accurate for large values of $r$. The new formula, however, should produce more accurate results for all ranges. An even more complex formula has also been devised, which would allow for adjustment of the height of the gun off the floor (or down from the top of the subject's head) at the time of firing, but at this point I feel that this is more than adequate to convey the conceptual background of the invention.

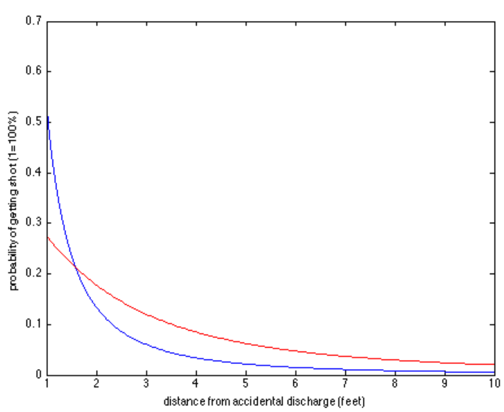


Fig. 9: Graph of impact probability as a function of distance from muzzle.
Blue: original formula. Red: revised formula.

The MATLAB script that generated Fig. 9 follows:

```
% shot_probability_2.m
% all measurements given in feet
clear all;
clc;
R = linspace(1.0, 10, 200); % min, max, # increments
sphere_surface_area = 4 * pi * R.^2;
human_surface_area = 6.79; % square feet
% compute probability per original equation
hit_probability_eq1 = human_surface_area ./ sphere_surface_area;
% compute probability per revised equation
c = human_surface_area;
w = 2.19;
h = 6;
hit_probability_eq2 = c * atan(h./R) .* atan(w./R) / (4 * pi^2);
figure();
plot(R, hit_probability_eq1, 'b'); %original eq in blue
hold on;
plot(R, hit_probability_eq2, 'r'); %revised eq in red
hold off;
xlabel('distance from accidental discharge (feet)');
ylabel('probability of getting shot (1=100%)');
```

And here is a plot of impact probability, using the revised formula only, for distances ranging from contact (*r*=0) to 15 feet (*r*=15). The latter being the approximate maximum range of the Maxbotix LV-EZ sensor line, beyond which, fire would be either always permitted, or never permitted, depending on the MuzzleSafe™ firmware mode. In live fire testing with the airsoft prototype, thus far it has been configured to always allow fire beyond the range maximum, which seems appropriate for utility's sake.

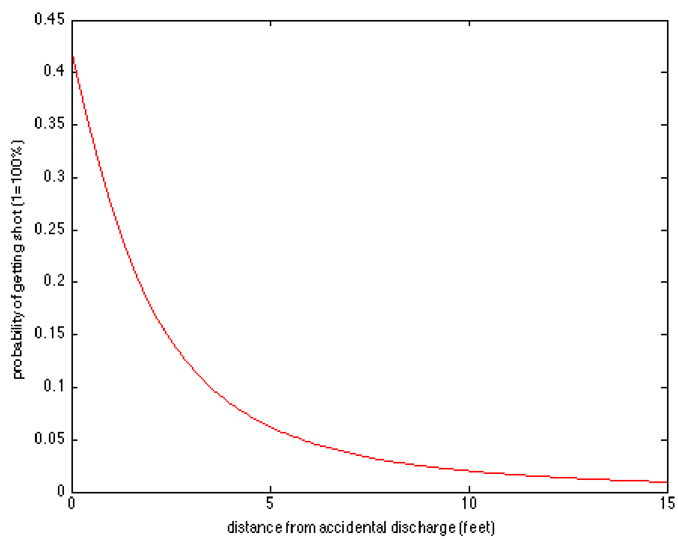


Fig. 10: Graph of impact probability as a function of distance from muzzle.
Revised formula; range *r*=0 to *r*=15 feet.

Although the numbers themselves have changed, note that the curvature resembles that of the original formula. Neither formula is 100% accurate (due to the fact that neither accounts for the exact contour of the silhouette), but the important takeaway is that probability of injury or death drops precipitously during the first few feet, thus validating the MuzzleSafe™ concept. This has been further corroborated through CAD simulation:


Fig. 11: An illustration made from the "[trajectory star]" CAD simulation tests.

**MuzzleSafe™ (PATENT PENDING) Simulated Experiment**

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DESCRIPTION: An OpenSCAD script was written to simulate firing 162 shots in all directions. A man-sized silhouette was imported into SketchUp to determine the number, type, and severity of injuries one is likely to receive at various distances from the gun. These findings corroborate those of my earlier mathematical models: proximity to an accidentally discharging firearm increases the likelihood of serious injury *dramatically*.

| DISTANCE (FT) | TOTAL HITS | HEAD | NECK | TORSO | EXTREMITIES | LIFE-THREATENING? | NOTES |
|---|---|---|---|---|---|---|---|
| 1 | 26 | 2 | 2 | 10 | 12 | YES | 2 LETHAL HEAD SHOTS, 2 NECK SHOTS, 10 TORSO SHOTS (2 OF WHICH WERE GRAZING), RIGHT SHOUL |
| 2 | 11 | 2 | 0 | 6 | 3 | YES | TWO GRAZING HEAD SHOTS, SIX TORSO SHOTS, BOTH KNEES, RIGHT WRIST |
| 3 | 5 | 0 | 0 | 1 | 4 | YES | RIGHT TORSO, LEFT ARM, LEFT HAND, RIGHT THIGH, GRAZING WOUND TO RIGHT LEG |
| 4 | 1 | 0 | 0 | 0 | 1 | MAYBE | LEFT ELBOW |
| 5 | 1 | 0 | 0 | 0 | 1 | NO | RIGHT HAND |
| 6 | 1 | 0 | 0 | 0 | 1 | NO | RIGHT HAND |
| 7 | 0 | 0 | 0 | 0 | 0 | NO | NO INJURIES |

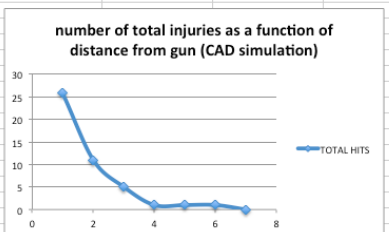


Fig. 12: A summary of injuries documented on the mannequin at varying distances from the muzzle.

Fig. 13: MuzzleSafe™ proof-of-concept prototype with 3D printed electronics enclosure.

The proof-of-concept prototype has also been built and successfully field tested as of 2016-05-04. A web site for the project ( www.MuzzleSafe.com ) is now live as well. Next steps include miniaturization, custom PCB design, and field testing on an actual firearm using an electromechanical safety switch actuator.