# The Ultimate Chairsofter's Handbook

# Table of Contents

# About This Book

This little book is written by a no-name airsofter in new jersey who started by playing paintball, but has since been playing Airsoft for about six years. Being un-impressed with existing airsoft equipment, I ended up designing my own airsoft guns. In doing so, I've had to learn a lot about how airsoft guns work and about airsoft as a whole. This handbook contains all of the useful information I've collected over the years.

This handbook will be updated as I learn more about airsoft and building airsoft guns. You can view the latest version of this handbook at: www.airsoftrnd.com/handbook/

# Basics

## Protection

Before you set foot in an airsoft field, there are a few things you should have to be safe and to have a good time. The first consideration when preparing for an airsoft game is eye protection. There are many different options for eye protection at different price points which advertise different advantages. There are extremely cheap glasses that only cover the eyes and don't offer much more than that. Some goggles are called 'full seal' because they have a foam or plastic band running around the lens which contacts the face to prevent ricochets from hitting the eyes. Some goggles even have fans in them to help prevent one's sweat from fogging the inside of the lens. However, whichever option you pick, make sure it is properly rated for use in an airsoft game.

The marking that fields look for is American National Standards Institute's (ANSI) Z87.1 marking. This standard, amongst other things, tests for impact resistance to make sure the lens does not crack when something hits it. Ideally you would want to use goggles that have a ANSI Z87.1+ marking which is the best rating for impact resistance.


*A marking on a rated set of goggles. Look for a marking like this when buying eye protection!*

One common problem that airsofters run into is fogging on the inside of their goggles lens. Since it's unsafe to remove goggles during a game to wipe them, fogged goggles end up being an impediment to having a good time. Some solutions to this problem include the aforementioned fans to circulate air behind the lens. Some of the more expensive masks/goggles have a 'thermal lens' which are advertised to be fog resistant. Lastly there are anti-fog coatings in either gel or spray forms which mitigate the fogging problem.

If you decide against using a mask that covers your face, there is also separate face protectors available, but the point is you should ***always*** use eye protection when using airsoft guns.

## My Thoughts on Safety

One thing that everyone worries about when considering airsoft is whether it's safe to play. Most people think that airsoft is very dangerous; they think airsoft *guns*, therefore ***guns***, therefore unsafe! It turns out however that airsoft is actually one of the safest sports to play in comparison to the more traditional sports.

**SPORTS INJURY STUDY**
**Total Injuries Ranked by Sport**

*Numbers are in thousands (000)*

| Sport Total | Total Sport Participants | Injured Participants | % of Total Injuries | Injuries Per 100 Participants |
|---|---|---|---|---|
| **TOTAL INJURIES** | **211,202** | **20,145** | **100.0** | **9.5** |
| Basketball | 36,584 | 2,783 | 13.8 | 7.6 |
| Running/Jogging | 35,866 | 1,654 | 8.2 | 4.6 |
| Soccer | 17,641 | 1,634 | 8.1 | 9.3 |
| Football (tackle) | 5,783 | 1,084 | 5.4 | 18.8 |
| Baseball | 10,402 | 602 | 3.0 | 5.8 |
| Bicycling (recreational) | 53,524 | 445 | 2.2 | 0.8 |
| Tennis | 16,353 | 415 | 2.1 | 2.5 |
| Ice Hockey | 2,612 | 415 | 2.1 | 15.9 |
| Skateboarding | 12,997 | 399 | 2.0 | 3.1 |
| Walking (recreational) | 84,986 | 384 | 1.9 | 0.5 |
| Golf | 27,812 | 291 | 1.4 | 1.0 |
| **Hunting** | **16,471** | **207** | **1.0** | **1.3** |
| Gymnastics | 5,149 | 149 | 0.7 | 2.9 |
| Ice Skating | 14,530 | 105 | 0.5 | 0.7 |
| Swimming (recreational) | 92,667 | 73 | 0.4 | 0.1 |
| Bowling | 53,160 | 50 | 0.2 | 0.1 |
| **Paintball** | **8,679** | **21** | **0.1** | **0.2** |
| **Shooting (trap & skeet)** | **3,696** | **16** | **0.1** | **0.4** |
| **Archery** | **6,650** | **16** | **0.1** | **0.2** |
| Canoeing | 10,933 | 11 | 0.1 | 0.1 |

Source: American Sports Data, Inc. - A Comprehensive Study of Sports Injuries in the U.S.

While this study doesn't list airsoft specifically, every shooting sport is significantly safer than the more traditional sports like soccer or football. The most similar sport to airsoft is paintball, which is essentially the same sport with the exception of some equipment differences, which makes it a great analogy to airsoft. (Airsoft/paintball is even safer than tennis! Who would've thought?)

While the injury rate is significantly lower than other sports it's not zero, so what are the dangers of airsoft? It depends on whether you're playing in an indoor or outdoor airsoft field. At indoor fields the main dangers are slips and falls when running, or running into others when rounding corners. These dangers aren't unique to airsoft though; they would be present in any sport that involves running!

At outdoor fields, there are some more dangers to consider. In addition to slipping on mud/dirt/etc., one would also want to be aware of whatever other dangers are involved with being in the wilderness. Ticks and mosquitoes can potentially be a problem depending on climate and the season. Since most outdoor fields are in partially managed forests, one may also encounter wildlife such as deer, snakes, or bears. It's worth mentioning again that these problems aren't specific to airsoft, but are associated with being in the wilderness.

The only other dangers would be from the airsoft guns themselves. It is possible to get welts if you are hit with a more powerful airsoft gun at close range; Welts clear up after a few days however. Another danger is that one's teeth could be chipped or knocked out if the teeth are hit directly. This danger can easily be eliminated with a mask that covers the whole face, or a mesh mask could be used to cover the mouth. Overall, there aren't that many dangers presented by the airsoft guns themselves; most of the danger is in the environment one plays in.

## The Case for Unlimited Muzzle Velocity/Energy

When discussing safety, most airsofters are divided on how to ensure that everyones' airsoft guns are safe to use. While most airsofters agree that there should be a limit on how powerful an airsoft gun should be, there's some disagreements over how to quantify the power of an airsoft gun. Some airsofters think that the measure of an airsoft gun's power should be its muzzle velocity, while others think it should be a muzzle energy measurement. However I'd submit the idea that both of these measurements are insufficient and a third measure should be used to determine if an airsoft gun is safe.

Regardless of the measure used to determine if an airsoft gun is safe, a chronograph is needed. A chronograph measures the time it takes for an object to pass between two known points, which allows it to produce a velocity. The muzzle velocity is simply a chronograph reading of a projectile as it leaves the muzzle of a gun. However the velocity of a projectile alone is not enough to prove that it is safe to use in airsoft. A 0.2 gram BB moving at 350 ft/s is very different from a 1 pound lead ball moving at 350 ft/s. As a result some airsofters prefer to measure an airsoft gun's power by its muzzle energy, or the amount of kinetic energy the projectile has as it leaves the muzzle of the gun. While this is an improvement over just using muzzle velocities it's not much of a substantial difference to make it the best measure of if an airsoft gun is safe.

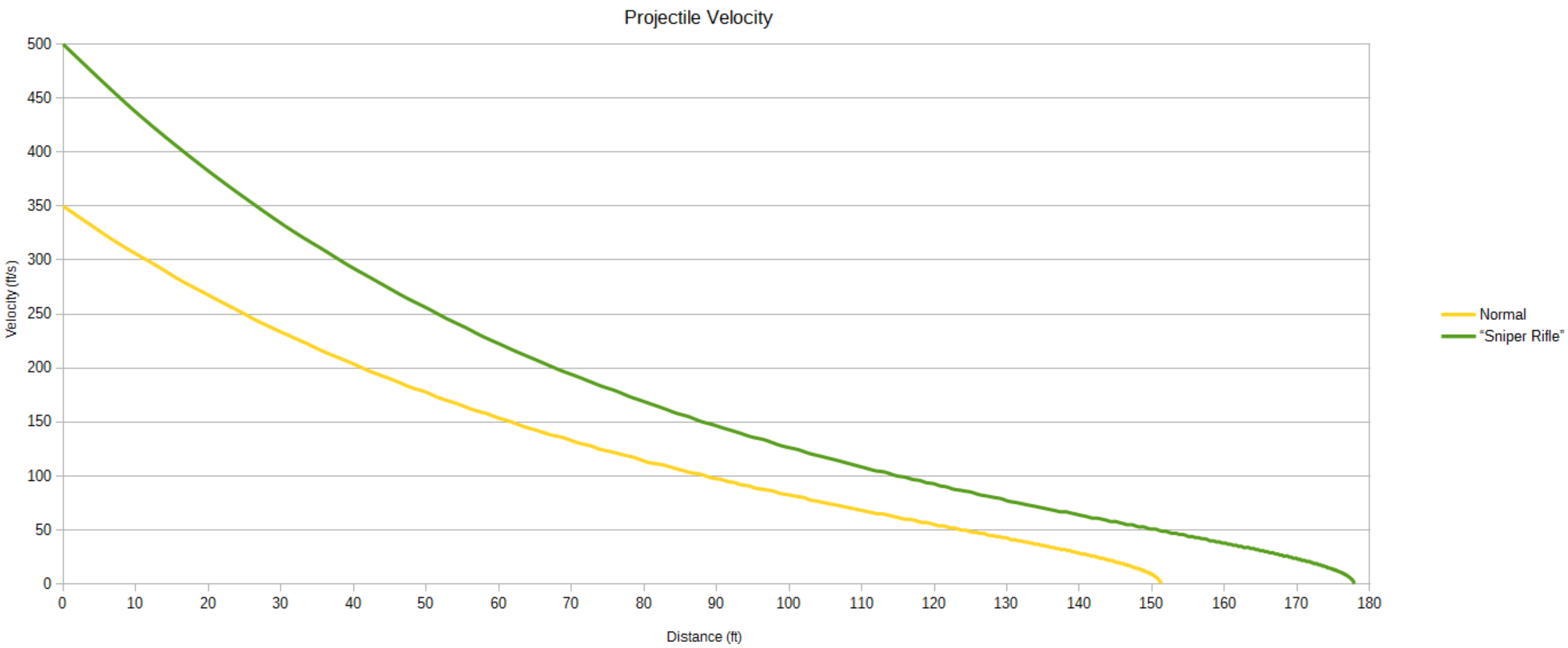
I think that both of these options fall short on their goal on proving that an airsoft gun is safe to use. One should not care how fast the muzzle velocity is, nor what the muzzle energy is (unless that is, you regularly press the muzzle into the chest of your opponent before firing). Not only are the existing options insufficient to determine if an airsoft gun is safe, the muzzle velocity/energy limits are for the most part arbitrarily decided. If one were to press a field owner on this arbitrariness, the only response would be: “I do what the insurance company tells me to do”. One should only care about how much energy is being put into the target; if an airsoft gun were to have a muzzle velocity of 1000 ft/s (i.e. a really high value), it can still be safe if there's enough distance between the shooter and target for the BB to slow down with air resistance. I would call this a ***Terminal Energy Limit****: An MED that is determined by the amount of kinetic energy a projectile has as it impacts its target.*

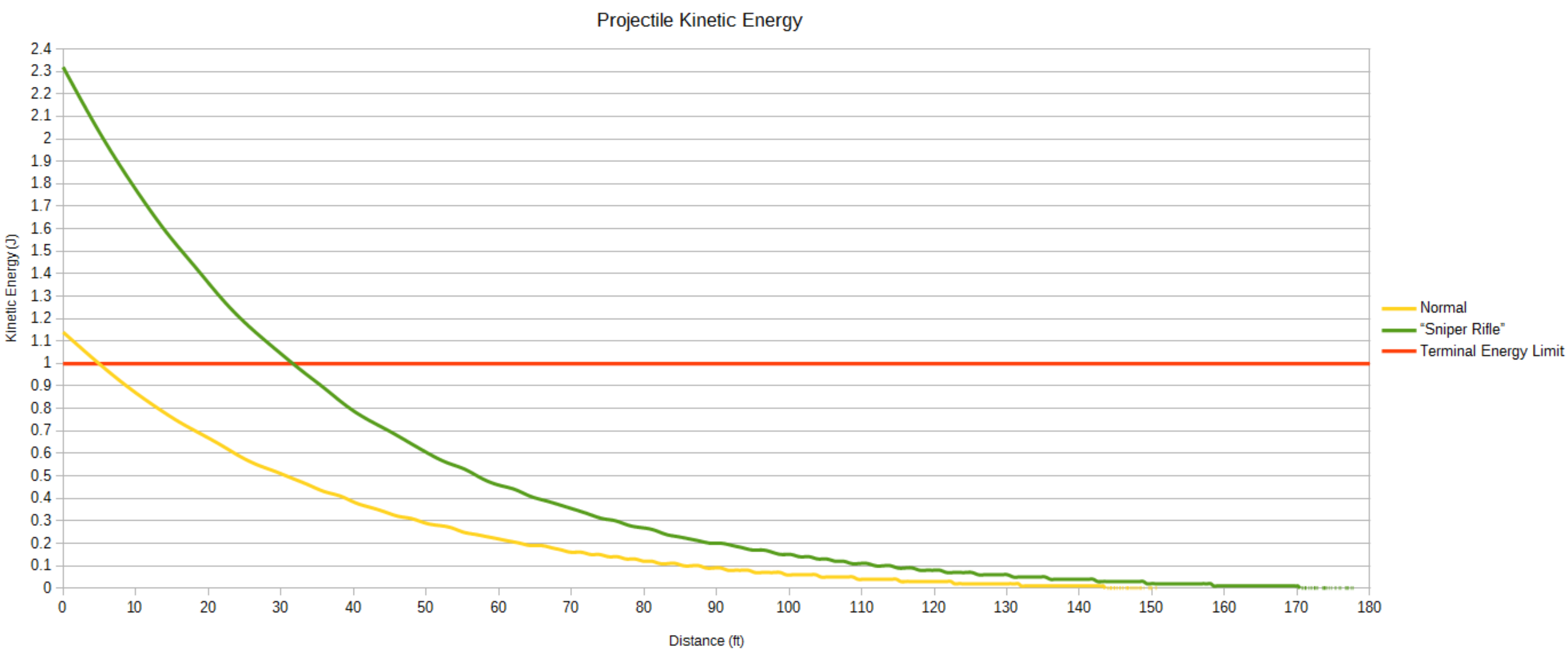
In order to find the proper MED for a projectile, we'll need to know the projectile's mass, shape, size, muzzle velocity, and the air's density (based on temperature and humidity). With this information we can calculate how much energy the projectile loses to air resistance as it travels through the air. When the projectile's kinetic energy drops below the *terminal energy limit*, we use the distance the projectile traveled as the airsoft gun's MED. Using an iterative function, we can calculate the drag force with the following formula:

$$\text{Drag Force} = 0.5 * \text{Drag Coefficient} * \text{Projectile Area} * \text{Velocity}^2 * \text{Air Density}$$

After calculating the drag force at a specific time, we can multiply it by a time interval and subtract the result from the projectile's kinetic energy. We'll keep iterating until the kinetic energy drops below our *terminal energy limit*. As we're iterating, we can track the distance traveled multiplying the projectile's velocity by the same time interval used before. Though this could be done by hand, it's far easier to program a computer to do the math for us.

The arbitrary kinetic velocity/energy limits and MEDs do not make sense from a safety standpoint, and we can prove this by calculating the *terminal energy* of airsoft guns at common energy limits and MEDs. One common standard is thus: For most airsoft guns a muzzle velocity limit is 350 ft/s with a 10 foot MED while for “sniper rifles” the velocity limit is 500 ft/s with a 100 foot MED. For this example we'll assume that the BB weight for both types is the same (0.2g) and the *terminal energy limit* is 1J. In the charts below, I've calculated the drag force of a BB over distance in a standard atmosphere in 0.01 second steps.



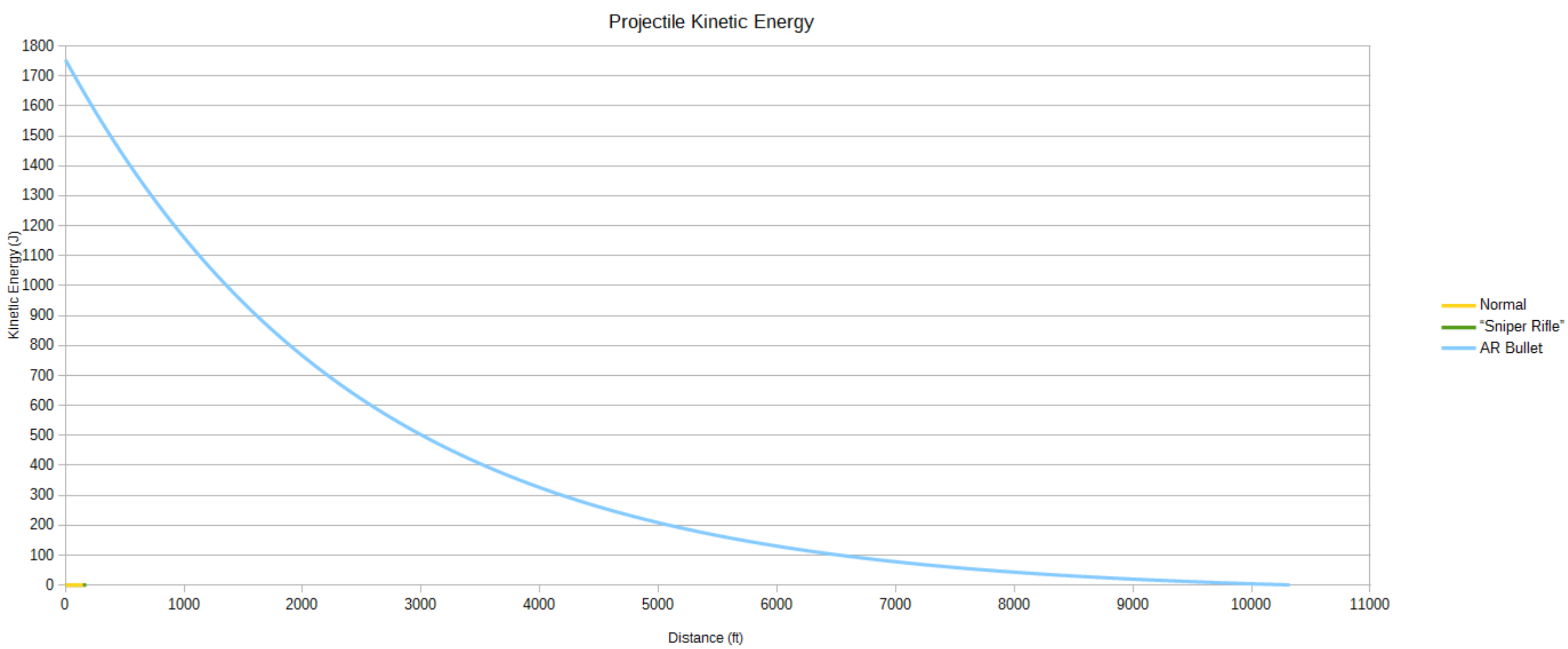




As shown above, even though the muzzle energy for the “sniper rifles” is nearly twice that of the normal airsoft guns, the *terminal energy* (i.e. *the energy put into the target*) of the normal airsoft guns at their MED is higher! This means that the normal airsoft guns at their MED are more dangerous than the “sniper rifles” are at their MED. If the *terminal energy limit* were 1 joule, the normal airsoft guns should have an MED of about 7 feet while the “sniper rifles” should have an MED of about 33 feet.

By using a *terminal energy limit*, we can allow any type of airsoft gun to be used in combination with a MED to match its muzzle energy. Airsoft guns with higher muzzle energies would have higher MEDs, while airsoft guns with lower muzzle energies would have a lower MED (or none at all if it's low enough). An airsoft field can set a *terminal energy limit*, and determine MEDs for airsoft guns as they come. This would allow airsoft guns of *all types* to be used, and each type would have its own advantages and disadvantages. The “sniper rifles” would be able to have as high a muzzle energy as the player likes, and he would be given a correspondingly high MED to match. Conversely, an AEG can be tuned to have a lower muzzle energy so that it can be used with no MED at all. It becomes self-evident that all of these types of airsoft guns would be useful to a team in different situations. Regardless of the muzzle energy of the airsoft gun, it would be safe to use as the *terminal energy*, the energy imparted into the target, is the same at each airsoft gun's MED.

In addition, a *terminal energy limit* can also apply the airsoft guns that don't use 6mm plastic BBs. It can be applied to things such as 8mm BBs, bullet shaped projectiles, or anything else one can think of. A simple muzzle velocity/energy check can't account for these other types of projectiles. To push this idea to its extreme, it is (theoretically) possible to use real firearms with real bullets in airsoft! Consider the following example:

Example AR-15 Bullet: Mass: 3.56g, Muzzle Velocity: 3257 ft/s




*(Do note however that the ballistic math becomes more complicated as the velocity drops from supersonic through trans-sonic speeds, so the above graph is not completely precise)*

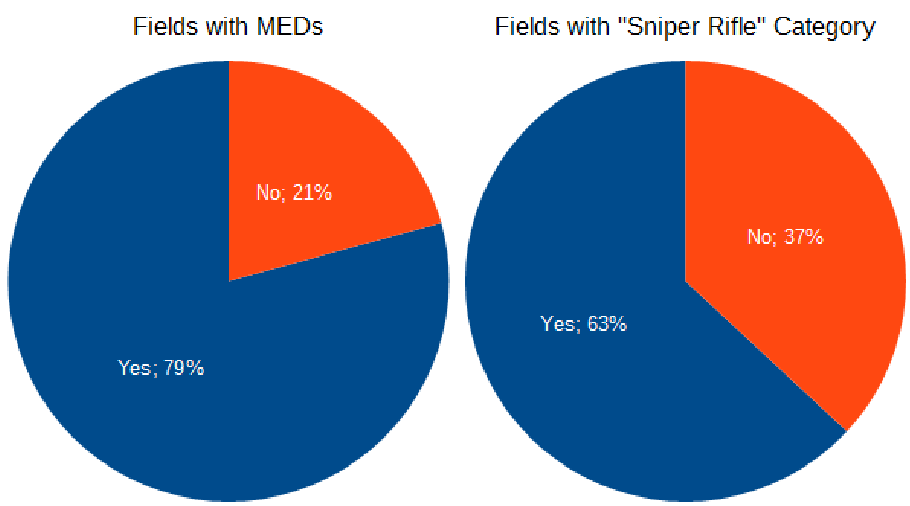
As a result, one could (theoretically) use a real AR-15 with real bullets in an airsoft game (if one can convince anyone else to let them); they would just have to have a MED of at least ***1.96 miles*** to match its extremely high muzzle energy.

There are some obvious objections to using terminal energy as a safety check. First: what happens if a player shoots at an opponent within their MED? An alternative is what if one cheats the safety check by changing their BB weight or modifying their airsoft gun after getting their MED to increase their airsoft gun's muzzle energy? In either of these cases, a safety rule was violated, which should result in an immediate ejection from the field. In the event that the cheating (whether by shooting within MEDs or changing projectile weights/muzzle velocities) is done in a malicious manner, the attacker should be banned and possibly reported to the police depending on the situation. Since Airsoft already relies on honor so much to run smoothly, it is not unreasonable to assign MEDs based on muzzle energy and expect players follow them.

One may also argue that the *terminal energy limit* a field selects is arbitrary; while this may be true a *terminal energy limit* is more precise in predicting if an airsoft gun can cause injury at a specific distance. In addition, an optimal *terminal energy limit* can be found with some research into the *terminal effects* of a BB hitting someone in various ways.

A much simpler objection would be that the math is too difficult, so we should use the older, easier rules to avoid doing math. If one were to use arbitrary, imprecise rules to determine if an airsoft gun is safe to use just to avoid a little math, could one say that they want to be safe at all? If your desire to avoid math is greater than your desire to be safe, than it could be said that you do not take safety seriously.

One may also say that enforcing different MEDs for each player is too difficult compared to enforcing one MED with a simple muzzle velocity/energy check. While giving each individual player their own MED could be harder than using one MED, it's also possible to sort players into different classes that use different MEDs. In fact this is already done at many fields, where players are sorted into a normal group and a “sniper” group that uses a longer MED.




*Most fields use MEDs and nearly two thirds sort players into at least two types. [Source: www.airsoftc3.com]*

In spite of the objections, I contend that using a *terminal energy limit* is far better than anything else in use today to ensure that every airsoft gun is safe. A *terminal energy limit* is more precise than simple muzzle velocity or muzzle energy check. A *terminal energy limit* is also able to handle any type of projectile shape/size/weight, which makes it future-proofed against any new airsoft gun that may be made in the future. An airsoft field also doesn't have to turn away anyone because of their equipment; a field owner only needs to enforce MEDs, as they already tend to do.

## On Rate of Fire

Another common safety rule (particularly at indoor fields) is a 'semi-only' rule. While almost all electric airsoft guns are capable of full-automatic fire, most fields ban its use. The goal of this ban is to prevent “bonus-balling”: shooting players after they are already hit without giving the player a chance to call themselves out. However this rule fails to accomplish its goal; instead of banning fire modes, a rate of fire limit should be used instead.

We can calculate an optimal rate of fire, so that players who want to use full-automatic fire can while also giving players that are hit the opportunity to call themselves out without being bonus-balled. This rate of fire is based off of the average person's reaction time plus the speed of airsoft BBs and sound. The average person's reaction time (courtesy of: www.humanbenchmark.com) is about 283 milliseconds. The speed of sound in a standard atmosphere is about 1116 ft/s. With these two values and a sample BB velocity of 400 ft/s, we can calculate the rate of fire needed to prevent bonus-balling.

$$_{O}ROF = (0.283 * 2) + (10 / 400) + (10 / 1116)$$

With the above example, we can see that the optimal delay between shots is about 0.6 seconds. This translates into about 100 rounds per minute, or 1.6 rounds per second. However this would be a mathematically optimal rate of fire; It might be worth adding additional time to take into consideration things like: less than average reaction times, the minute shock of being hit by a BB, failing to hear the first shouting of 'hit!', the time it takes to release a trigger, shooting over longer distances, etc. In contrast it may also be worth subtracting some time due to the inaccuracy of airsoft guns over range and the possibility of individual BBs being blocked by structures and/or foliage.

As an aside this low rate of fire might only be needed at short distances. Most arguments in airsoft are a result of being hit at a close range when the BB still has a lot of kinetic energy. At longer ranges this isn't as much of a problem as the BBs don't hurt nearly as much at such distances. Therefore it might be worth allowing higher rates of fire at longer ranges, in combination with MEDs and a low terminal energy limit.

# Airsoft Gun Principles

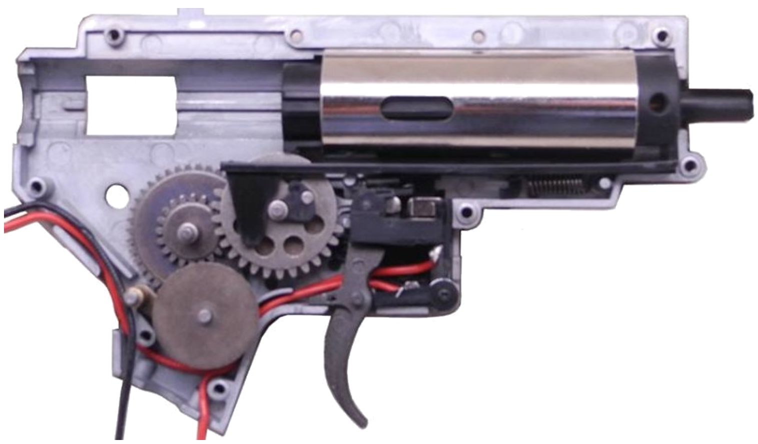
**WARNING: THINKING REQUIRED**

If you intend to use the following information to fix or upgrade your airsoft gun, note that the information in this section is merely an overview of how airsoft guns of different types work. You will need to seek out more information for the specific model of airsoft gun you're working on.

## Automatic Electric Guns (AEGs)

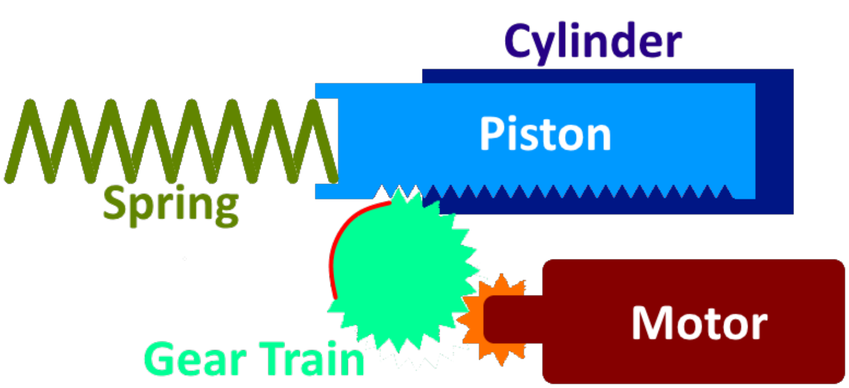
Let's build a model of an AEG to learn more about how it works. We're not modeling any specific airsoft gun, but this theoretical model should give a better understanding of how an AEG works.

In general, AEGs contain an electric motor, a battery, a trigger to complete the electric circuit, a piston to compress air, a spring to drive the piston, a train of gears to compress the spring and retract the piston, and a gearbox shell to contain all of these parts.



*The internals of a standard version 2 gearbox. Parts not shown include the motor, spring, and spring guide.*

The motor, while it doesn't rotate that fast, has a lot of torque. This torque is needed in order to compress the spring which is difficult to compress by hand. The motor is connected to a series of gears which interface with the teeth in the piston. As the gears rotate, the piston is retracted which compresses the spring. After the piston is retracted and the spring is compressed, an 'untoothed' portion of the last gear rotates into position, which allows the piston to slip out. The spring drives the piston forward, compressing air to propel the BB.

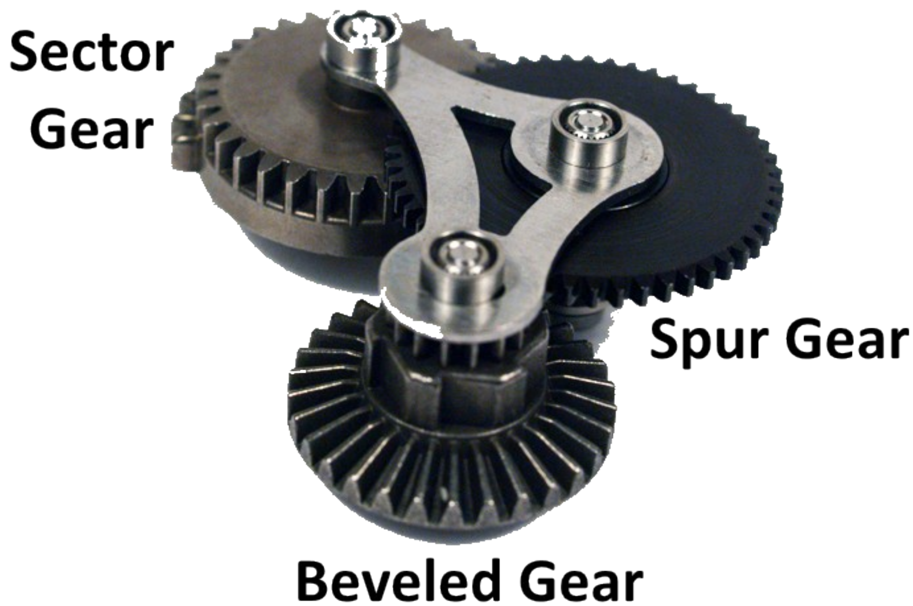



*A basic abstract view of the internals of a gearbox.*

That's the simple overview how an AEG propels BBs, but there's more details that have been left out.

The gears which interface with the piston have a few extra properties. The gears are engaged in a specific sequence to drive the piston and spring. A beveled gear transfers the rotational force at an angle, to transfer the rotational force from the motor (which is perpendicular to the gears) to the other two gears. The spur gear connects the beveled gear to the sector gear. The sector gear retracts the piston, and is missing teeth along a portion of its circumference. The missing teeth allow the piston to slip out of the gears to be driven forward by the spring. As the gears continue turning, the sector gear re-engages the piston after it reaches its forward-most position.

In the event that the gears cannot complete a full cycle, a latch (the anti-reversal latch) prevents the gears from rotating backwards. This latch interfaces with the beveled gear and is spring loaded to allow the latch to catch the gear if it attempts to move backwards. The three gears have multiple sets of teeth, with different tooth counts and circumferences, which gives the gear train a gear ratio. The gear ratio can be useful for allowing the last gear, the sector gear, to turn faster, with more torque, or some combination of the two.




*The three gears in sequence. Note the missing teeth in the sector gear. The anti-reversal latch interfaces with the upper portion of the pictured beveled gear.*

The piston is actually made up of five parts: the cylinder, the cylinder head, the piston, the piston head, and the nozzle. The cylinder is a simple tube, used to contain the air that's being compressed. The piston fits inside of the cylinder and has teeth running along its length to interface with the sector gear. The piston head is affixed to the front of the piston and is used to seal the inside of the cylinder as the piston is driven forward. The cylinder head is attached to the front of the cylinder and is used to guide the compressed air into the nozzle. The nozzle is used to chamber the BB and seals the barrel as the compressed air is sprayed in to propel it.

In order for an AEG to chamber a BB, it needs the nozzle to move out of the way of the barrel for a BB to be inserted. This is accomplished with a tappet plate, which is connected to the nozzle. The tappet plate runs along the side of the cylinder, and is engaged by a pin (or other protrusion) on the sector gear. As the sector gear rotates it pulls the tappet plate backwards which pulls the nozzle, opening the barrel. This occurs right before the piston slips out of the 'untoothed' portion of the sector gear. As the pin slips out from under the tappet plate a spring pulls it forward, pushing the nozzle forward and chambering a BB.

*A gearbox with the spring, spring guide, and piston removed. Note the black tappet plate below the cylinder and the black nozzle protruding from the front of the gearbox. The small expansion spring below the tappet plate retracts it before the piston moves forward.*

There are also a few miscellaneous parts that were left out. The spring envelops a spring guide, which prevents the spring from buckling as it is compressed. The trigger is a simple electric switch which completes the electric circuit to power the motor. All of the parts described above are contained inside a gearbox shell, and the entire system is referred to as a gearbox.

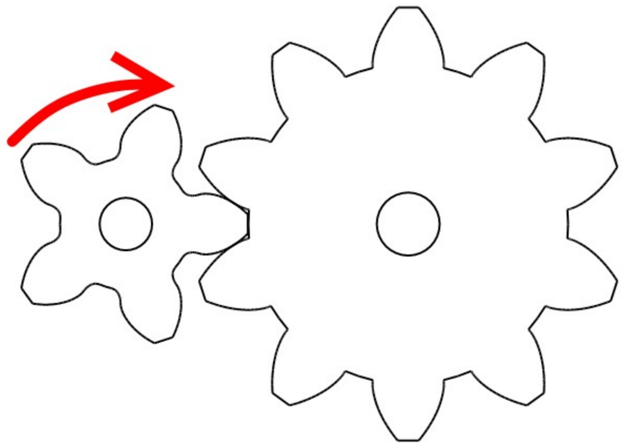
## Fire Modes

Most AEGs are capable of semi-automatic and full-automatic fire. As the gearbox was designed with full-automatic fire in mind, it is the standard fire mode for AEGs. In order to change fire modes between full-automatic, semi-automatic, and safe, a selector is needed. The selector switch on the outside of the airsoft gun slides a selector plate which creates different results when pulling the trigger. When the safe mode is on, a safety lever is moved to stop the trigger from being pulled. When the full-automatic mode is on, the circuit is completed when the trigger is pulled, which powers the motor to fire continuously until the trigger is released. There is more involved when the semi-automatic mode is selected; A cutoff lever is used to prevent the gearbox from firing more than once when the trigger is pulled. As the piston is driven forward, the cutoff lever breaks the electric circuit to prevent the airsoft gun from firing more than once. When the trigger is released, the cutoff lever resets to allow the airsoft gun to fire again.

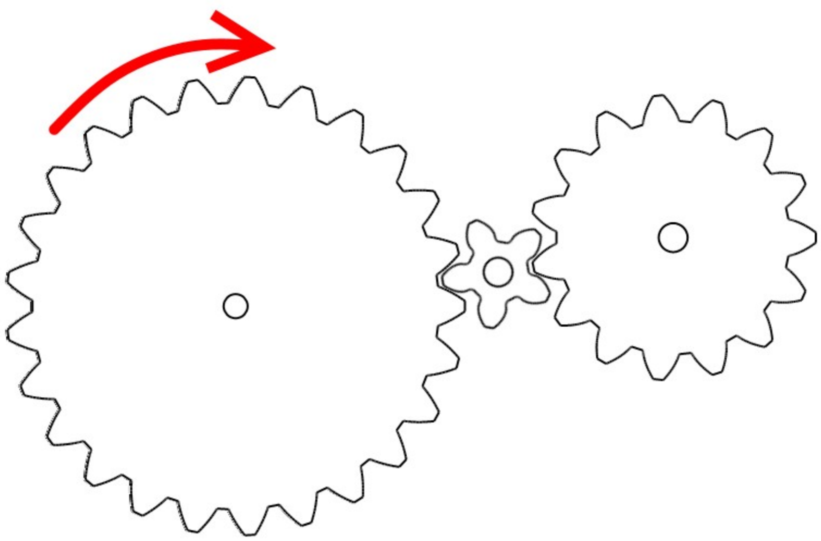
*The left side of a standard version 2 gearbox; Note the black selector plate above the trigger. The cutoff lever is on the inside of the gearbox.*

## Gear Ratios

When a train of gears have different tooth counts, they are said to have a gear ratio. A gear ratio describes the number of rotations needed for a drive gear (the input gear, or the gear being rotated) to rotate a driven gear (the output gear, or the gear performing work) once. For example, in the following 2 to 1 gear ratio the drive gear has to make two full rotations to rotate the driven gear once.



Although a gear ratio is technically calculated by comparing the gears' diameters, there is an easier way to find a gear ratio. To calculate a gear ratio, count the number of teeth on the drive gear and driven gear. The number of teeth on any intermediate gears are irrelevant, as they do not effect the rate of rotation of the drive and driven gears. Divide the tooth count of the driven gear by the tooth count of the drive gear; the result is your gear ratio.

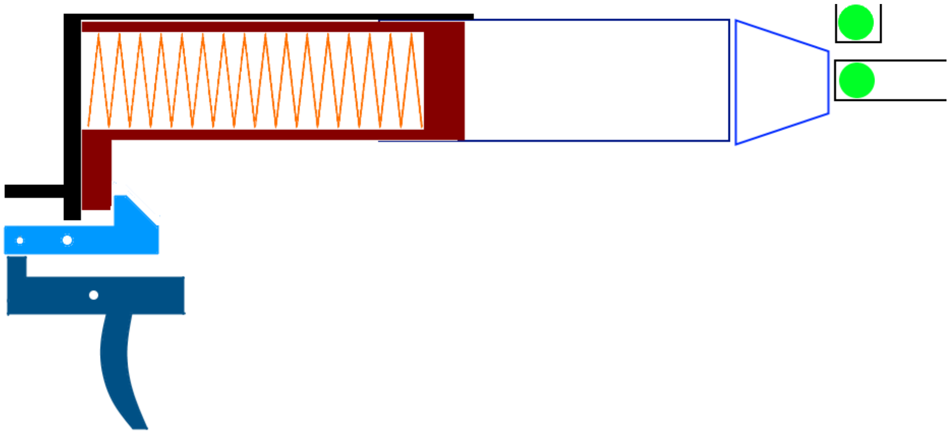


In the following gear train the drive gear has 25 teeth and the driven gear has 15 teeth. The gear ratio is 15/25, or 3/5. This means that as the drive gear rotates three times, the driven gear rotates five times. The 5 tooth intermediate gear is irrelevant when calculating the gear ratio.

Gear ratios are used to change the torque of the gear train. When a high gear ratio (such as 5/1) is used, the driven gear turns faster than the drive gear, but has less torque applied. The inverse is also true; a low gear ratio turns the driven gear more slowly, but with more torque.

## Spring Powered Guns

Spring powered guns are relatively simple compared to AEGs, but work with the same principles. A piston is used to compress air and propel a BB, though in this case the piston is retracted manually. The piston and spring can then be released by a sear which is connected to the trigger.



*An abstract diagram of a spring powered airsoft gun. The piston (dark red) is manually pulled back and is held by the sear (light blue), which is released when the trigger is pulled.*

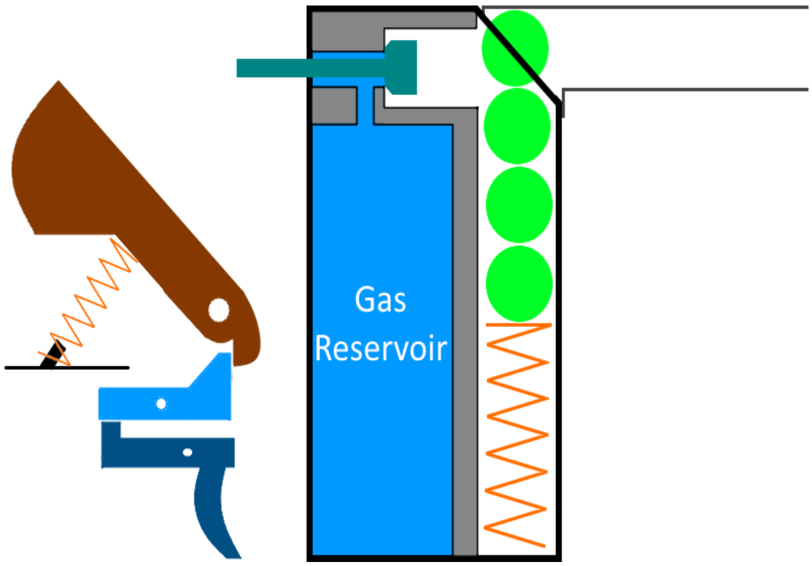
## Gas Powered Guns

Gas powered airsoft guns are those which use pre-compressed gasses to propel BBs as opposed to compressing gas as needed with a piston. In most gas powered guns, the removable magazine is the pressure vessel that stores the compressed gas. A hammer is used to strike a valve which releases enough gas from the magazine to propel one BB and actuate all of the mechanical systems to prepare the gun for another shot.

Any type of compressed gas could potentially be used in gas powered guns, though there are generally three types that are used. Some gas powered guns use disposable $CO_2$ cartridges while others use compressed propane. In addition, there is a product known as 'green gas' which is simply compressed propane with a lubricant as an additive.
It's important to note that when propane is used the propane is not burned during firing, as an airsoft gun that relies on burning propane would likely be considered a firearm.

*An example of a green gas magazine. The port on the bottom is the input valve and the button on the back is pressed to release gas.*

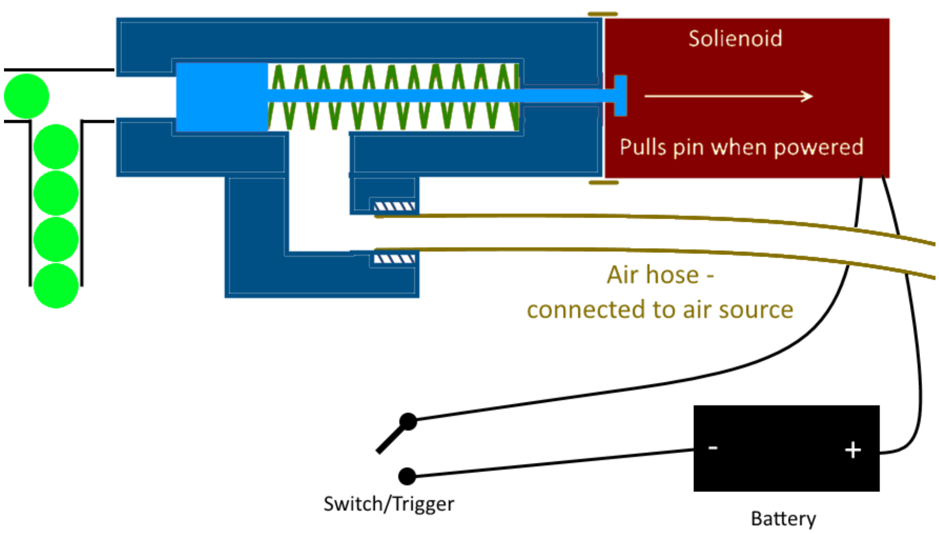
In either case, the compressed gas is under enough pressure to be condensed into a liquid form. During firing, the liquid $CO_2$/propane is released into the airsoft gun, which expands into its normal gaseous form. Although the pressure of the gas alone can propel BBs, the expansion of the liquid $CO_2$/propane into gas is what provides most of the propulsive energy to the BB. We can deduce this because as the gas expands it cools the surrounding air/objects, and when the airsoft gun is cold it does not perform as well as if it were hot. This is the reason that many airsofters complain that gas powered guns “don't work during the winter”.




*An abstract drawing of a gas powered airsoft gun. When the trigger is pulled the hammer strikes the pin on the magazine, which releases compressed gas to propel a BB.*

Another type of gas powered gun is an electro-pneumatic airsoft gun. This type uses both an air tank and a battery, where the battery is used to actuate a solenoid valve to release compressed air. Since the compressed air is released by a solenoid rather than a hammer striking a valve, the pressure and actuation time can be adjusted to change the amount of air that is released for each shot. The pressure is changed with a regulator which reduces the pressure of the air coming from the tank.

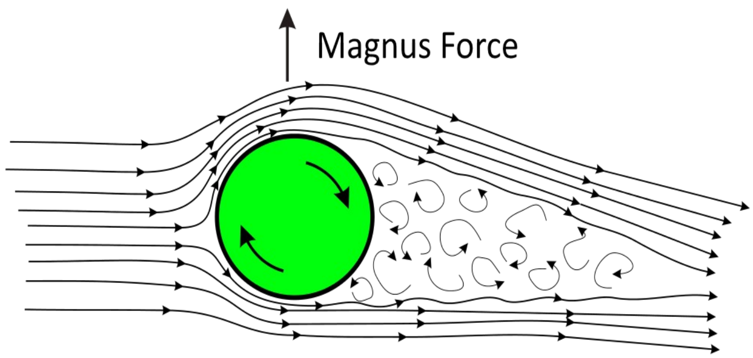
Unlike the other gas powered guns, the air often used in electro-pneumatic airsoft guns is compressed to such an extent that the pressure alone is enough to propel the BB. This greatly reduces the effect of cold weather on the performance of this type of airsoft gun. However since air does not condense into a liquid when pressurized, it must be brought to a much higher pressure for airsofters to carry a usable volume of air. Air tanks for these airsoft guns are rated for 3000PSI, or in some cases 4500PSI. Special air compressors are needed to generate such high pressures, and not all Airsoft fields have them. This can make using an electro-pneumatic airsoft gun difficult if your local field does not have a compressor; however, these types of airsoft guns are becoming more popular and more fields are investing in compressors, so this should become less of a problem over time.




*An abstract diagram of an electro-pneumatic airsoft gun. Note how the battery is only used to open the valve to release air.*

## Hop-up

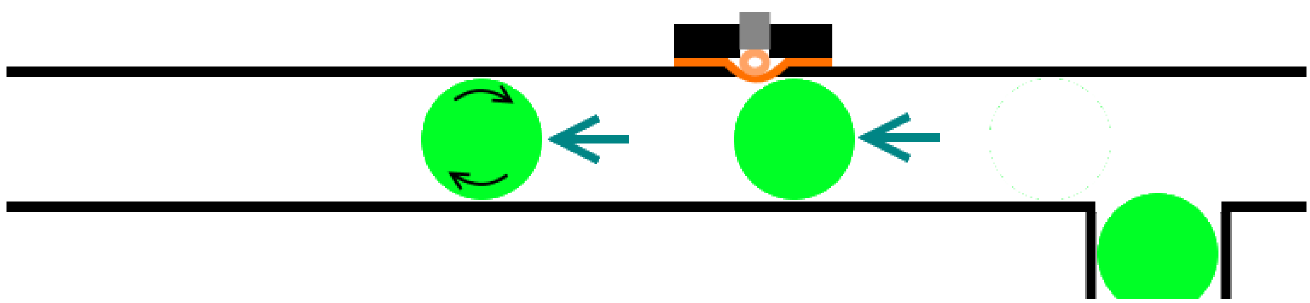
Many airsoft guns have a component called a hop up unit. A hop up unit allows the airsoft gun to shoot significantly farther than an equivalent airsoft gun without one. As such, having a high quality and well tuned hop up unit is a desirable feature to have in an airsoft gun. Hop up units use an aerodynamic phenomenon called the Magnus Effect to make the spherical BB generate a lifting force to counteract gravity. Under the Magnus Effect, a spinning cylinder or sphere in an airstream will direct some of the incoming air in the direction it is spinning, due to friction between the object and the air. The asymmetric flow of air creates a pressure difference around the object, causing the object to deviate from its direction of travel.




*As the object rotates, the incoming air is pushed up by friction with the object, creating a pressure difference.*

In the case of hop up units and BBs, the hop up unit provides a 'backspin' to the BB which causes the BB to have a lifting force. As the incoming air is 'pushed' upwards by the BB's backspin, the pressure above the BB drops relative to the other sides and the BB is pulled into the low pressure area. The hop up unit applies this backspin by adding a protrusion to the inside of the airsoft gun's barrel. As the BB is propelled through the barrel, the top of the BB strikes the protrusion and rotates to move through it.

Most hop up units consist of a rubber hop up nub, a spacer, and a screw or a set of gears. As the screw (or gears) is tightened, the spacer stretches the rubber nub into the barrel, providing the obstruction for the BB to get its backspin from. As the BB passes through the hop up unit, the rubber nub is pressed back by the BB, which compresses the rubber spacer. When the BB clears the hop up unit the spacer expands, pressing the rubber nub back into the barrel to obstruct the next BB.



*An abstract cross section of a typical hop up unit. The screw (gray) pushes the spacer (light orange) and nub (dark orange) into the barrel, obstructing the BB to provide a backspin.*

# Do it Yourself

If you want to have something better than a chineseism replica, you're gonna have to *DIY it yourself*. However you may find that it's more fun to build airsoft guns than it is to use them. You can use almost anything to build a DIY monstrosity, as most of the parts you can buy are either very robust or otherwise standardized. If you can think of a good design and use the proper materials, you can build something that can last for years without needing to be fixed. You'll also turn heads at your next day at the field, where everyone asks: “What the **** is *that*?”.

Do note however that when you build a DIY contraption, you have to hold yourself to a higher standard when it comes to safety. You'll need to prove that your invention is safe to use in airsoft, so always plan for that when building things.

## Power Sources

There are three main power sources to choose from when DIYing. You've got mechanical power in the form of springs and pistons, electric power with a standard gearbox, and compressed air. Using gunpowder or other combustibles is forbidden, as using even a single grain of gunpowder would classify your DIY contraption as a firearm, so don't use it!

The advantages and disadvantages should be self-evident, but let's list them anyway. With mechanical power sources you don't need to carry batteries, air tanks, or other consumables to use your DIY contraption. If built well, mechanical power sources can be more reliable than the others. However you'll need to manually actuate whatever mechanism you make to fire.
Electric systems can be useful if you want full automatic fire, and are relatively compact for what they're capable of. They're also cheap to power since they use rechargeable batteries. However off the shelf gearboxes are cheaply made, so unless you buy the highest end parts, or have parts custom made they will probably fail often. Using off the shelf gearboxes also limits you to shooting 6mm projectiles or smaller, whereas with the other two power sources you can scale things up or down to shoot larger, smaller, or heavier projectiles.
Gas power sources provide the greatest amount of energy of the three types for its size, and can still be very reliable. However gas systems are probably the most expensive of the three and there are additional safety concerns when building.

## Gas System Safety

Gas systems need special attention given to safety, so as to avoid explosions and shrapnel. All parts available for gas/water/air systems should have a max pressure rating. When a manufacturer tests a part for its pressure rating, they pressurize the part until it fails catastrophically (i.e. *explodes*). This failure point is often called the burst pressure, while the pressure rating is usually half or even less than half of the burst pressure. Thus, making sure that every part you use for a gas system has a pressure rating that is greater than the max pressure you intend to use will ensure that the gas system is safe.

There are additional safety devices you can use in a gas powered DIY contraption. You can use a regulator to reduce the pressure of the gas system. However everything 'upstream' of the regulator must have the proper pressure rating for whatever pressure you intend to use. In the event that your regulator fails, or whatever gas source you use inputs a higher pressure than normal, a burst disk can be installed. Burst disks are designed to break at a specific pressure in a safe, predictable way, which will release all of the pressure in the gas system to prevent a catastrophic failure. You'll need to replace the burst disk before using your gun again however.

It's also important to use the correct types of lubricant if you need them. Some lubricants (and other fluids) can combust when under pressure; combusting lubricant in a gas system would lead to a massive increase in pressure, which would almost guarantee a catastrophic failure.

You may want to use Polyinyl Chloride (PVC) pipes in your DIY contraptions due to its low cost and easier machinability, however PVC should not be used for high pressure systems. In addition to its relatively low pressure rating, PVC loses structural integrity as it's exposed to ultraviolet light (e.g. *sunlight*), and tends to become less impact resistant over time. A UV light exposed PVC pipe will shatter on impact with things rather than flex, which would have nasty results. The only exception to this could perhaps be in the case of prototyping, where the prototype will be thrown away after testing.

Each type of gas one can use has a different pressure rating (on average). Green gas/propane has the lowest pressure level while CO2 capsules have more and High-Pressure-Air (HPA) has the highest. More recently there are new gas types being produced by a company called Nuprol which they call “Red Gas” and “Black Gas”. These new products are the same as green gas chemically, but are packaged at a higher pressure.

The table to the right shows the average pressure of each type of gas. To ensure that your designs are safe you should always use parts that are rated for more than the average pressure. This is because the pressure of a gas changes with temperature; as the temperature increases so does the pressure.

| Type | Average Pressure (PSI) |
|---|---|
| Propane | 145 |
| Green Gas | 108 |
| “Red Gas” | 144 |
| “Black Gas” | 189 |
| CO2 | 850 |
| HPA | 850+ |

# DIY Part Ideas

When building DIY contraptions, you do not necessarily need to use parts that are “for airsoft guns”. Anything can be used as a part for a DIY contraption, provided that you're using your imagination. Below are some ideas for things you can use for your DIY contraptions. These ideas should get you to think about how you can use anything to make an airsoft gun.

**Empty cartridges/shells**

Empty shotgun shells can be used, provided that they are de-primed, to hold whatever you're going to shoot. Empty cartridges (being de-primed) could be used to hold a single BB in place. Compressed air can then be sprayed into the hole formerly occupied by the primer to propel the BB/shot. Using once-fired shells/cartridges would be a significantly cheaper alternative to using proprietary shells designed for airsoft.

A couple good candidates for cartridge sizes for standard airsoft BBs include 5.8×21mm DAP92 and 5.8×42mm. Curiously both of these cartridge types were invented in China, so they might be hard to find in the US.

**Hose Barbs**

Can be useful to pass air through a small space (e.g. into a barrel), or with flexible tubing it could be connected to a magazine to feed BBs. If the barb is cut off, it could be a threaded piece with flat end to mate with the back of a cartridge/shell.

**Break Lines**

These can be used as an alternative to barrels for airsoft guns. However not all break lines are useful; one must make sure that the inner diameter is slightly over 6mm to fit BBs.

**Door hinges**

Can be used with folding stocks, or for dust covers. Could also be used to connect two parts of a break-barrel type gun.

**Clevis Pins**

Useful in combination with a pin for a quick disconnect system. A large enough clevis pin could potentially be used as a robust magazine for BBs.

**Hose Barb Wye**

Could be used as the joint where BBs and compressed air meet. It could act as a venturi valve which would 'suck' the BBs into the joint.

**Copper Tube Straps**

These can be used for their intended purpose, or could be flattened out easily for a cheap flexible copper piece for other things.

**Split Ring Pipe Hangars**

These can be used to fasten a pipe/barrel into place.

**Airsoft Gun Barrels**

Besides using these as barrels, they could also be used as internal magazines if you add a compression spring and follower.

**Pressure Washer Wand/Gun**

These are excellent mechanisms for releasing a lot of gas quickly. They're capable of holding a lot of pressure, and the plastic enclosure can be drilled through to attach other things.

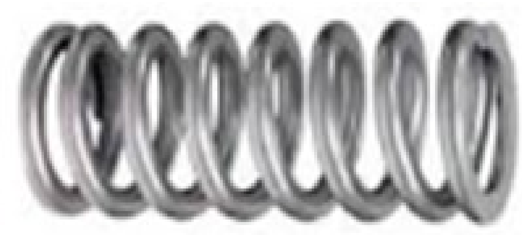
**Reball**

These projectiles could be a larger and heavier alternative to regular 6mm BBs.

# Springs (And Things)

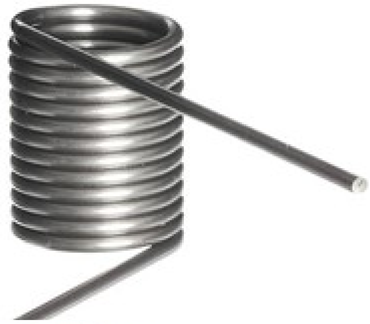
Springs are used often in airsoft guns for many different purposes. Below is a quick list of the types of springs available so you know what you're looking for if you need a spring for your DIY things.

**Compression Spring**
This type of spring is used to push things apart; it's compressed as a load is applied to it. These are the types of springs used to drive pistons in AEG gearboxes and spring powered guns.



**Extension Spring**
This type of spring is used to pull things together; it extends as a load is applied to it. Some uses for this spring type include 'resetting' parts like the tappet plate in an AEG.

**Torsion Spring**
This type of spring rotates as a load is applied. These springs could be used to rotate a hammer or to return a trigger.



**Constant Force Spring**
This type of spring is a tightened band of steel which provides a constant pulling force as it is unraveled. On example of these springs in use is in a tape measure. These are also used in 'high-cap' airsoft magazines to feed BBs after it's winded up.

# Candy as Ammunition

Some types of candy could be useful as ammunition in DIY contraptions. Below are a few notes on different types of candy and their properties found during testing. Cost per shot may vary depending on location. The notes provided were found by testing each type of candy using the Petite A.S.S. (more info available at: airsoftrnd.com/the-petite-ass/)

**Skittles**
Mass: ~1.04g
Muzzle Energy (@200 ft/s): ~0.193J
Size: 0.5” x 0.5” x 0.3125”
Cost per Shot: ~$0.0024/each
Performs well as a buckshot like projectile. Has a tighter grouping than BBs at medium range when fired in groups.

**M&Ms**
Mass: ~0.90g
Muzzle Energy (@200 ft/s): ~0.167J
Size: 0.5” x 0.5” x 0.25”
Cost per Shot: ~$0.00252/each
Performs similarly to the skittles, but can be crushed prematurely if loaded incorrectly. Tends to deform when impacting hard objects, which probably delivers more of its energy to the target. Leaves chocolate as residue on impact point in hot weather.

**Mentos**
Mass: ~2.80g
Muzzle Energy (@200 ft/s): ~0.39J
Size: 0.75” x 0.75” x 0.40625”
Cost per Shot: ~$0.75/each
Works well as a slug like projectile. Interestingly, it can “hop up” itself due to its shape, causing them to gradually glide up as they fly. They fit in 12ga shells perfectly.

**Tic-Tacs**
Mass: ~0.50g
Muzzle Energy (@200 ft/s): ~0.93J
Size: 0.4375” x 0.4375” x 0.25”
Cost per Shot: ~$0.0172/each
The closest candy in size/mass to regular BBs with similar ballistic properties.

**Whoppers**
Mass: ~0.572g
Muzzle Energy (@200 ft/s): ~0.11J
Size: 0.75” x 0.75” x 0.75”
Cost per Shot: ~$0.0042/each
Another effective slug like projectile. Leaves a small mark of chocolate at the point of impact. Also tends to shatter on impact.

**Marshmellows**
Mass: ~6.31g
Muzzle Energy (@200 ft/s): ~1.17J
Size: 2.125” x 2.125” x 1.25”
Cost per Shot: ~$0.023/each
Completely ineffective; it's difficult to load and has terrible ballistic properties.

# Appendix

## Formulas

Below are a few formulas used for ballistic calculations that are relevant to airsoft BBs.

Kinetic Energy

$$KE = {}^{1}/_{2} * M * V^{2}$$

KE: Kinetic Energy, in Joules or foot-pounds
M: Mass, in kilograms or slugs
V: Velocity, in meters per second or feet per second

This formula is used to calculate the kinetic energy of a projectile. Though this formula can be used at any point in time in the projectile's flight, it is most often used to find the muzzle energy.

Velocity Estimation

$$V_2 = V_1 * \sqrt{(W_1 / W_2)}$$

$V_1$: Velocity of projectile 1, in meters per second or feet per second
$V_2$: Velocity of projectile 2, in meters per second or feet per second
$W_1$: Mass of projectile 1, in kilograms or pounds
$W_2$: Mass of projectile 2, in kilograms or pounds

This formula can be used to estimate the velocity of a similar projectile based on the performance of a reference projectile.

Aerodynamic Drag

$$F_D = {}^{1}/_{2} * D_C * D_A * V^{2} * A$$

$F_D$: Drag force, in newtons
$D_A$: Air density, in kilograms per cubic meter
V: Projectile velocity, in meters per second
$D_C$: Drag coefficient, a unitless value for how well the projectile can pass through air. On average, the drag coefficient for a sphere is 0.47.
A: The area of the projectile exposed to an airstream, in square meters

This formula can be used to find the force applied to projectiles as they pass through air.

Reynolds Number

$$Re = \frac{Vi * L}{Kv}$$

Re: The reynolds number
Vi: The velocity of the projectile, in meters per second
L: The length of the projectile, in meters
Kv: The kinematic viscosity of the air, in square meters per second. Air at 10°C has a kinematic viscosity of: 0.000014207 $m^2/s$.

The reynolds number is used to estimate the coefficient of drag for an object.

## Optimal Rate of Fire

$_{O}ROF = (rt * 2) + (d / pv) + (d / s)$

$_{O}$ROF: The optimal delay between shots, in seconds
rt: The reaction time of the average player, in seconds
d: The distance between the players, in feet or meters.
pv: The projectile's velocity, in feet per second or meters per second.
s: The speed of sound, in feet per second or meters per second.

This formula can be used to calculate the optimal time between shots to prevent bonus-balling.

## Terminal Energy

Calculating Terminal Energy requires a multi-step process that is best done by a computer. However here's how to step through one iteration of the process. The required information includes:

TE: The terminal energy limit in Joules
M: The projectile's mass in kilograms
KE: Kinetic energy of the projectile in Joules - starts at the airsoft gun's muzzle energy
D: The distance the projectile traveled in meters - starts at 0
V: Projectile velocity, in meters per second
$D_C$: Drag coefficient, a unitless value for how well the projectile can pass through air.
A: The area of the projectile exposed to an airstream, in square meters
$D_A$: Air density, in kilograms per cubic meter
$T_S$: The time step used for each iteration, in seconds - a smaller value is more precise, but requires more iterations to find D

Step 1: Increase the distance traveled by the projectile's velocity times the time step

$$D \mathrel{+}= V * T_S$$

If KE is less than or equal to TE at this point, the distance value is your MED

Step 2: Calculate the drag force of the projectile at its current velocity using:

$$F_D = \tfrac{1}{2} * D_C * D_A * V^2 * A$$

Step 3: Multiply the drag force by the projectile's mass. If the projectile is a hopped up BB, add gravity (~9.8) to the total deceleration.

$$V_D = (F_D * M) + G$$

Step 4: Reduce the projectile's velocity by the deceleration times the time step

$$V \mathrel{-}= V_D * T$$

Step 5: Recalculate the projectile's energy using the kinetic energy formula:

$$KE = \tfrac{1}{2} * M * V^2$$

# Round Ball Ballistics Info

Here's some information I've compiled which is useful for ballistics calculations for BBs and other BB-like projectiles.

One pound ball with a 1 inch diameter:

Ballistic Coefficient: 0.645
Form Factor: 1.55
Sectional Density: 1

Standard 0.2g BB

Ballistic Coefficient: 0.005
Form Factor: 1.55
Sectional Density: 0.0079

Standard 0.43g BB

Ballistic Coefficient: 0.011
Form Factor: 1.55
Sectional Density: 0.017

Reball

Diameter: 0.68 inches
Mass: 41 grains (2.65676 grams)

Ballistic Coefficient: 0.008
Form Factor: 1.55
Sectional Density: 0.0127

## Pipe Diameters

Pipes of various types are excellent for barrels and expansion chambers. If you're looking to launch a specific projectile, find the pipe with the closest inner diameter to your projectile diameter. Below is a set of tables for different pipe standards. All sizes are in inches. Note that the nominal size is what we refer to when talking about specific pipe sizes, although the nominal size often does not match its actual size.

Copper (ASTM B-88)

| | | Inner Diameter | | |
|---|---|---|---|---|
| Nominal | Outer Diameter | Type K | Type L | Type M |
| 3/8 | 1/2 | 0.402 | 0.430 | 0.450 |
| 1/2 | 5/8 | 0.528 | 0.545 | 0.569 |
| 5/8 | 3/4 | 0.652 | 0.668 | 0.690 |
| 3/4 | 7/8 | 0.745 | 0.785 | 0.811 |
| 1 | 1 1/8 | 0.995 | 1.025 | 1.055 |
| 1 1/4 | 1 3/8 | 1.245 | 1.265 | 1.291 |
| 1 1/2 | 1 5/8 | 1.481 | 1.505 | 1.527 |
| 2 | 2 1/8 | 1.959 | 1.985 | 2.009 |

Copper ACR (ASTM B-280)

| | Flexible | | Rigid | |
|---|---|---|---|---|
| Nominal | Outer Diameter | Inner Diameter | Outer Diameter | Inner Diameter |
| 1/8 | 0.125 | 0.065 | N/A | N/A |
| 3/16 | 0.187 | 0.128 | N/A | N/A |
| 1/4 | 0.250 | 0.190 | N/A | N/A |
| 5/16 | 0.312 | 0.248 | N/A | N/A |
| 3/8 | 0.375 | 0.311 | 0.375 | 0.315 |
| 1/2 | 0.500 | 0.436 | 0.500 | 0.430 |
| 5/8 | 0.625 | 0.555 | 0.625 | 0.545 |
| 3/4 | 0.750 | 0.680 | 0.750 | 0.666 |
| 7/8 | 0.875 | 0.785 | 0.875 | 0.785 |
| 1 1/8 | 1.125 | 1.025 | 1.125 | 1.025 |
| 1 3/8 | 1.375 | 1.265 | 1.375 | 1.265 |

| Steel (ASTM A53) | | | | |
|---|---|---|---|---|
| | SCH 40 | | SCH 80 | |
| Nominal | Outer Diameter | Inner Diameter | Outer Diameter | Inner Diameter |
| 1/8 | 0.405 | 0.27 | 0.41 | 0.22 |
| 1/4 | 0.540 | 0.36 | 0.54 | 0.30 |
| 3/8 | 0.675 | 0.49 | 0.68 | 0.42 |
| 1/2 | 0.840 | 0.62 | 0.84 | 0.55 |
| 3/4 | 1.050 | 0.82 | 1.05 | 0.74 |
| 1 | 1.315 | 1.05 | 1.32 | 0.96 |
| 1 1/4 | 1.660 | 1.38 | 1.66 | 1.28 |
| 1 1/2 | 1.900 | 1.61 | 1.90 | 1.50 |
| 2 | 2.375 | 2.07 | 2.38 | 1.94 |
| 2 1/2 | 2.875 | 2.47 | 2.88 | 2.32 |
| 3 | 3.500 | 3.07 | 3.50 | 2.90 |
| 3 1/2 | 4.000 | 3.55 | 4.00 | 3.36 |
| 4 | 4.500 | 4.03 | 4.50 | 3.83 |
| 5 | 5.563 | 5.05 | 5.56 | 4.81 |
| 6 | 6.625 | 6.07 | 6.63 | 5.76 |

| PVC (ASTM D1785) | | | | |
|---|---|---|---|---|
| | SCH 40 | | SCH 80 | |
| Nominal | Outer Diameter | Inner Diameter | Outer Diameter | Inner Diameter |
| 1/2 | 0.840 | 0.622 | 0.840 | 0.546 |
| 3/4 | 1.050 | 0.824 | 1.050 | 0.742 |
| 1 | 1.315 | 1.049 | 1.315 | 0.957 |
| 1 1/4 | 1.660 | 1.380 | 1.660 | 1.278 |
| 1 1/2 | 1.900 | 1.610 | 1.900 | 1.500 |
| 2 | 2.375 | 2.067 | 2.375 | 1.939 |
| 2 1/2 | 2.875 | 2.469 | 2.875 | 2.323 |
| 3 | 3.500 | 3.068 | 3.500 | 2.900 |
| 4 | 4.500 | 4.026 | 4.500 | 3.826 |
| 5 | 5.563 | 5.047 | 5.563 | 4.813 |
| 6 | 6.625 | 6.065 | 6.625 | 5.761 |

# ASTM Thread Standards

Although you might not need this information if you DIY things with parts from a hardware store, the following tables can be very useful if you're drawing blueprints or designing things on a computer. All dimensions below are in inches.

| Unified Coarse Thread (UNC) | | | | |
|---|---|---|---|---|
| Nominal | Threads Per Inch | Major Diameter | Tapping Drill Size | Pitch |
| #1 | 64 | 0.073 | 0.059 | 0.0156 |
| #2 | 56 | 0.086 | 0.071 | 0.0178 |
| #3 | 48 | 0.099 | 0.830 | 0.0208 |
| #4 | 40 | 0.112 | 0.0925 | 0.025 |
| #5 | 40 | 0.125 | 0.104 | 0.025 |
| #6 | 32 | 0.138 | 0.112 | 0.031 |
| #8 | 32 | 0.164 | 0.138 | 0.031 |
| #10 | 24 | 0.190 | 0.157 | 0.042 |
| #12 | 24 | 0.216 | 0.183 | 0.042 |
| 1/4 | 20 | 0.250 | 0.211 | 0.050 |
| 3/8 | 16 | 0.375 | 0.325 | 0.062 |
| 1/2 | 13 | 0.500 | 0.439 | 0.077 |
| 5/8 | 11 | 0.625 | 0.553 | 0.091 |
| 3/4 | 10 | 0.750 | 0.669 | 0.100 |
| 1 | 8 | 1.000 | 0.8996 | 0.125 |
| 1 1/8 | 7 | 1.125 | 1.009 | 0.143 |
| 1 1/4 | 7 | 1.250 | 1.136 | 0.143 |
| 1 1/2 | 6 | 1.500 | 1.366 | 0.167 |
| 1 3/4 | 5 | 1.750 | 1.590 | 0.200 |
| 2 | 4.5 | 2.000 | 1.823 | 0.222 |
| 2 1/4 | 4.5 | 2.250 | 2.073 | 0.222 |
| 2 1/2 | 4 | 2.500 | 2.303 | 0.250 |
| 2 3/4 | 4 | 2.750 | 2.549 | 0.250 |
| 3 | 4 | 3.000 | 2.799 | 0.250 |

| Unified National Fine Thread (UNF) | | | | |
|---|---|---|---|---|
| Nominal | Threads Per Inch | Major Diameter | Tapping Drill Size | Pitch |
| #0 | 80 | 0.060 | 0.049 | 0.0125 |
| #1 | 72 | 0.073 | 0.061 | 0.0139 |
| #2 | 64 | 0.068 | 0.075 | 0.0156 |
| #3 | 56 | 0.099 | 0.085 | 0.0178 |
| #4 | 48 | 0.112 | 0.094 | 0.0208 |
| #5 | 44 | 0.125 | 0.106 | 0.0227 |
| #6 | 40 | 0.138 | 0.116 | 0.025 |
| #8 | 36 | 0.164 | 0.138 | 0.0278 |
| #10 | 32 | 0.190 | 0.161 | 0.0313 |
| #12 | 28 | 0.216 | 0.185 | 0.0357 |
| 1/4 | 28 | 0.250 | 0.216 | 0.0357 |
| 3/8 | 24 | 0.375 | 0.335 | 0.0417 |
| 1/2 | 20 | 0.500 | 0.453 | 0.0500 |
| 5/8 | 18 | 0.625 | 0.571 | 0.0555 |
| 3/4 | 16 | 0.750 | 0.689 | 0.0625 |
| 1 | 12 | 1.000 | 0.915 | 0.0833 |
| 1 1/8 | 12 | 1.125 | 1.043 | 0.0833 |
| 1 1/4 | 12 | 1.250 | 1.161 | 0.0833 |
| 1 3/8 | 12 | 1.375 | 1.289 | 0.0833 |
| 1 1/2 | 12 | 1.500 | 1.417 | 0.0833 |

## Imperial-Metric Conversion Table

Here's a simple table for various units of measurement to convert values from Imperial to Metric, or vice-versa. Simply multiply the value you have by what's in the table and you'll have your converted value. (Note that there may be a negligible amount of error when converting back and forth repeatedly.)

| | |
|---|---|
| Grains to Grams | 0.0647989 |
| Ounces to Grams | 28.3495 |
| Pounds to Kilograms | 0.453592 |
| | |
| Foot-Pounds to Joules | 1.35582 |
| | |
| Yards to Meters | 0.9144 |
| | |
| Bar to Pascals | 100000 |
| | |
| Feet per Second to Meters per Second | 0.3048 |

| | |
|---|---|
| Grams to Grains | 15.4324 |
| Grams to Ounces | 0.035274 |
| Kilograms to Pounds | 2.20462 |
| | |
| Joules to Foot-Pounds | 0.737562 |
| | |
| Meters to Yards | 1.09361 |
| | |
| Pascals to Bar | 0.00001 |
| | |
| Meters per Second to Feet per Second | 3.28084 |