P.O. Box 299 Geneseo IL 61254 Tel 309-944-6939 fax 309-944-6949 info@armalite.com

September 4, 2013 Rev 1

TECHNICAL NOTE 104: SOME THOUGHTS ON DESIGN AND RELIABILITY OF AR-STYLE FIREARMS

BACKGROUND:

All self-powered firearms are dynamic systems. Dynamic movement and relative timing of various components of the mechanism during the firearm's cycle of operation are critical to the firearm's reliability.

The original AR-15 Rifle design was dynamically well balanced. The AR-15 was designed to assure that all components were given enough time, and enough power, and enough space, and enough strength to perform their functions.

Subsequent variants of the AR-15 (particularly carbines) required design tradeoffs that caused some loss of that dynamic balance.

The U.S. military's M4 Series Carbines have developed a reputation for reduced reliability compared to the excellent reliability of the full length M16 Series Rifles. The somewhat higher malfunction rate of the M4 Carbine is due to dynamic imbalances in the mechanism itself, exacerbated by heat. The dynamic imbalances are a result of the desire for a shorter, lighter firearm. Consciously, or unconsciously, the requirement for more compactness inevitably resulted in a reduction in reliability.

A complete, detailed explanation of all dynamic considerations in firearm design is far beyond the scope of this Technical Note. However, some basic considerations can be presented.

The dynamic cycle of self-powered firearms is typically powered by two forces. Recoil is powered by the cartridge. Counterrecoil is powered by a spring.

In order for the firearm to cycle reliably in recoil, the cartridge must provide enough energy to push the bolt and bolt carrier assembly and empty cartridge case fully to the rear of its stroke without overpowering the bolt, thereby causing collateral wear and damage to the mechanism. And, the firearm must "time" the recoil cycle after the gas pressure in the barrel has subsided enough that the cartridge case can be freed from the chamber walls and successfully extracted. During recoil, the cartridge's energy will be expended unlocking the bolt, extracting and ejecting the empty cartridge case, recocking the hammer, and pushing the bolt and bolt carrier to the rear. The amount of power needed to accomplish these tasks varies somewhat from shot to shot, and varies even more depending on the environment and cleanliness/lubrication of the firearm.

In order for the firearm to cycle reliably in counterrecoil, the cartridge must provide enough energy to fully compress the recoil spring to give the spring its maximum potential energy. That full compression also gives the bolt maximum dwell time behind the feed position so that a new cartridge has time to be raised up in the magazine to the feed position. Then the recoil spring must have enough energy to feed the new cartridge into the chamber, lock the bolt, and (with assistance from the buffer) resist the natural tendency for the bolt carrier to bounce out of battery.

Let’s explore why the requirement for a more compact carbine forced tradeoffs that were detrimental to reliability.

DURING RECOIL:

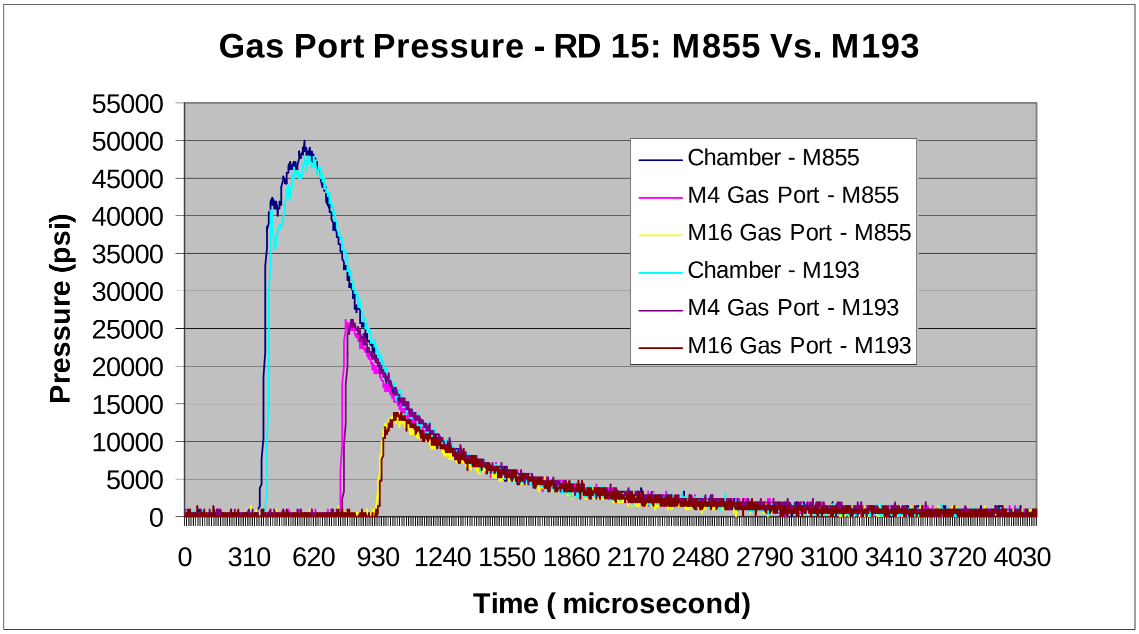
Analysis of carbine reliability issues during recoil requires a good understanding of the bolt carrier group and barrel of the rifle, and the functions of the cartridge case.

The distance from the chamber to the gas port, the length of barrel beyond the port, and the pressure of the propellant gasses determine the amount of energy provided to the action of the M-16 series rifle.

The heart of the M-16 operating system, the bolt carrier group, was designed to function well with the original 20 inch long barrel of that rifle. The bolt carrier group and the location of the gas port were carefully balanced to provide outstanding reliability with the ammunition that was designed for the M16.

A change in the cartridge (bullet weight or powder), the length of the barrel, or the location of the gas port along the barrel can substantially change the pulse of gas that enters the carrier group and drives the rifle action. Short versions of the M16 (including the M4) suffer from relocation of the gas port and changes in barrel length. The shorter the barrel, and the nearer the gas port to the chamber, the more sensitive the firearm is to variations in ammunition.

The below U.S. Army graph of gas pressure in various locations for the M16 Rifle and M4 Carbine is very instructive. Let’s see what we can learn from it.



(Note: The timeline of the government-generated chart above is measured in millionths of a second)

The early 5.56mm cartridge was designated the M193. Years ago, the M193 was replaced by the M855 which contained a heavier projectile. The Army changed propellants to assure that the pressure that powered the firearm didn't change. Note that the chamber pressure and gas port pressures of the M855 are nearly identical to those of the M193. The Army was well aware of the need for consistency in these pressures.

However, note the difference in the pressure and timing of the gas port pressures in the M4 versus those in the M16. The gas port pressure of the M4 is approximately twice as high as that of the M16, and the projectile reaches the gas port in the M4 much sooner than it reaches the gas port in the M16.

Also note the slope of the curves at the M4 and M16 port locations. The slope of the curve for the M4 is much steeper than that of the M16. The slope shows how rapidly the gas pressure is changing. So, the gas pressure at the M4 port location is changing much more quickly than at the M16 location. What this means is that small variations in propellant will have much more effect on port pressure of the M4 than on port pressure of the M16. And increased variation implies decreased reliability.

The carbine gas port is located closer to the chamber than the gas port of the rifle: 7.5 inches instead of the 13 inch distance on the rifle. The gas pulse therefore enters the gas tube sooner and reaches the carrier group earlier than it does in the rifle length barrel. In addition to reaching the carrier sooner, it reaches it at higher pressure. The gas pressure at the carbine's gas port is double that of the rifle: 26,000 psi vs. 13,000 pounds per square inch.

To compensate for the higher pressure, the carbine's gas port must be smaller in diameter than the rifle's port. The smaller port is naturally more sensitive to variations in pressure as well as to contamination than the larger port. The higher pressure and temperature at the carbine port also causes more erosion of the barrel at the port.

The early pressurization of the carrier causes the carbine to begin to extract earlier than the rifle does. At the same time, the gas in the carbine's carrier is of higher pressure than it is in the rifle, and it forces the carrier to move the rear at a higher velocity than it moves in the rifle. Because of the earlier extraction, the cartridge case has less time to transfer heat to the chamber wall and shrink away from it before extraction begins. The cartridge case has a tendency to adhere to the chamber wall, and resistance to rearward movement can be high.

When the bolt, drawn rearward by the high velocity bolt carrier, tries to pull this stuck case to the rear, both the extractor and cartridge case are heavily stressed. The resistance can cause the whole mechanism to become sluggish or stop, or to cause early failure of the extractor or bolt.

As discussed above, the distance from the chamber to the gas port is important. So too is the length of the barrel *past* the gas port.

That's because the bullet serves as a plug to keep the gas pressure trapped in the barrel so that some of it can pass into the gas tube and back to the carrier. If the length of barrel beyond the gas port is too short, so is the "dwell" of the plug in the barrel. The gas pulse supplied to the carrier can be too short to deliver all of the energy that the carrier group needs. Too long a section of barrel beyond the gas port can cause too long a gas pulse.

Carbines with very short barrels (less than 12 inches) have a very short segment of barrel beyond the gas port; and the gas pulse is thus shorter than the carrier group needs. This problem combines with the carbine problems already described resulting in reliability of carbines with short barrels to be significantly poorer than carbines with longer barrels.

Efforts to adjust for the short length of barrel beyond the gas port by enlarging the gas port produce a firearm that is extremely sensitive to differences in ammunition. Efforts to correct the problem by using different springs or buffers or by changing the volume of the gas used are only partially successful.

The faster movement of the carrier group in carbines also creates an interesting and largely unknown problem with the extractor. During extraction, the extractor opens for a very short period, and then recovers to complete extraction. The faster movement of the carbine bolt increase the time that the extractor is open. This tends to decrease extractor efficiency and increase extraction trouble.

And, to exacerbate the problem, the propellant has not burned as completely when the gas reaches the carbine's port, so the firearm's internal mechanism gets dirtier, increasing the need for cleaning and potentially causing malfunctions if a stringent cleaning regimen isn't followed.

DURING COUNTERRECOIL:

The effect on reliability of shortening the rear end of the rifle is, perhaps, more subtle than the effect of shortening the front end. In order to reduce the length of the rear half of the M16, the buffer tube, the recoil spring, and the buffer all had to be redesigned. The redesign changes the nature of the power stroke provided by the recoil spring. In addition, one purpose of the buffer is to inhibit the bolt carrier from "bouncing" back out of battery. A bolt carrier slightly out of battery can absorb the blow of the hammer, causing failures to fire. The shorter carbine buffer simply isn't as efficient at preventing bolt carrier bounce as is the rifle buffer.

OTHER SYSTEM EFFECTS OF REDUCING BARREL LENGTHS:

Remember that the only purpose of the firearm is to project a bullet to it a target. Reducing barrel length has consequences beyond the firearm itself. Negative "system" impacts of reducing barrel length include:

1. reducing muzzle velocity;
2. increasing the arch of the bullet's trajectory;
3. increasing muzzle blast and muzzle flash;
4. reducing the effectiveness of terminal ballistics (damage) to the target.

The shorter the barrel, the worse the consequences. So, wise customers do not purchase barrels shorter than absolutely necessary for their tactical situations.

EFFECT OF HEAT ON FIREARM FUNCTION:

Heat increases the carbine problems listed above. Understanding the effect of heat requires a firm understanding of the purpose and action of a component of the firearm system that is often overlooked: the cartridge case. The cartridge case is a highly sophisticated component that performs a number of functions

1. The case holds components (bullet, primer, powder) together precisely.
2. It engages key surfaces of the magazine and rifle to transport the cartridge's components into the chamber.
3. Upon firing, it expands into intimate contact with the chamber wall to seal high pressure gas in the barrel.
4. It contracts from the chamber wall when pressures lower to an acceptable level.
5. It transfers some of the heat within the case to the chamber wall.
6. It transports heat out of the weapon when extracted.

When the weapon heats up from extended firing, it is harder for the cartridge case to transfer heat to the hot chamber wall and shrink away from it. Adhesion of the cartridge case to the chamber wall results in increased resistance to extraction.

Heat affects carbines more than it affects rifles because of the carbine's earlier extraction at higher pressures and temperatures. Because heat affects a carbine, let's discuss heating in more detail

.

EFFECTS OF HEAT ON THE BARREL:

BARREL STRUCTURAL FAILURES: In addition to increasing the malfunction rate, excess heat weakens the material of the barrel. The barrel of the M4 carbine is made of chrome-molybdenum-vanadium steel, and is chrome lined. It is a high quality grade of steel capable of long service. This steel tolerates high temperatures well. At a temperature of approximately 1100 degrees, however, the structure of this alloy (and most alloys) undergoes a permanent transformation that substantially, and permanently, alters it. The steel becomes prone to rupture under high pressure. It may not fail at the time of overheating, but instead may fail at a later date and far lower temperature. Thus, the cause of the failure may not be apparent to the user.

USEFUL BARREL LIFE: In actuality, very few barrels reach the end of their useful life via catastrophic failure. Most of them become inaccurate before they physically fail. The higher the rate of fire, the hotter the barrel gets. The hotter the barrel gets, the more erosion eats away at the bore's surface. Eventually, the bore surface is so eroded that it can't adequately spin the projectile to stabilize it. So, to maximize barrel life, minimize rate of fire.

COOKOFFS: If too many rounds are fired too rapidly, the firearm's barrel can become so hot that a live round left in the chamber will ignite. This is called a "cookoff". If a firearm is often fired at such a high rate that a cartridge will cook off, the barrel life will certainly be adversely affected. In addition, cookoff can be a serious safety hazard. Typically, the cartridge will cookoff unexpectedly. If the firearm happens to be pointed in an unsafe direction at the time, unintended casualties and/or damage can result. Cookoff is taken so seriously by the military that military manuals contain maximum advisable rates to avoid it. For the M16, maximum **sustained** rate to avoid cookoff is 12-15 rounds per minute. Firing an M16 as rapidly as possible for less than 150 rounds can also cause a cookoff.

ELIMINATING BARREL FAILURE:

Design efforts to reduce barrel failure have taken at least three approaches: 1 different materials or coatings; 2. adding mass to serve as a heat sink; and 3. providing other features like cooling fins or water jackets to cool the barrel. All of these techniques provide either little benefit or result in serious disadvantages like increased weight and/or cost.

There is a novel design effort underway to avoid heat by designing ammunition that will reduce the amount of heat that the case transfers to the barrel in the first place. This effort is in its early stages and, even if successful, would not result in a change to service ammunition for some years to come.

Users can prevent barrel failures by limiting their rates of fire to the minimum necessary.

SUMMARY:

Tradeoffs in AR-style carbine design are more subtle than they appear.

Performance of the M4 Carbine has been repeatedly reviewed by Service authorities. The tradeoffs summarized above have been deemed worth the tactical advantages gained in portability and maneuverability in close confines. The Services continue to seek small, but significant, improvements in all of their small arms, including the M4.

Changes to the hardware or ammunition can improve firearm performance, and research into the dynamics of the M4 is pointing the way to improvements. Additional benefit can be obtained by operator discipline in maintenance (lubrication) and controlling heat. Overheating is an especially crucial issue in M4 Carbine reliability and in barrel failure in all models.

Regardless of the rate of fire a soldier or police officer wishes to shoot, the designs and materials available require control of the firing rate except in the most critical circumstances. The potential of damage from overheating thus combines with the general need for ammunition conservation and accurate fire to force users, regardless of instinct, to maintain discipline over their firing rates. In the final analysis, tactics must bend to a number of influences, among which is physics.

Most importantly, carbine users must remember that there is no free ride: the advantages of short barrel length and an adjustable-length buttstock come at the expense of reduced reliability, increased sensitivity to differences in ammunition, reduced muzzle velocity, increased muzzle flash and blast, and less effective terminal ballistics.

In order to balance the needs for reliability, portability and tactical superiority, our customers are advised to:

1. select carbines with barrels at least 16" long;
2. select carbines with mid-length gas port locations (8" rather than the 6" of the M4);
3. to test and select ammunition that functions reliably in their short-barreled arms instead of purchasing based on price alone;
4. conduct regular, thorough maintenance on their carbines;
5. Maintain fire discipline, using the minimum rate of fire needed to successfully resolve the tactical situation.

While there are differences in reliability between rifles and carbines, those differences don't account for the majority of malfunctions. The most common causes of malfunctions are poor maintenance and damaged (or low quality) magazines. Interestingly, both insufficient and excessive maintenance can cause malfunctions. Insufficient maintenance causes malfunctions rapidly as contamination slows the motion of the firearm's components. Excessive and/or improper maintenance may cause even more serious trouble by damaging critical components of the firearm. Common causes include the use of improper cleaning materials, tools, and processes intended to meet the "white glove" standards of insufficiently trained supervisors.

 THE WIZ