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Technical Note 48, The Effects of Barrel Design and Heat on Reliability

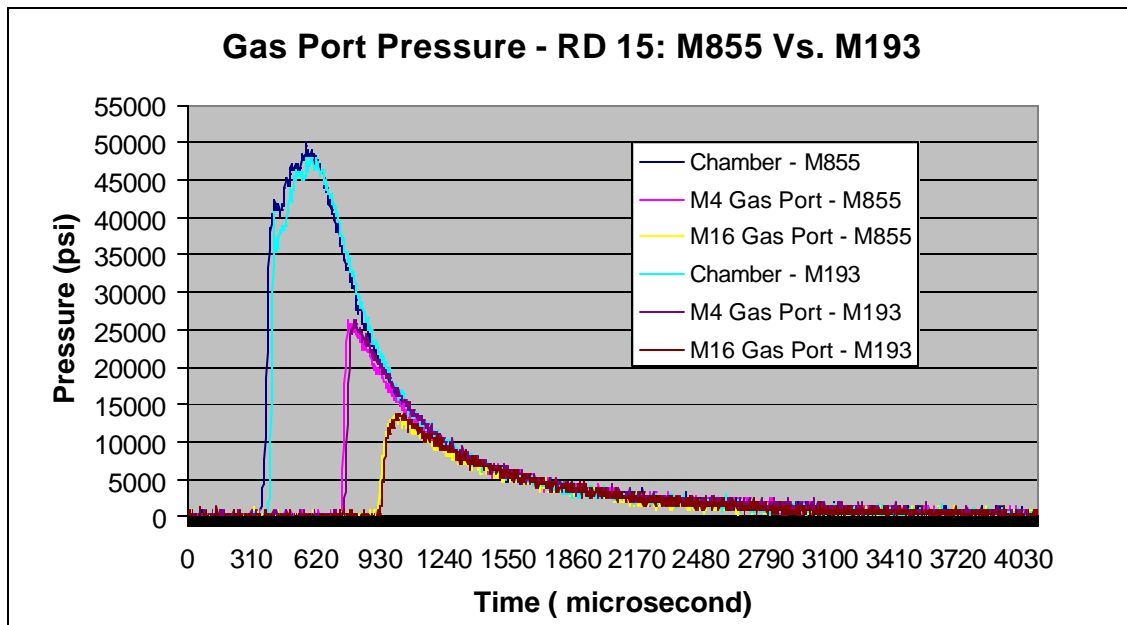
Background: The M4 Carbine has developed a reputation for poor reliability. The excessive malfunction rate of the M4 Carbine is due to physical imbalances in the mechanism itself, exacerbated by heat. Analysis of the problem requires a good understanding of the carrier group and barrel of the rifle, and the functions of the cartridge case.

Facts:

Relation of carrier group design, barrel length, gas port location, and propellant gas pressure. 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 carrier group, was designed to function well with the original 20 inch long barrel of that rifle. The 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.



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

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.**

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 stick to the chamber wall, and resistance to rearward movement is 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 11.5 inch long barrels have a very short segment of barrel beyond the gas port and the gas pulse is thus shorter than the carrier group requires. This problem combines with the carbine problems already described, and the reliability of carbines with 11.5 inch long barrels is somewhat poorer than carbines with longer barrels. Efforts to adjust for the short barrel 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.

Correcting basic carbine weaknesses:

1. Reduce the diameter of the gas port to reduce high pressure gas flow to the carrier. This can render the mechanism somewhat more prone to powering problems than the larger gas port of the rifle.
2. Provide an expansion chamber to buffer the gas flow and/or store gas to power the carrier. Such chambers tend to cool the gasses and can become clogged with powder residue over time, reducing the buffer effect. The flash hider of the Vietnam-era XM177 Carbine provided a buffer effect and stored gas.
3. Shift the gas port. ArmaLite has shifted its carbines gas port two inches forward compared to the M4 Carbine. Since the commercial minimum barrel length is set by law, this change serves reduce the gas pressure, delay its transmission to the carrier group, and reduces the length of barrel (and thus gas pulse duration) beyond the gas port. This change is easy in a commercial setting but has logistics implications for the military.
4. Decrease the tendency of the extractor to open by increasing extractor spring strength, adding material to rear of the extractor to reduce the tendency to open, or adding various elastomer forms to the extractor to reinforce the spring.

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 rifle system that is often overlooked: the cartridge case. The cartridge case is a highly sophisticated component that performs a number of functions

1. It holds components (bullet, primer, powder) together precisely.
2. It engages key surfaces of the magazine and rifle to transport these 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 and when some of the heat within the case is transferred to the chamber wall.
5. It transports heat out of the weapon when extracted.

When the weapon overheats, 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 worse than it does rifles because of their earlier extraction

Effect of heat on the barrel.

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 temperature well. At a temperature of approximately 1100 degrees, however, the structure of this alloy 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. This confuses the user as to the reason for failure

Eliminating barrel failure.

1. Efforts to reduce barrel failure have centered around tests of different materials or coatings, adding mass to serve as a heat sink, and 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 cost.
2. There is a private effort underway to avoid heat by designing ammunition that will not put it into 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.

Summary:

Problems with the M4 and other carbines and some commercial rifles based on the M16 design are more subtle than they appear. Changes to the hardware or ammunition can improve firearm performance, and research into the dynamics of the M4 are 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.

Most importantly, carbine users must remember that there is no free ride: the advantages of short barrel length come at the expense of increased sensitivity to differences in ammunition. Carbine users **MUST** test and select ammunition that works well in their short-barreled arms instead of purchasing based on price alone.

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 lower their firing rates. In the final analysis, tactics must bend to a number of influences, among which is physics.

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