Pressure Factors: How Temperature, Powder, and Primer Affect Pressure

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The Curiosity Cycle Initiated…Again

It's well accepted that temperature influences pressure. But the temperature of what? Is it the ambient temperature? Or the temperature of the barrel? Or the temperature of the powder[i]? Or is it some combination of all these factors? If so, do different powders and primers respond differently to temperature? Is there a combination of reloading components that works better than the others?

Soon after I instrumented two rifles with strain gages, and started making pressure measurements, I became convinced that barrel temperature influenced pressure. I started taping a thermocouple to the barrel, just forward of the receiver, and doing all my pressure measurements at close to constant barrel temperature. Is that thermocouple really necessary, or is it excess baggage?

With my trusty PressureTrace[ii] in hand, I decided to find out.

The Experiment Designed

The most common way to do experiments is to hold all factors constant except one, and to look at the influence that the one variable factor has on the outcome. The usual statistical tool for evaluating the results is the Student's T Test. The T Test is an excellent test, but this is a very inefficient approach. The really efficient experimental tools let you look at multiple variables, and all of their interactions, at the same time. You can investigate five factors and all 26 of the possible two, three, four, and five-way interactions for the same amount of work as a T Test, and with the same "clarity" as a T Test. The simple T Test just investigates one variable and no interactions[iii].

The efficient way is to gather data in a special way, known as a "balanced design". This is a simple example of a balanced design, where two states are allowed for each input variable, A, B, and C. For each combination of A, B, and C, the output variable, such as peak pressure, is recorded.

A	B	C	Output Variable
Low	Low	Low	
High	Low	Low	
Low	High	Low	
High	High	Low	
Low	Low	High	
High	Low	High	
Low	High	High	
High	High	High	

One complete set of data like this is called a "replicate". More than one replicate is required for a lot of the analysis that is usually needed[iv].

The math "magic" is that we can evaluate each variable, and each interaction, as though the others were not there. If you look at the states of B and C that happen with the low state of A, you will find that you have equal and opposite pairs of both B and C. The same is true of each state of each variable and each interaction. That's why the balanced design is so useful.

This is a very efficient scheme for investigating systems with multiple input variables that might interact, like rifle chamber pressure.

I chose four input variables.

1. Type of powder (IMR4350 vs H4350)[v],
2. Type of primer (CCI 200 large rifle primers vs. CCI 250 magnum large rifle powders),
3. Barrel temperature (50 vs. 95 degrees F, and
4. Powder temperature, (45 F vs. 100 F).

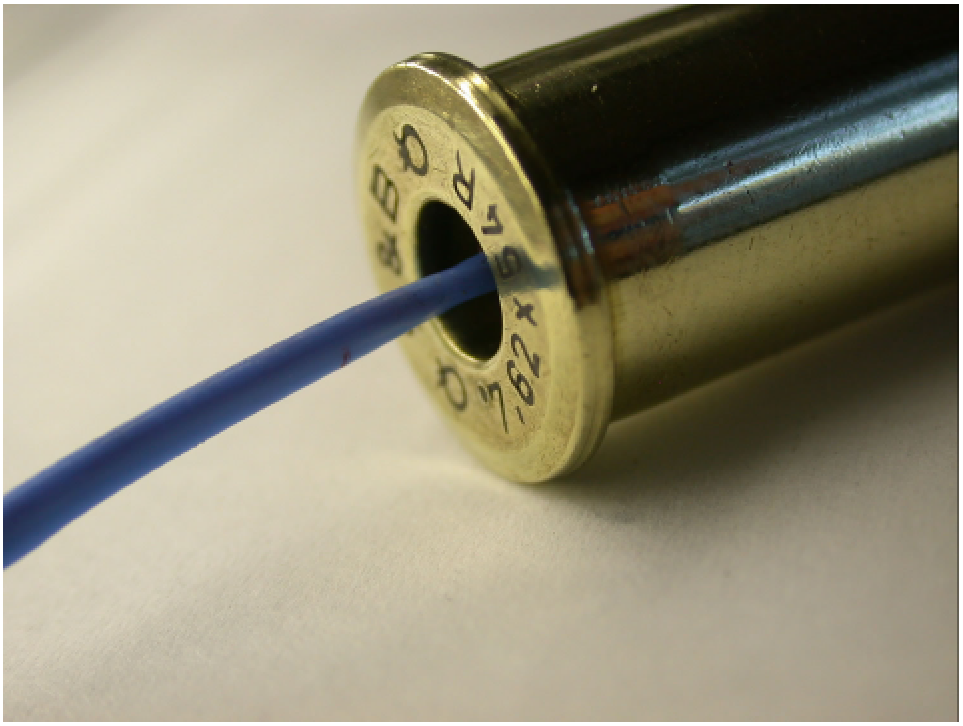
It's also easy to investigate more than one output variable (result) at a time, and since the PressureTrace gives both pressure and risetime, I took data for both output variables. I wanted to investigate ambient temperature as the fifth variable, but it is just too awkward to try to keep the barrel **and** ammunition at pre-selected temperatures, independent of ambient temperature. I gave up on that one. I don't think ambient temperature is important, anyway, except for its effect on powder temperature and barrel temperature.

I would not be too hasty to apply these results to other cartridges, powders or primers. They may behave differently. Also, there is no practical way to be sure that the particular jars of powder or boxes of primers I have on my shelf are representative of all lots of IMR or Hodgdon 4350 powder, or CCI primers.

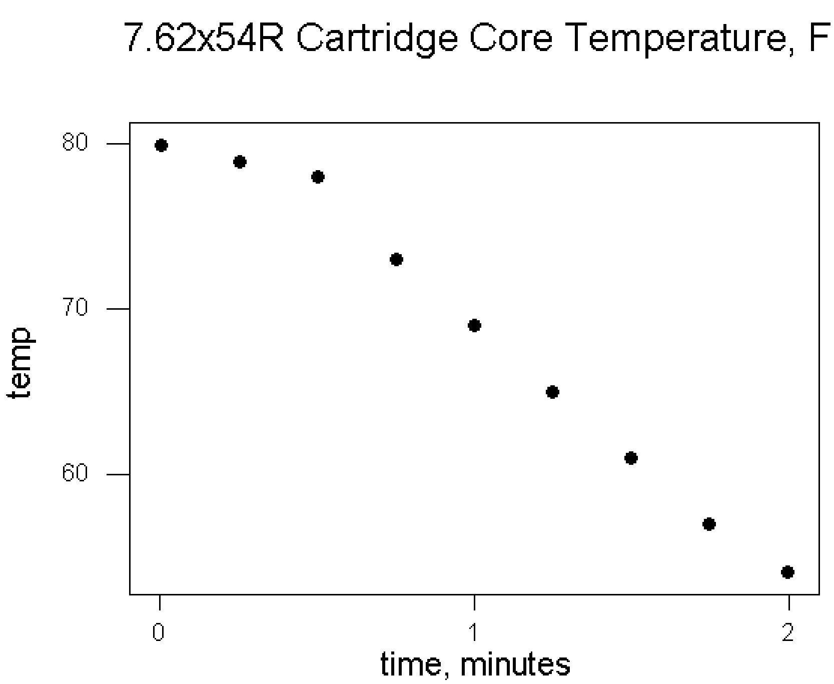
The rifle used for the experiment was a Finnish M39 milsurp. It does run a little less pressure than modern firearms do, but it is a fairly heavy rifle, which is pleasant when you have a lot of shooting to do, and it was already instrumented and ready to go.

I wondered if I could really separate barrel temperature from powder temperature. As soon as you put a cold cartridge in a hot barrel, it starts to warm. The outer layers warm first, and most of the volume is in the outer layers. Even if you shoot single-shot style, and fire as quickly as you can, will the heat of the barrel warm a cold cartridge before you can fire?

I prepared a special cartridge with bullet, casing, and powder, but no primer, with a thermocouple in the center of the cartridge. I packed the cartridge in a plastic bag full of ice, and watched the temperature at the core start to fall, due to roughly a 50 F temperature difference. The straight-line portion of the curve fell at about 1/4 degree F per second, which leads me to believe that if you load and shoot quickly, barrel temperature will have only a small effect on powder temperature. You can separate the two temperature variables, if you're quick.



7.62x54R casing, filled with very old H4831 powder, and with thermocouple inserted into the center of the case, through the primer hole.



This also indicates that the SAAMI practice of letting ammunition sit at test temperature for 24 hours before doing a test is overly cautious. 24 hours isn't going to hurt anything, but an hour or two is actually ample.

To the Range!

Early in September, with the dog days of August behind us, and a pleasant 81 F ambient temperature, I headed out to the range to do the "hot barrel" part of the test. I strapped a thermocouple to the barrel, and fired several shots to bring the barrel up to 92 F. For the remainder of the test, I kept the barrel between 92 and 98 F.

Ammunition was held at my low (45 degrees F) and high (99 degrees F) temperatures, and fired as quickly as I could get a cartridge out of storage, load, and fire it. The whole cycle took less than 10 seconds.

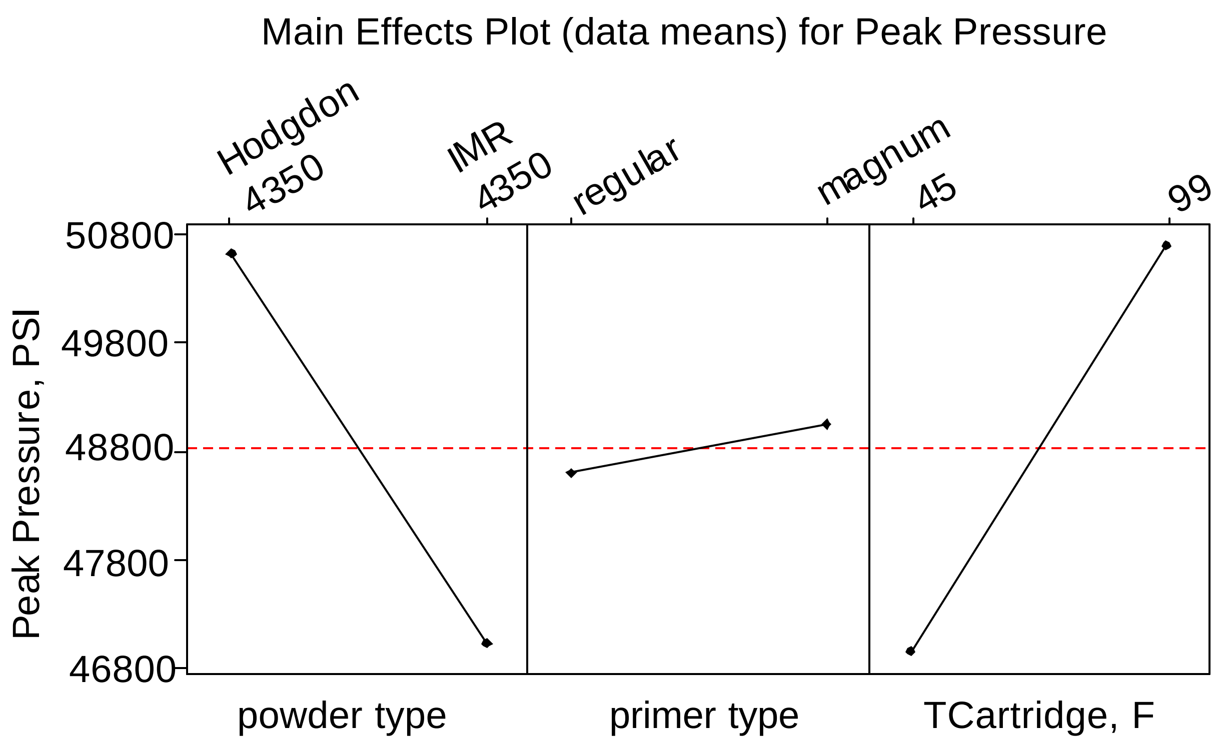
Test cartridges packed for the test. A few pounds of river rock in the bottom of the cooler regulated the temperature. A towel, folded on top of the ammunition boxes, provided additional insulation.

The cold weather testing turned out to be a bit more challenging. December did provide exactly the day that I had been waiting for. It was a Saturday, so the outdoor range was open. The ambient was about 40 F, which is cold enough to let me keep the barrel close to 50 F.

I let the cold ammo sit overnight in an unheated shop, which brought it very close to 45 F. I put power resistors under the river rock of the hot ammo cooler, and applied power, to bring it up a bit above 100 F. I even took a husky battery to the range with me, so I could warm the ammo anytime the thermocouple in the river rock said it was cooling off too much. Unfortunately, after about six rounds, my thermocouple meter abruptly started giving strange readings. Apparently, the cold had gotten to circuitry. With no way to regulate barrel temperature, there was nothing to do but to pack up and go home.

Since I already had a three-factor balanced design completed with a warm barrel, I decided to simply pursue the effect of barrel temperature on pressure with a separate, single factor regression test at an indoor range. In that case, everything was held constant except the barrel temperature, which was allowed to rise as shots were fired at about one minute intervals. This will not allow discovery of barrel temperature interactions, but it is a satisfactory solution. The loads fired were 150 grain bullets, propelled by Varget. Peak pressure and pressure risetime were measured as a function of barrel temperature[vi].

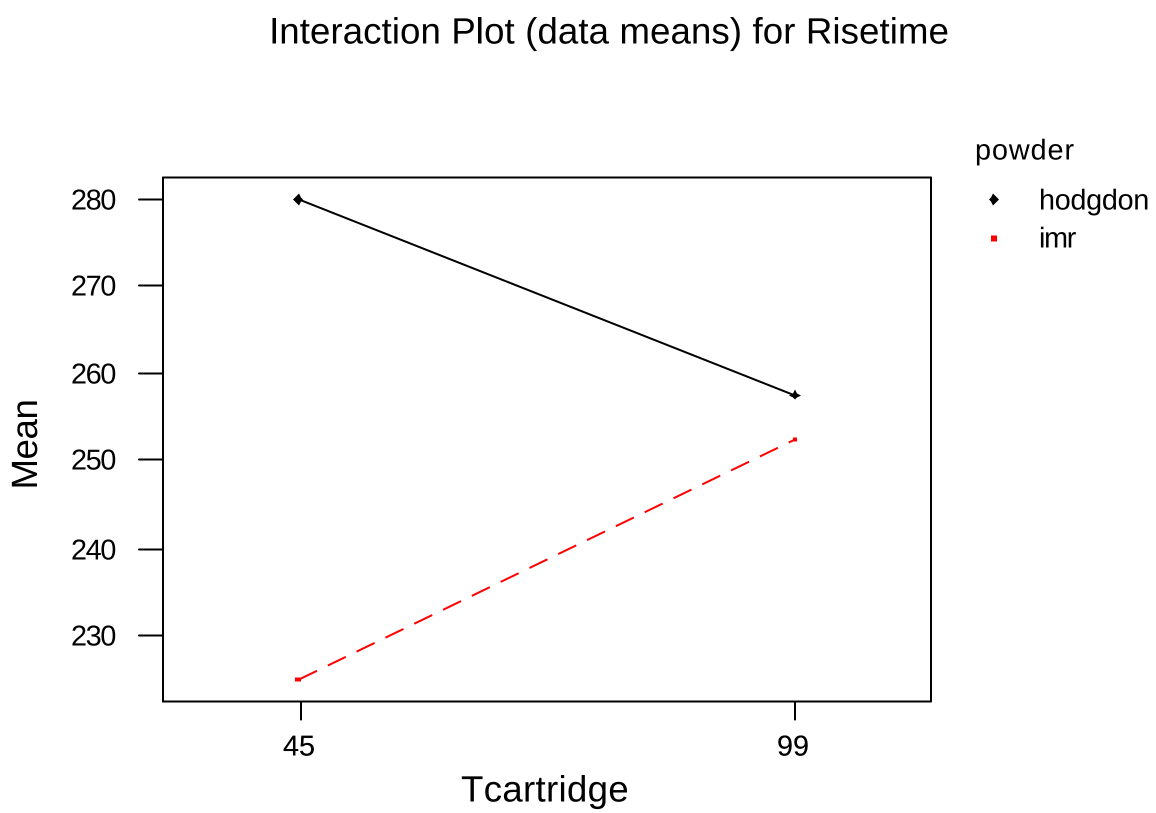
Test Results and Conclusions



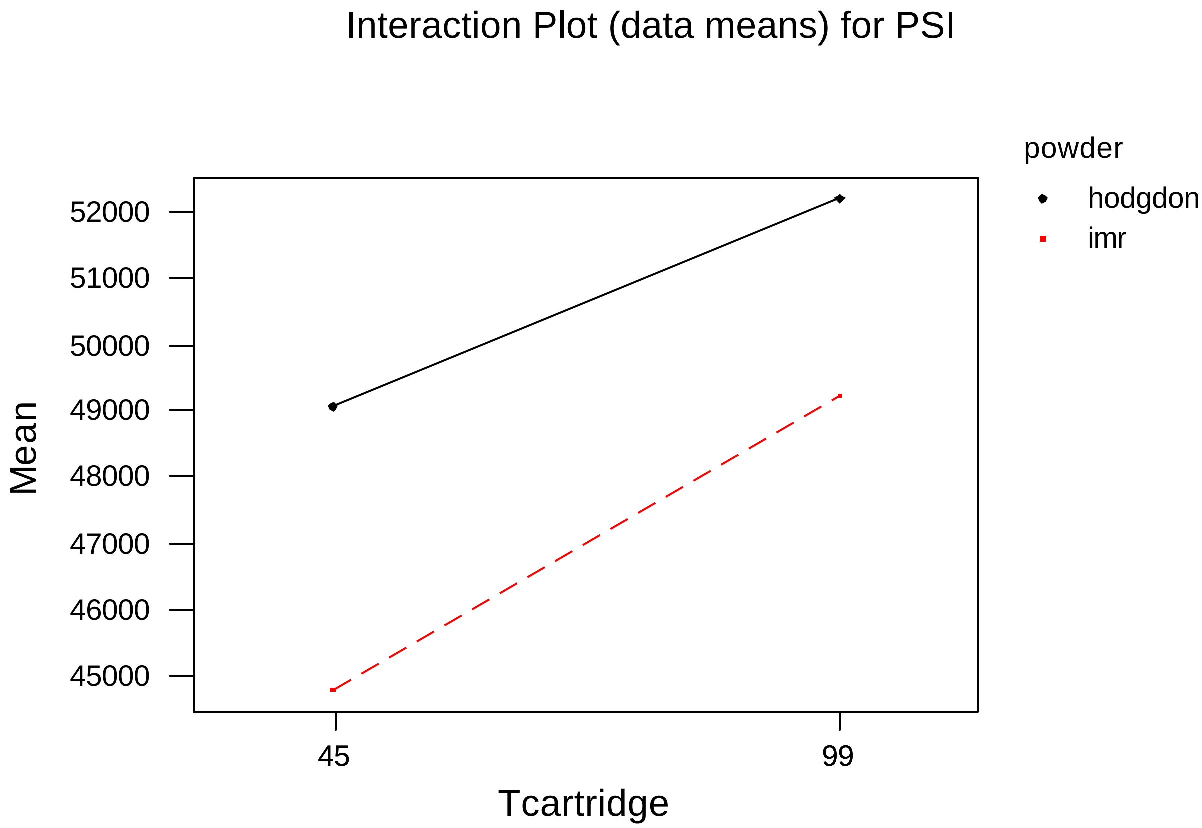
1. This is the Main Effect plot for pressure vs. powder type (Hodgdon and IMR 4350), type of primer (CCI200 and CCI250), and the temperature of the cartridge (45 and 99 F). Going from Hodgdon H4350 to IMR 4350 reduces pressure by 3624 PSI. There is about one chance in 1,000 of getting a difference as big as this one, just from the random chance in the experiment. This effect is real.

Going from the CCI200 (regular primer) to the CCI250 (magnum primer) produces 432 PSI additional peak pressure. There is a 63% chance of getting a difference this large, just from random variation, so this difference is attributed to random variation. That is, switching from CCI regular large rifle primers to CCI magnum large rifle primers, produced no detectable effect on pressure. It's worth noting that in a separate test, I found that switching to a magnum primer actually reduced peak pressure slightly, with 4831 powder in this cartridge.

Going from a powder temperature of 45 F to a powder temperature of 99 F increases pressure by 3797 PSI, or about 70.3 PSI per degree F. There is less than one chance in 1,000 of getting a result at least this big, just by random chance. This effect is real.



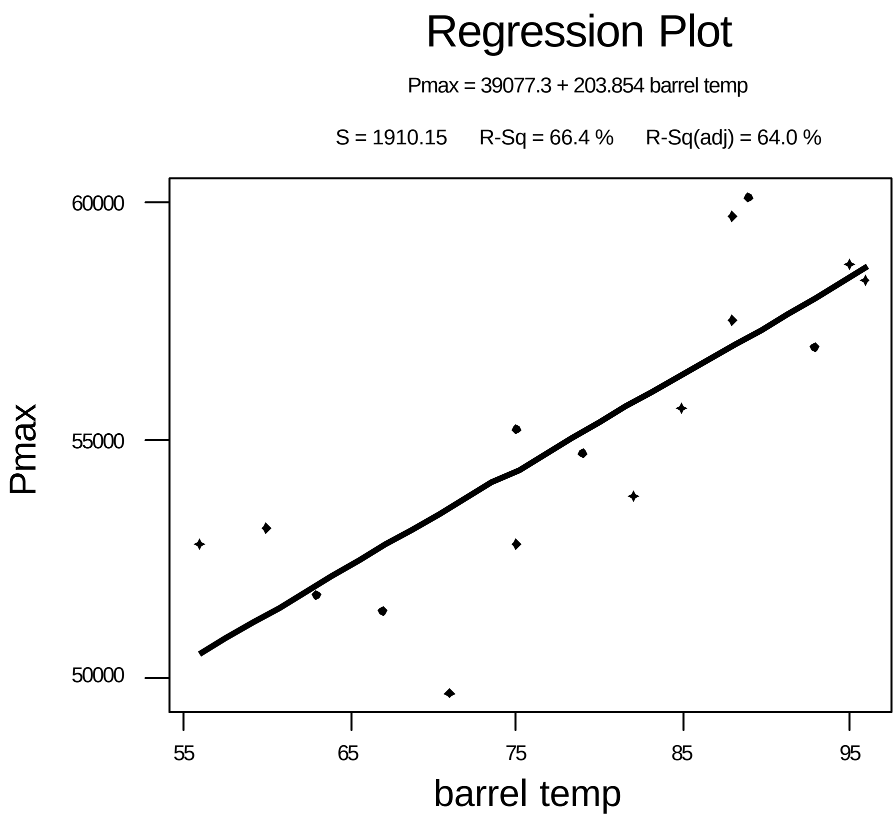
2. Now this is interesting. It is pretty likely that as powder temperature goes up, Hodgdon's H4350 has a faster pressure risetime, and that IMR has a slower risetime. This one doesn't quite meet the usual statistical standard for confidence. There is a 9% chance of getting a result at least this big, just by random chance. For now, we can say it is more likely true than not, and the subject of some future experiment.



3. The pressures generated by IMR4350 and H4350 are, for all practical purposes, equally affected by powder temperature in this case. Yet Hodgdon advertises that their "Extreme Powders" are not affected by temperature. Indeed, when I load H4350 in my 30-06, and Varget in my 308, I do get loads that are very temperature stable. So what could explain this discrepancy?

It is apparent that there is another factor at work. It is probably case capacity, or something closely related to it. 46 grains of Varget behind a 165 grain bullet gives me excellent temperature stability in my 308. Varget in my 223 is not as temperature stable as the military rounds that are sold over the counter. I did extensive tests on this, but, unfortunately, that was before I learned to control both powder and barrel temperatures.

Clearly, H4350 is not at all immune to the effects of temperature in the 7.62x54R cartridge. Nor, as we shall see, is Varget. Getting temperature insensitivity requires more than just filling the case with a particular brand.



4. In this load[vii], Hodgdon's Varget is highly affected by barrel temperature, with powder temperature held constant[viii]. These data were taken at an indoor range, and, as usual, the rifle was fed single-shot style.

This is a very important finding. **Both barrel temperature and powder temperature are important variables, and they are not the same variable. If you fail to take barrel temperature into account while doing pressure testing, your test results will be very significantly affected.** As nearly as I can determine, SAAMI does not rigorously control this variable, though individual testers might[ix].

The effect of barrel temperature is around 204 PSI per degree F for the Varget load. Also, the small sample gathered with 4350, before my thermocouple meter went kerflooey, is consistent with this result. Since the 4350 sample is small, the uncertainty is high, but the best estimate is 177 PSI per degree F. **If you're not controlling barrel temperature, you about as well might not bother controlling powder temperature, either. In the cases investigated, barrel temperature is a much stronger variable than powder temperature.**

I suspect that the mechanism for the effect of barrel temperature on pressure is from the large thermal mass of the rifle quickly bringing the primer to the same temperature as the chamber, and that what we are seeing really represents primer temperature. That's the topic of yet another experiment, to come.

For the Varget load, there is less than one chance in a thousand of getting a slope at least this big, just from the random variation of the data. This effect is real.

Also, the risetime of Varget, in this particular load, increases by about .62 microseconds per degree F of barrel temperature. This effect gives P=.01, which is the chance of getting an effect at least as large as the one seen, just by random variation. This effect is real.

5. If you're not worried about a 3 degree F change in powder temperature, don't worry about a tenth of a grain of powder more or less, in rifle cartridges similar to this one. Both produce about the same change in pressure and muzzle velocity.

6. If there is a fortuitous combination of powder brand and primer that gives less sensitivity to temperature changes in all cases, I have not yet discovered it. The original claim of magnum primers was that they give more uniform and reliable ignition of slow powders under very cold conditions[x]. When it's -20 F, it's starting to qualify as "very cold." The relatively balmy 40 F at the range doesn't adequately test this variable. That's still another experiment, yet to come.

Once again, gentle reader, we have succeeded in answering a few of life's puzzles, but have also raised new questions. Indeed, we may say that we are as confused as ever, but on a higher plane, and about more important things. Such is the curse of the curiosity gene.

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[i] According to Ackley, who references the powder manufacturers, it's the temperature of the powder. See *Handbook for Shooters and Reloaders, Vol. II*, p96

[ii] For product data, see http://www.shootingsoftware.com/pressure.htm

[iii] Center points in an experimental design test for curvature, and Response Surface Modeling builds a model that accounts for curvature if it is found. Dr. Brownell's work at University of Michigan showed that charge vs. pressure is non-linear. The same should apply here, but, we are working in such a small portion of the curve that I think the effect of curvature is small. I have chosen the simpler model. See Brownell, Lloyd E., Phd, *Firearms Pressure Factors*, Sept.-Oct 1967, p15.

[iv] It's usually better to randomize the sequence of your test runs, if you can. However, with only a few replicates, randomization does not provide much insurance against lurking variables, and, in practice, it is almost impossible to pull the rifle temperature back and forth between the two temperature states separated by 40-50 degrees F. So this experiment is not randomized, but that's not a big issue.

[v] The 4350 loads were 51 grains of Hodgdon or IMR powder, behind a 174 grain bullet.

[vi] It is worth noting that strain gauges are relatively temperature insensitive. Over the range 35 F to 100 F, the effect of temperature on the strain gauge is in the neighborhood of 165 PSI, which is negligible in this case.

[vii] The Varget load was 51 grains of powder behind a 150 grain bullet.

[viii] Given the results of Ackley's experiment, on p76 of *Handbook for Shooters and Reloaders, Vol. II*, we can safely conclude that the increase in pressure is NOT the result of progressive copper fouling of the barrel.

[ix] The 1992 SAAMI standard requires warming shots, and warns against overheating the barrel by too rapid a rate of fire, *Centerfire Rifle, SAAMI Voluntary Performance Standards*, p8-9. The standard carefully specifies the electronic test equipment to be used, and how it is to be set up and calibrated. I have found no reference to measuring or specifically controlling barrel temperature, other than the reference given.

[x] See Ackley's *Handbook for Shooters and Reloaders, Vol. I*, p97.

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