Who's Getting Drilled?

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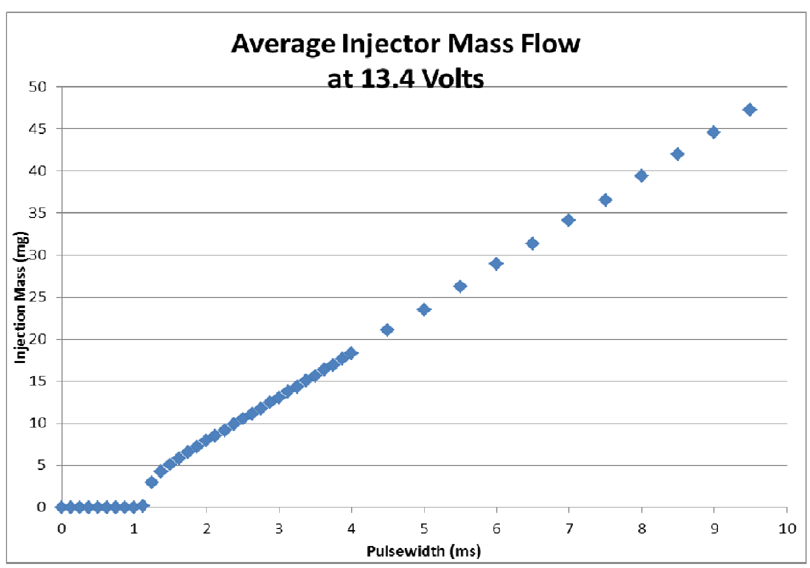
There has been a lot of interesting progression in the tuning community since I released my first DVD, ***GM Tuning Beginner's Guide*** *(Summit P/N SME-DVD-1, http://www.summitracing.com/parts/SME-DVD-1/?rtype=10)* that included raw injector data for many popular applications. Apparently, this opened a lot of eyes to just what a proper tuning procedure should look like and how good the results could be if one just followed the science and math instead of village wisdom being regurgitated by other "training schools." Seeing so many people be successful in their own calibration efforts after buying my training material really makes the huge effort of putting this stuff together worthwhile.

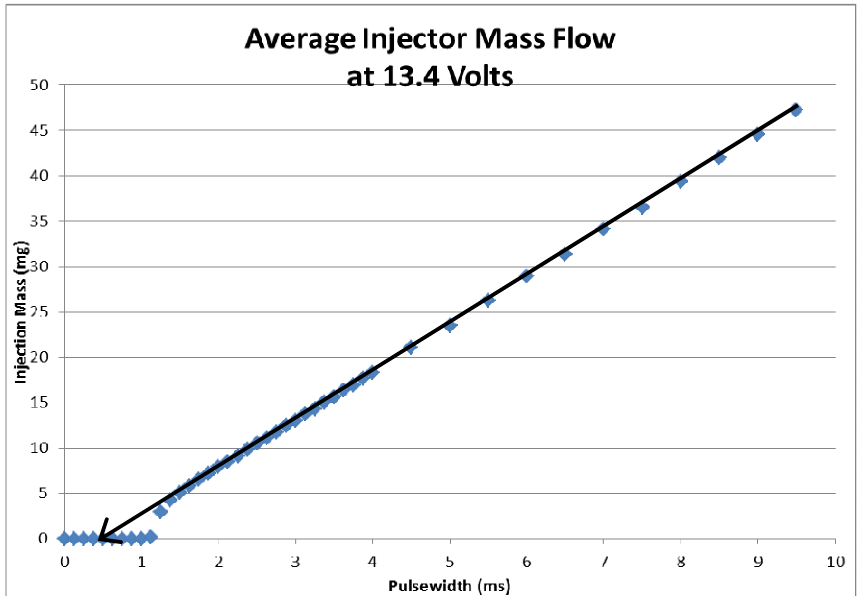
One of the questions that I get asked a lot is "What about these redrilled injectors?" It's usually followed by conversation points like: "They look the same." "They're made from the stock injector, so it should be the same offsets and short pulse data, right?" "But they make great horsepower." "So and so said they work." Or my favorite, "I got a good deal on them."

So the question really becomes, "What are you getting when you buy a set of redrilled injectors?"

Until recently, my answer had always been "I'm not sure." It really depends on how they did the modification and what effect that has upon the flow, both static and dynamic. Once upon a time, I spent a couple hours on the phone with the purveyor of one of these redrilling companies discussing the finer points of injector operation. The gentleman on the other end of the phone assured me that he had years of experience as a precision machinist and that his holes were very consistent. I have no reason to doubt this, but there's more to an injector than just the orifice plate. He also indicated that since he was using the original coils, that their activation time (and thus "injector offset") should be the same as the original part. WRONG! This is where I began to wonder if anyone in the aftermarket had been paying attention in fluid dynamics class before they set out selling a device that is exactly a fluid dynamics control mechanism.



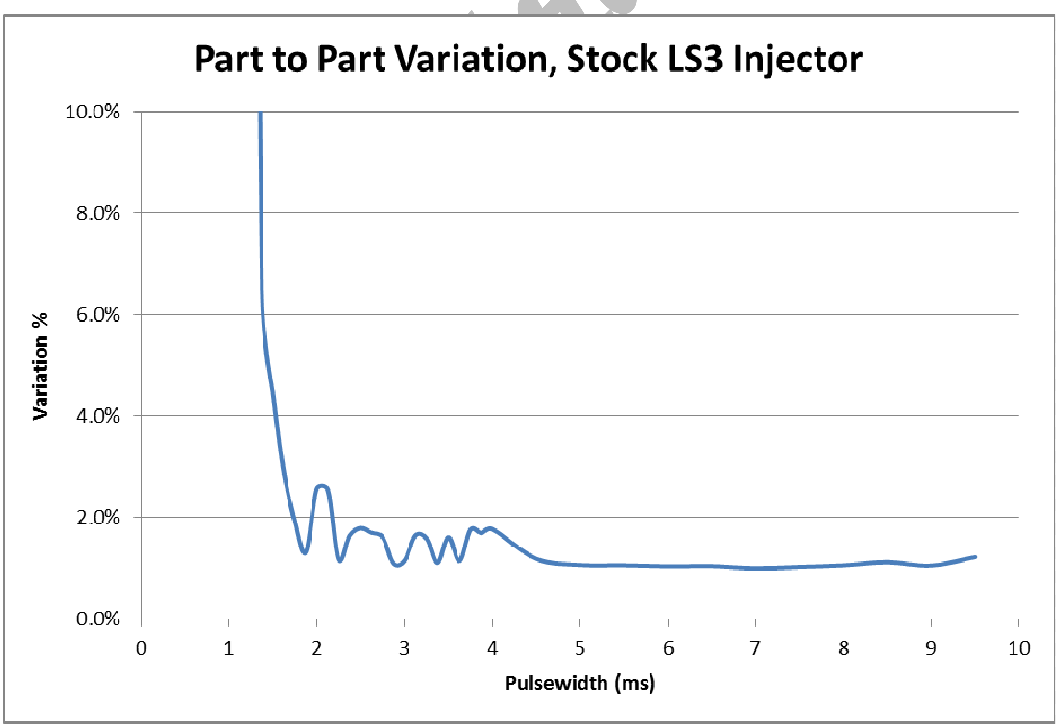
I guess this is where we need to start drawing pictures. First, let's look at the normal response curve for a modern high impedance port fuel injector. To the right, you see the factory Bosch injector for the GM LS3 engine. The data for this graph comes from a series of individual tests, each at a specific pulsewidth and voltage. If we plot the delivered fuel mass against pulsewidth, we get the "characterization" of the injector. Obviously, you should note a straight line through most of the data. The slope of this line is defined as "the rise divided by the run" (in units of mg/ms, or g/s) and IS the normal flow rate for the injector. Some shops simply flow injectors continuously for 20-30 seconds and report that total flow as the flow rate of the injector. While this should get close, it doesn't represent how the injector is actually used in the engine, so the test method shown above was adopted by the Society of Automotive Engineers. Since I keep paying for my SAE membership, I'll continue to use their industry standard for testing.



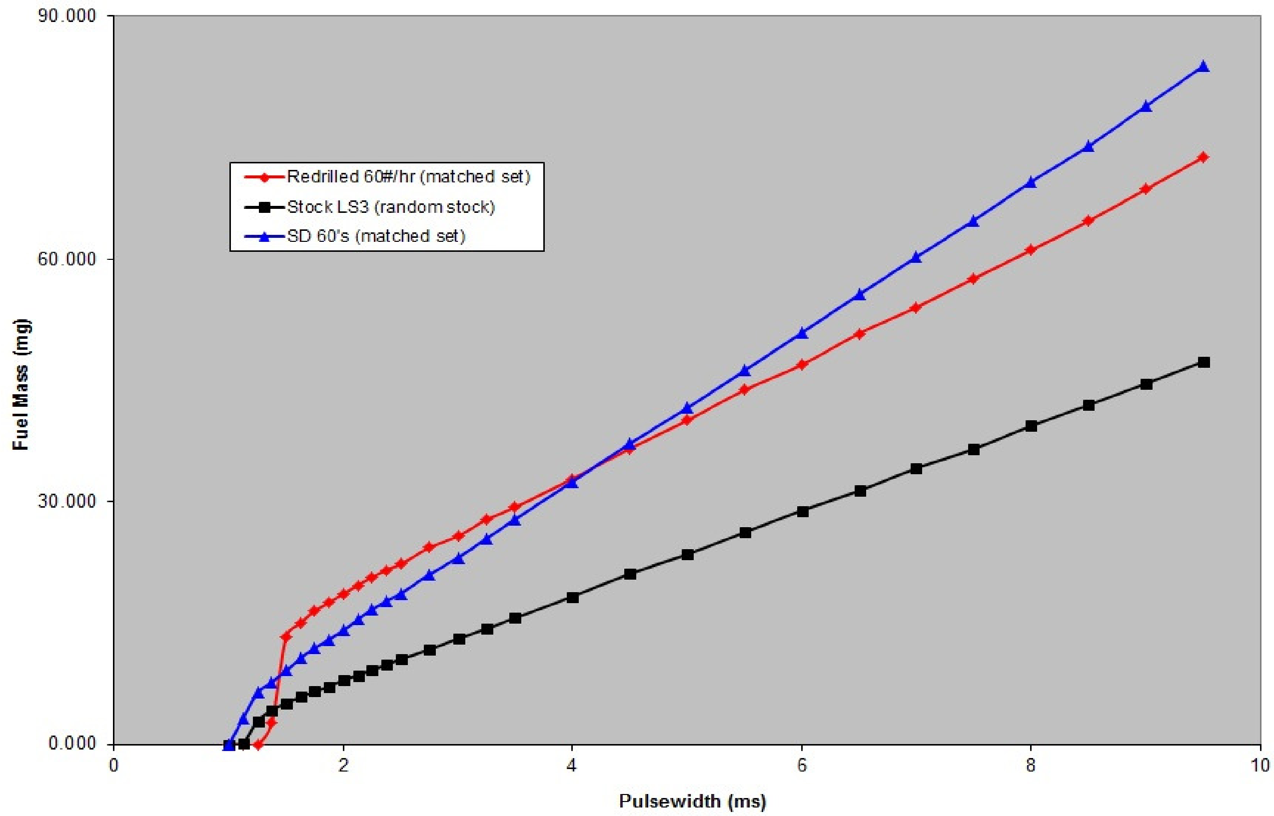
Taking it a step further, one can draw a straight line through the string of data points and see where it intersects the X-axis. THIS is the standard definition of injector offset, NOT just the opening time or electrical activation time. The trick here is that the location of the line is a function of several things. It includes the linear flow rate, but it's also affected by the opening delay and the closing delay. All of these factors work together to give us the injector characterization that we need in order to properly calibrate the EFI system when using that particular injector. Any time we change injectors, we need new data to give the ECU a sporting chance at delivering the right fuel mass as a result of the exact on-time for the circuit.

But wait, there's more.

Not only do we expect the injector to deliver a specific mass of fuel for a specific on-time, we expect that mass to be consistent from shot to shot and from one injector to another. This is where manufacturing processes come into play. OEM injectors made by Bosch and Continental (formerly Siemens VDO) are usually laser cut or wire EDM'd for an exceptionally tight tolerance. In the OE calibration world, we'd like the injector variation to be less than 5% in order to get "good" control of air-fuel ratios in the engine. We are usually most critical of this at lower pulsewidths where variation in injector behavior affects idle quality, part throttle driveability, fuel economy, and emissions. In the graph shown here, one can see that variation drops well below 5% before we even get near the typical idle on-time of approximately 2ms with the Bosch LS3 injector. This is exceptionally good behavior, and makes the job of the engine calibrator that much easier.



So let's take a look at some higher flow injector data. Let's overlay the stock LS3 injector with a set of Siemens Deka 60's (that really flow about 73#/hr at 4 bar) *and* a set of LS3 injectors that were redrilled to flow 60#/hr. The data shown here is from 8 averaged samples (one complete set) of each injector variety. Keep in mind that the stock LS3 injectors were just 8 random units that came off a production car, the other two sets were shipped as "flow matched" sets.

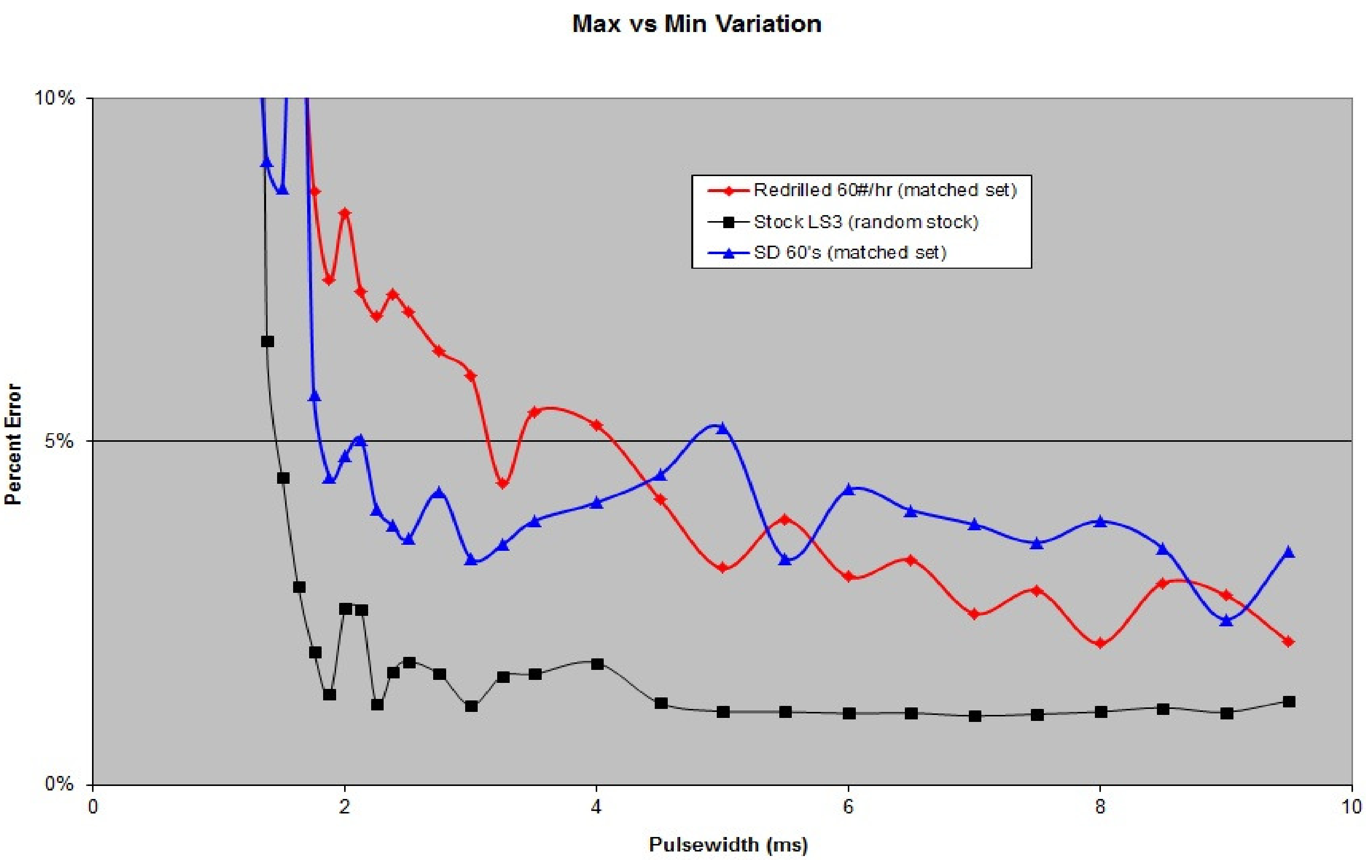


Overlaying all three immediately shows us several key lessons:

1) The slopes are different. Although the redrilled injectors flow more than the original injector, they are not "60#/hr" at 4 bar. My testing actually showed a slope of 7.105g/s for the averaged flow on the redrilled injectors. This translates to 56.39 lb/hr. By comparison, the SD60's flow 9.25g/s (73.41 lb/hr) at the same pressure.
2) The red line (redrilled injectors from a "matched" set) isn't nearly as straight as the other two. This is because the shot to shot variation is much worse than the two production samples. If the opening and closing are inconsistent or flow through the modified orifice is unsteady due to the change in geometry, it can have negative effects upon the predictability of this curve.
3) Opening time and initial flow characteristics are radically shifted with the redrilled injector. Remember that the red line started life as the black line before someone drilled it. In this particular case, the process of drilling the orifice plate has made the process of filling the tip of the injector during the very beginning of a shot MUCH more non-linear. One of the things that made the stock LS3 and SD60 injectors so nice to work with was that they were not only consistent, but almost completely linear down to zero. This is no longer the case after the modification.

4) The offset of the red line (modified injector) is nowhere near the offset of the black (stock) injector! "But it's the same coils!" I hate to say I told you so, but *I told you so*. Opening time is not the only thing in play here, remember? It appears that the closing delay and tip filling phenomena are now driving the behavior more prominently. The result is that the offsets are very different and so are the corrections necessary for short pulses. In GM-tuning-speak, this would be the short pulse adder table values. For you Ford guys, it's the Low Slope and offset (but *in a different direction* than the GM change). If you're still with me, take a closer look at where that offset point would be on the graph for the red line. That's right, my math showed a *NEGATIVE time offset number after the modification*! Some ECUs can not process such a request.

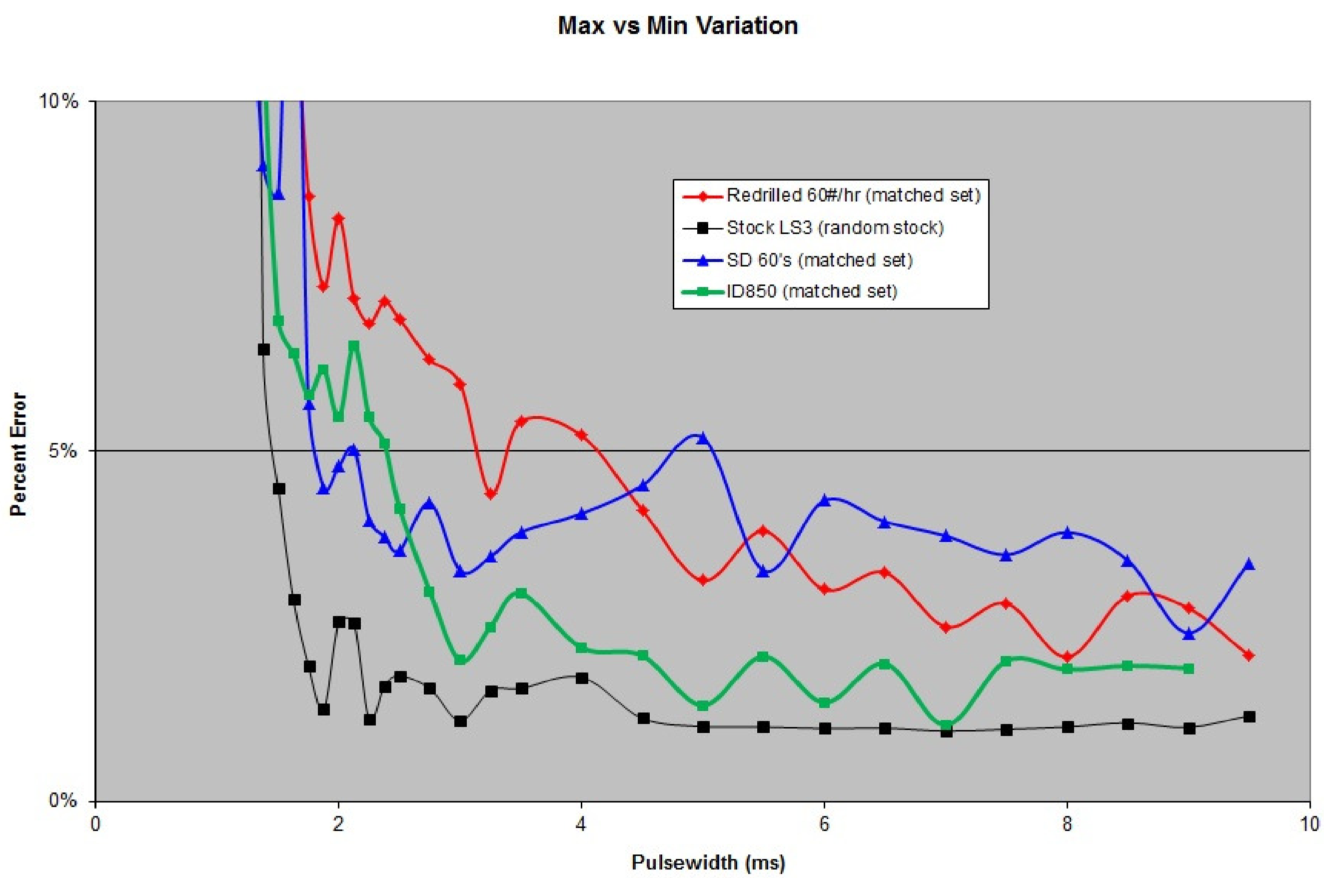
I'm not done yet. Now it's time to look at variability again. By looking at the min and max delivered fuel masses on each set of eight injectors and plotting it against pulsewidth, we get another interesting discovery. Remember that the guys at the OEM level want less than about 5% variation across the cylinders and less would be better.



The stock LS3 injector was excellent here, and the SD60s weren't too bad with the exception of a single outlier around 5ms. We know that it's never going to be perfect and that the engine itself will have some variability from the combustion process, but anything we can do to reduce the number of variables certainly helps make the job of the engine calibrator that much easier. As you can see from the red line, the redrilled injectors didn't really become statistically consistent until beyond 4ms pulsewidth. This means that the majority of time that the engine is running (idle, cruise, part throttle), you don't really have consistent cylinder to cylinder fuel delivery. How does one expect to accurately adjust MAF and VE tables when you have over 8% variation at 2ms and below? If your injector hardware has you chasing your tail on MAF and VE calibration, how does one expect to get precise ignition timing, a stable idle or good drive quality? I can't fix this with a keyboard.

So by this point, you're surely thinking *"Greg must really hate modified injectors."* This isn't entirely the case. I just recognize that the process of modifying the injector has the *POTENTIAL* to screw a lot of things up. Some companies do it blindly and just copy/paste injector data from some other source and hope that their customers aren't discriminating enough to tell the difference. Other companies recognize the effects of each modification and go through the trouble to do the same SAE-spec testing to completely characterize their product and deliver good data along with the hardware for each individual part.

As a specific example, Injector Dynamics uses the same Bosch injector body as the starting point for their ID850 fuel injector. A key difference here is that the ID850 flows about 12g/s (98 lb/hr) at 4 bar, so we're looking a a huge step away from the stock flow rate with more than double the flow capacity. It would stand to reason that such a drastic modification would yield even worse results than the mildly modified samples we saw earlier if one were not careful. This is where it gets interesting. Injector Dynamics not only provides accurate, complete characterization data for all of their parts (http://www.injectordynamics.com/ApplicationData.html), but the parts themselves are more consistent than other redrilled examples. Check out their website for mass vs time plots at various pressures. I just plotted the variation results of my own testing here:



The green line shows the same variation comparison for a set of ID850 injectors across the spectrum of pulsewidths. Yes, there's still some variation at idle, but it's significantly less than other modified injectors at idle and even better than the production SD60's at higher flow. I don't want this to sound like a commercial. I'm just using this example to prove that injector modifications or rebuilding can be done without completely messing up the fundamental behavior.

Making high flow injectors work seamlessly on a modern EFI system is tough enough if everything goes right. Adding inconsistent, unpredictable, or uncharacterized parts in the mix only makes it tougher. So what did we learn here?

1) Show me the data. Don't just blindly accept someone's assertion that the offset and short pulse data is the same just because they started with the same physical injector body. The act of modification changes EVERYTHING!

2) Good injector data is absolutely key to getting the engine to perform well. All of the airflow models (either MAF or VE) can be greatly impacted by incorrect fuel injector delivery assumptions. This can lead to poor idle quality, driveability, fuel economy, or emissions. The region where we are most critical of these behaviors is exactly where modified injectors vary the most from the predictions.

3) If consistency is important to you as an engine builder, calibrator, or racer, then pick your hardware wisely. Sometimes you get what you pay for on a bargain. Not everyone with a drill bit understands what they're doing to the dynamic flow behavior of an injector.

4) If you're in the business of modifying injectors, understand that today's consumers are smarter than ever and expect to know more about your product. If you perform the proper testing, using the proper methods, and are prepared to show your work then people will take you seriously and buy your product.

Thanks for reading. Special thanks go to Phil at ASNU (www.asnu.com) for loaning me their latest digital laptop-controlled injector test bench. Lots of shops have similar equipment, but the trick to doing this testing was understanding how to use the bench for something more than just pattern and continuous flow testing. My unit is modified to allow continously variable voltage control from an external regulated supply. The USB interface and PC based controls allowed me to dial in exact test conditions and generate far more useful data that supports valid engineering conclusions. Remember, if you don't have *data*, you have an *opinion* on the subject.

Want more? Hang in there, I'm working on a video version of this fuel injector training as part of my "Secrets of EFI Calibration" DVD that will be added to the existing line of Calibrated Success training materials. Check for updates at www.calibratedsuccess.com or on my YouTube channel at http://www.youtube.com/user/eficalibrator

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