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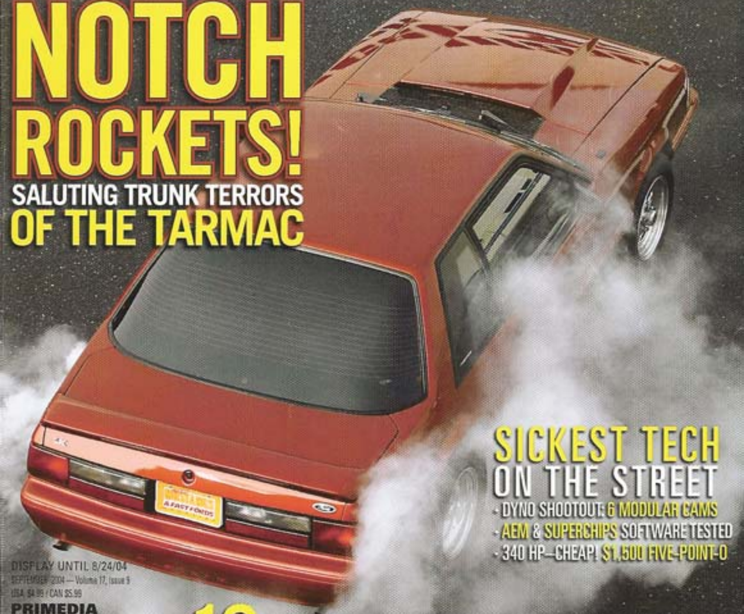

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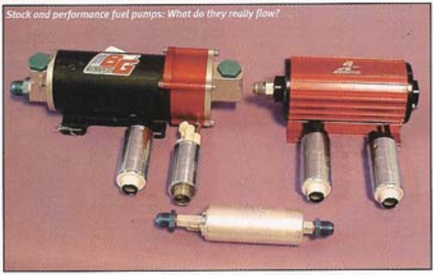


Stock and performance fuel pumps: What do they really flow?

Fuel-Flow FORENSICS

Pumps x Pressure = Performance.

By Richard Holdener

The advent of the fuel-injected, 5.0 Mustang back in 1986 ushered in a whole new era of Ford performance. The 5.0 H.O. created an entire industry, one continued to this day since the introduction of the Modular-powered fast Fords.

Though the current overhead cam engines differ from their traditional pushrod counterparts, the two do share a number of things in common. In addition to sharing the V-8 configuration and even the firing order, the injected 5.0s and 4.6s share the high-pressure fuel system common to most fuel-injected motors. Unlike traditional carbureted engines, fuel-injected versions rely on much higher fuel pressure. The elevated fuel pressure helps atomize the fuel as it flows through the fuel injector.

While carbureted motors traditionally run fuel pressure near 7 psi, (port) fuel-injected combinations run best around 40 psi. We specify port fuel injection here as throttle-body injection systems employ fuel pressure ranging from 9-15 psi, but our beloved SEFI Mustangs are not so equipped.

While both EFI engines employ high-pressure fuel injection, the two systems differ in their approach. The conventional return-style fuel-injection system (used on the 5.0 and some early 4.6 motors) featured an in-the-tank fuel pump—a feed line (and fuel filter) running from the fuel pump to the fuel rail. The fuel rail was designed to distribute fuel flow to the eight injectors and incorporated a fuel-pressure regulator designed to control the system pressure.

Most factory fuel-pressure regulators were not adjustable, but many enthusiasts soon replaced the stock non-adjustable unit with one of the many adjustable regulators available from the aftermarket. Using a spring and diaphragm, the regulator controlled fuel pressure in the system and allowed excess fuel flow to return back to the fuel tank. Re-circulating the fuel helped keep the temperature down, as the elevated pressure in a fuel-injection system has the undesired effect of heating the fuel. Re-circulating it back to the fuel tank eliminates the pressure and allows the heated fuel to join the relatively cooler fuel in the tank. Obviously, constant circulation can elevate the temperature of the fuel tank as well.

A better understanding of the role of the fuel pump is necessary before going on to the non-return-style fuel system. In a return-style fuel system, the fuel pump is constantly flowing the maximum amount possible. The flow rate of a fuel pump is determined by the size and design of the pump itself but also by two very important external factors, namely supply voltage and system pressure. We will take a closer look at these two variables later, but for now, know that in a return-style fuel system, the fuel pump is flowing at the maximum flow dictated by the pressure and voltage supply.

While the fuel supply (pump) is flowing at a constant rate, the fuel demand obviously varies with the engine speed and load. At idle, the fuel demand is much lower than when running at 6,000 rpm at wide-open throttle. The fuel pump must be sized to support the greatest fuel demand. The job of the fuel-pressure regulator is to bypass the difference between the fuel supply and the fuel demand while maintaining the preset fuel-system pressure.

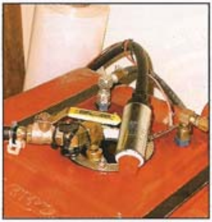
The non-return-style fuel system differs from the conventional return-style fuel system by way of the fuel-pressure regulator or, more specifically, the lack thereof. In a non-return-style fuel system, the fuel pressure is controlled by the supply voltage to the fuel pump. Like any electric fuel pump, the output of these pulse-width modulated fuel pumps are dictated by the supply voltage. The fuel pumps used in a return-style fuel system are supplied a constant voltage, usually near 13 volts—depending on the effectiveness of the charging system and accessories currently drawing from that system.

The fuel pumps in a non-return-style system are not supplied a constant voltage and instead receive pulses much like a fuel injector. The pulses do not actually start and stop the fuel pump, but act much like limiting full system voltage to control the fuel pressure. The pulse width is determined by the computer and is based on fuel-pressure information supplied by a pressure transducer in the fuel rail. It makes things easier if you think of the system as an electric version of the mechanical fuel-pressure regulator. The beauty of the system is that the pump is not constantly supplying maximum fuel flow, only that which is needed to produce the desired pressure specified by the computer.

We mentioned previously that the fuel flow rate of an electric fuel pump is determined by the size (and design) of the pump, as well as the supply voltage and system (fuel) pressure. Physical size obviously helps determine the flow rate of a fuel pump. Spin a larger set of gears the same speed as you do a smaller set and the

Though similar in shape, the early positive displacement (5.0 and early 4.6) electric fuel pumps and the later turbine (late 4.6) pumps differ in design. The two are not interchangeable, though turbine pumps can be used in positive displacement applications.

All of our production in-the-tank pumps were tested on the Kenne Bell computerized fuel-pump test bench. The bench can be set to test a pump at any system pressure or supply voltage—just the thing for our needs.



The in-the-tank pumps were submerged into the 10-gallon fuel cell for testing.

larger set will flow more. Picture the difference between a standard and high-volume oil pump if you have a hard time coming to grips with the gear size. The size of the fuel pump is somewhat determined by the available space in the pump assembly; this is especially true of in-the-tank pumps. For most Mustang applications, the physical size is predetermined, but not so for the voltage supply and system pressure. Let's take a look first at how the system pressure affects the fuel flow and where elevated pressures may become necessary.

As a rule of thumb, the flow rate of a pump decreases with system pressure. Simply stated; it is harder for the pump to flow against higher pressure than lower pressure. Need verification? Check out the changes in flow rate as we increased the fuel pressure from 40 to 60 psi and finally to 80 psi. Like everything else in nature, fuel pumps like to take the easy route.

As mentioned previously, fuel-injected motors typically run fuel pressure somewhere near 40 psi. This all changed once we discovered how easy it was to install forced induction onto the new fuel-injected 5-ohs. Using the early return-style fuel systems, additional fuel was supplied to the boosted motors by simply increasing the fuel pressure. This was accomplished by shutting off the return line to temporarily override the fuel pressure regulator, thus (sometimes) dramatically increasing the fuel pressure supplied to the injectors. Greater fuel to the injectors increased fuel to the motor, hopefully in proper proportion to the airflow supplied under boost.

The problem with this type of rising-rate fuel management system (FMU) is that it made life much harder on the fuel pump. Not only were we asking the fuel pump to support the additional power potential of the force-fed Ford, but also to do so at a greatly increased fuel pressure. Not surprisingly, many early attempts met with less-than-stellar results as the stock fuel pumps simply refused to cooperate under such adverse conditions. The cure to the problem was to increase the flow potential of the fuel pump.

Many approaches were taken to improve fuel flow. Naturally it was possible to simply install a better-flowing fuel pump in place of the stock 88 lt-hr pump. The aftermarket supplied fuel pump upgrades ranging from 110 lph all the way to a whopping 255 lph. It was also possible to install an inline fuel pump to work in conjunction with the stock (or upgraded) in-the-tank pump. The benefit of the inline pump is that it can be installed without dropping the gas tank.

Additionally, the high-flow inline fuel pump helps improve the fuel flow of the feed pump (stock or otherwise) by reducing the system pressure between the two pumps. Since the inline pump outflows the in-the-tank pump, the pressure between the two pumps decreases. The reduced pressure helps increase the flow potential of the feed pump, thus improving the overall system. It is important to note that the limiting factor of the inline system will still be the pump with the lowest flow rate. If the stock 88 lph fuel pump increases to 150 lph at 0 psi and your inline pump flows 200 lph, the maximum system flow will still be limited to 150 lph.

Another popular method made popular by Kenne Bell is to increase the supply voltage to the fuel pump. The K-B Boost-a-Pump improves the flow rate of an electric fuel pump by increasing the supply voltage. Most fuel pumps are (flow) rated at 12-13 volts. If you have a fuel pump rated at 255 lph at 13 volts, know that the flow rate will dramatically increase if the voltage supply is increased from 13 to 17 or even 20 volts.

Check out the supplied charts to illustrate the increase in flow rate offered by the Kenne Bell Boost-a-Pump. All of our fuel pumps were flow tested at 13 volts and then again at 17 volts. The increase in flow rate was impressive, especially when you consider that the installation of a Boost-a-Pump is much easier than even an inline pump. Hooking up the Boost-a-Pump is a simple matter of connecting two power wires and a single ground. The Kenne Bell unit can even be dialed in to produce the desired voltage and activated under boost or 0 vacuum (wide-open throttle).

Internet rumors that the increased voltage will somehow diminish the life of the fuel pump are unfounded. Ease of installation, the ability to control onset and supplied voltage, and to increase the flow rate of nearly any electric fuel pump by 30-50 percent makes the Boost-a-Pump an attractive option.

For the 5.0 and early 4.6 applications that feature the return-style fuel system, the installation of a 255-lph fuel pump will provide sufficient fuel flow for nearly 800 hp—assuming a .5 brake specific fuel consumption (BSFC). Actually, testing has shown that most normally aspirated fuel-injected 5.0s and 4.6s applications exceed a .5 BSFC number and often dip down into the mid .4s. This means that the motor will require less fuel to produce a given amount of power.

While your first thought might be that this entails a lean mixture, it is possible to increase the power output without affecting the air/fuel ratio, thus improving (decreasing) the BSFC number. Producing 800-plus hp with a 255-lph fuel pump also assumes a fuel pressure of 40 psi. While most normally aspirated motors can get by with 40 psi , the same doesn't hold true for forced-induction applications unless overly

The pump that started it all, the 88-lph 5-liter pump, checked in at 91 lph on our test bench at 13 volts and 40 psi.

The stock 2V 4.6 pump flowed much better than the 5.0 pump, registering 158 lph at 40 psi and 13V.

The SVT Focus pumped really cranked out the flow, registering 217 lph. The SVT Focus topped the list of production fuel pumps.

The supercharged 5.4 Lightning pump flowed just 149 lph, surprising given the power rating of the force-fed Modular V-8.

We even took the liberty of flowing the stock Zetec Focus pump, which responded with 143 lph at 40 psi.

After running the production pumps, we switched over to the common pump upgrades. The Holley 155-lph, in-the-tank pump (#12-912) registered 121 lph on our test bench at 13 volts.

large injectors are employed. Combining a 255-lph in-tank pump with a Kenne Bell Boost-a-Pump should handle just about any normally aspirated combination you are likely to throw at it. This of course assumes you have large enough injectors, adequate-size wiring to the fuel pump, and a good fuel system including fuel filter and rails.

While a simple 255-lph fuel pump combined with a Kenne Bell Boost-a-Pump might take care of most normally aspirated (return-style) combinations, the same does not

The 190 lph pump (#12-901) flowed 176 lph, but would not run above 65 psi without popping off externally.

hold true for turbo or supercharged combinations. For all but low-boost, bolt-on applications, the rising-rate fuel-management units that increase fuel pressure in (somewhat) relation to boost should be avoided. The key to a successful supercharged or turbocharged motor is in the tuning. A major portion of the tuning is the fuel system, namely the injectors and fuel pump (combined with the proper dyno-tuned computer chip).

The reason that the fuel pumps will not support as much power on forced-induction applications is that the fuel pressure will always increase at a (minimum) 1:1 rate with

The high-pressure 255 pump (12-915) flowed slightly more than the low-pressure version, registering 244 lph.

boost pressure. This means that if you run 10 psi of boost, the fuel pressure that started out at 40 psi will now be 50 psi, as the fuel-pressure regulator on all return-style fuel systems are vacuum/boost referenced. This is done to decrease fuel pressure under vacuum (low fuel demand) conditions to help lean the mixture. As mentioned earlier, the flow rate of the fuel pump will decrease with the increase in pressure, thus the pump will be able to support less absolute power at 50 psi than it could at 40 psi. It should also be pointed out that though the injectors see 50 psi of fuel pressure, it must flow against 10 psi of boost

The 255-lph, in-the-tank pumps come in both high-pressure and low-pressure versions. The low-pressure 255 pump (12-902) flowed 233 lph at 40 psi.

pressure, thus giving the injector the delta flow of only 40 psi.

This same scenario occurs on the later returnless fuel systems due to the pressure transducer in the fuel rail. When running a blower or turbo on a 4.6 equipped with a returnless fuel system, boost pressure will be applied to the diaphragm of the pressure transducer, thus making the computer increase fuel pressure to compensate to produce the original desired pressure.

After running the in-the-tank pumps, we turned our attention to the inline fuel pumps. This T-rex pump from Vortech flowed 162 lph at 40 psi.

Holley offers this inline pump (#12-920) that flowed 276 lph at 40 psi.

The Aeromotive 11101 pump flowed a whopping 383 lph at 40 psi and 13 volts. Upping the voltage to 17 volts increased the flow rate to 536 lph.

The Aeromotive 11104 inline fuel pump was quite impressive at 512 lph at 40 psi and 13 volts.

The highest flowing pump of the test belonged to Barry Grant. The King Sumo pump flowed 608 lph at 40 psi and 13 volts and an amazing 759 lph at 40 psi and 17 volts. Figure on a dedicated wiring harness for the King Sumo, as the amp draw was pretty significant on the bad boy.

If the computer called out for 40 psi of fuel pressure under a given situation, but the supercharger (or turbo) was producing 10 psi of boost, the computer would continue to provide pulse width modulation (voltage) to the fuel pump until a delta pressure of 40 psi was achieved. This would require the computer to raise the actual fuel pressure to 50 psi to compensate for the additional 10 psi of boost.

This same scenario takes place on the supercharged '03-up Cobra, especially as owners

	13V			BAP 17V		
	40 psi	60 psi	80 psi	40 psi	60 psi	80 psi
5.0 & SN95	98	73	46	137	100	63
4.6 2V late	158	115	65	264	201	152
4.6 4V Late	154	131	100	211	189	162
'03-04 Cobra (x2)	167	145	119	236	215	189
Lightning Late	149	127	95	204	181	158
Focus Zetec	147	103	54	230	190	160
SVT Focus	217	185	143	302	278	244

The '03-04 Cobra features two of the listed in-the-tank fuel pumps, so double the flow rates when calculating the power potential.

COMMON UPGRADES

	13V			BAP 17V		
	40 psi	60 psi	80 psi	40 psi	60 psi	80 psi
155	121	98	73	177	153	107
190	176	146	*	242	216	*
255 Low Press	233	199	162	312	287	248
255 High Press	244	217	180	322	290	256
Vortech T-Rex	162	137	108	223	203	169
Holley Inline	276	252	221	354	333	307
Aero 11101	383	324	268	536	491	422
Aero 11104	512	421	333	708	640	561
BG King Sumo	608	525	415	759	707	620

*The 190-lph pump externally bypassed fuel above 65 psi.

HIGH IMPEDANCE INJECTOR FLOW RATINGS

Injector	Max Power (at .5 BSFC)
19 lbs.	304 hp
24 lbs.	384 hp
30 lbs.	480 hp
36 lbs.	576 hp
40 lbs.	640 hp
42 lbs.	672 hp
50 lbs.	800 hp
55 lbs.	880 hp

The injector flow rating can be increased (or decreased) with a change in the fuel pressure. Most injectors are rated at 43 psi. The maximum power level is obtained by dividing the flow rating by the BSFC number then multiplying by the number of cylinders. In the case of the 19 lb/hr injectors, the formula looks like this:

Max power=19/.5 x 8, 19/.5=38 x 8 cylinders =304 hp.

It is possible to increase the power output of a given flow rating by improving the BSFC number. If we use the 19 lb/hr injector and run a (more efficient) motor with a .4 BSFC we get the following:

Max power=19/.4 x 8=47.5 x 8=380 hp.

increase the boost pressure by installing larger crank or smaller blower pulleys. We have seen fuel pressure as high as 80 psi on modified '03-04 Cobras equipped with twin-screw blower upgrades. The fuel pump(s) on these Cobras flow well, but the fuel flow decreases dramatically when jumping from 40 psi to 80 psi.

Many of you may now be asking why not simply install the 255-lph fuel pump used on the early return-style fuel system into the late-model, non-return fuel systems and be done with it? Would if it were that easy. Unfortunately, the early and late fuel pumps differ in their construction. The early pumps are positive displacement while the later pumps are turbine. The later turbine pumps will stand up to pulse-width modulation, but apparently the early positive displacement pumps will not. According to Jim Bell of (Kenne Bell), the later pumps can be used in early applications, but the reverse is not true.

To find out what can be done to improve the flow rates of both the early- and late-model fuel pumps, we gathered together as many as we could get our hands on and headed over to Kenne Bell for flow bench testing. We flowed all of the available factory pumps at 40, 60, and 80 psi at 13 volts, then reflowed the three pressures at 17 volts using the Boost-a-Pump. We chose the three different pressures to demonstrate the drop-in fuel flow generated by the pressure increase. The Boost-a-Pump was employed to demonstrate the improvements offered by increased voltage. The data should allow the readers to finalize a system that will work with their current combination. After running the factory in-the-tank pumps, we grabbed a number of after market in-the-tank and inline pumps and subjected them to the same procedure. The largest of the aftermarket pumps were flowed at Westech using the fuel turbines on their SuperFlow engine dyno. The turbine flow numbers supplied by the Super Flow engine dyno were verified physically by taking random measurements using a graduated container over time.

The first thing that should be evident from the flow numbers is that increasing the pressure from 40 to 60 psi and then again to 80 psi has a dramatic effect on pump flow. In the case of the 2V 4.6 GT fuel pump, the flow rate dropped from 158 lph at 40 psi to 115 lph at 60 psi and then down to just 65 lph at 80 psi. To put this into perspective, the pump would support over 500 hp at 40 psi (.5 BSFC), but only 215 hp at 80 psi. That is a pretty dramatic drop in fuel flow my friends. The ironic thing is that increased fuel pressure usually coincides with forced induction, so added fuel flow is needed with the increased pressure, not the other way around. Unfortunately, more pressure means less fuel flow from the pump, so you'd better make sure the pump is able to support the desired power level at your intended fuel pressure.

Check out what happened when we increased the supply voltage to the same 4.6 GT pump from 13 to 17 volts. Running at 40 psi, the increased voltage upped the flow rate from 158 to 264 lph. Note also that the flow rate of the GT pump at 80 psi and 17 volts nearly equaled the flow rate at 40 psi with 13 volts. In most cases, the pump flow at 17 volts at 80 psi actually exceeded the flow with 13 volts at 40 psi.

The guys at Kenne Bell came up with some interesting data regarding the SVT Focus fuel pumps during flow and dyno testing. The SVT Focus pumps are a common upgrade offered for the '03-04 Cobras. Checking out the flow data, it is pretty easy to see why you might want to replace the dual Cobra pumps with the SVT Focus units. The SVT Focus pumps flow 143 lph (at 80 psi) compared to just 119 (at 80 psi) for the stock '03-up Cobra pumps.

According to Kenne Bell, the swap is not quite as easy as the flow figures would have you believe. Physically, the Focus pumps will bolt in place of the stock Cobra pumps, but the wiring is not a direct plug and play. This, of course, means you have to drop the fuel tank to perform the intended surgery. In addition to the tank removal and power- and ground-plug issues, there is also the matter of the increased current draw from the larger pumps. Apparently, the increased amp draw from the dual Focus pumps is too much for the maximum 30-amp (mini) fuse.

For proper operation, the mini-fuse assembly must be replaced by a dedicated 40-amp (standard size) fuse, to say nothing of the wiring from the fuse to the pumps. The increase of 48 lph hardly seems worth all the trouble compared to just increasing the supply voltage with a Boost-a-Pump (or other equally effective voltage amplifier). Running 17 volts increased the pump flow of each of the two Cobra pumps from 119 to 189 lph for a total gain of 140 lph.

Since we had the fuel flow bench at our disposal, we decided to run some testing on some of the more popular in-the-tank and inline fuel pump upgrades. Check out the flow results, as we ran the aftermarket pump upgrades at 40, 60 and 80 psi at both 13 and 17 volts just like the stock pumps. The in-the-tank pumps were run on the same flow bench used to test the stock pumps, while the inline pumps were flow tested using turbine readings from the Westech Superflow dyno.

The test procedure was pretty straight forward. All we had to do was install the pumps, provide 13 volts (and 17V with the BAP), and adjust the pressure. The amount of fuel bypassed equaled the flow rate at the given pressure and voltage. The flow rate was recorded by the Superflow dyno, as well as physically verified by running the bypass into a graduated container over a given period of time (60 seconds). The two readings were within a couple of lph—certainly accurate enough for our needs. As with the stock in-the-tank pumps, fuel pressure fell off dramatically with pressure, and increased after upping the supply voltage.

Check out the flow rates of the Aeromotive 11104 and Barry Grant King Sumo pumps. How does 708 lph at 40 psi (at 17 volts with BAP) sound for the Aeromotive or 759 lph for the Barry Grant King Sumo? It should be noted that the Barry Grant pump will require a serious electrical system, as the amp draw was dramatically higher than any of the other pumps. Since the King Sumo

STEEDA 4.6 GT PUMP UPGRADE

Steeda offers an interesting upgrade for the late-model 4.6 GT. Actually, Steeda offers a pair of performance pump assemblies, including upgrading your single GT pump to a dual-pump setup from the '03-up Cobra. According to our flow data, this would replace the single 158-lph pump (at 40 psi and 13 volts) with a pair of pumps flowing 167 lph. This would give you the ability to produce significantly more power, but the possible downside is cost, as the Cobra upgrade requires not only the pumps but also the Cobra fuel tank—a cost of $648.

The second option offered by Steeda is to upgrade the existing GT pump assembly to accept a pair of pumps with a combined flow of 268 lph (at 43 psi). The GT pump upgrade requires sending your existing pump assembly for modification by Steeda to accept the dual-pump upgrade. Since the twin-pump system does not require replacement of the fuel tank, the cost is a much more reasonable $399.

It is possible to ship Steeda a pump assembly purchased from Ford or from a wrecking yard to keep you vehicle on the road during the upgrade, but make sure that the pump assembly is from the same year Mustang, as the late-model ('01-up) wiring plugs differ from the earlier ('99-00) models. The one downside to the dual pump upgrade is that the system may experience fuel starvation under hard (sustained) cornering with a low-fuel tank level. Check with Steeda for full details on the limitations of the dual-pump assembly. —R.H.

pump is capable of supporting 2,500 hp at 40 psi (at 17 volts), figure this unnecessary for anything but an all-out racecar.

The flow data should help you decide which pump/voltage combination would be right for your application. Remember to accurately judge the operating pressure of your motor, especially if you plan on running a blower or turbo. While we have provided the fuel pump figures, it is important to recognize that the fuel-pump flow is only part of the fuel equation. We have included injector flow ratings and maximum power levels for many of the common injector sizes. The horsepower calculations are based on a .5 BSFC number at 43 psi. It is possible to increase the flow rating of the injector by increasing the fuel pressure.

It is also important to understand that increasing the fuel pressure at a 1:1 rate with boost pressure does not actually increase the flow rate of the injector, since the additional fuel pressure only compensates for the additional boost pressure. The fuel must spray against the boost pressure in the intake tract, so the delta pressure remains the same. Your injectors must be capable of supporting the desired power level (at a delta pressure) and the air/fuel and timing curves must be spot on for maximum safe performance.