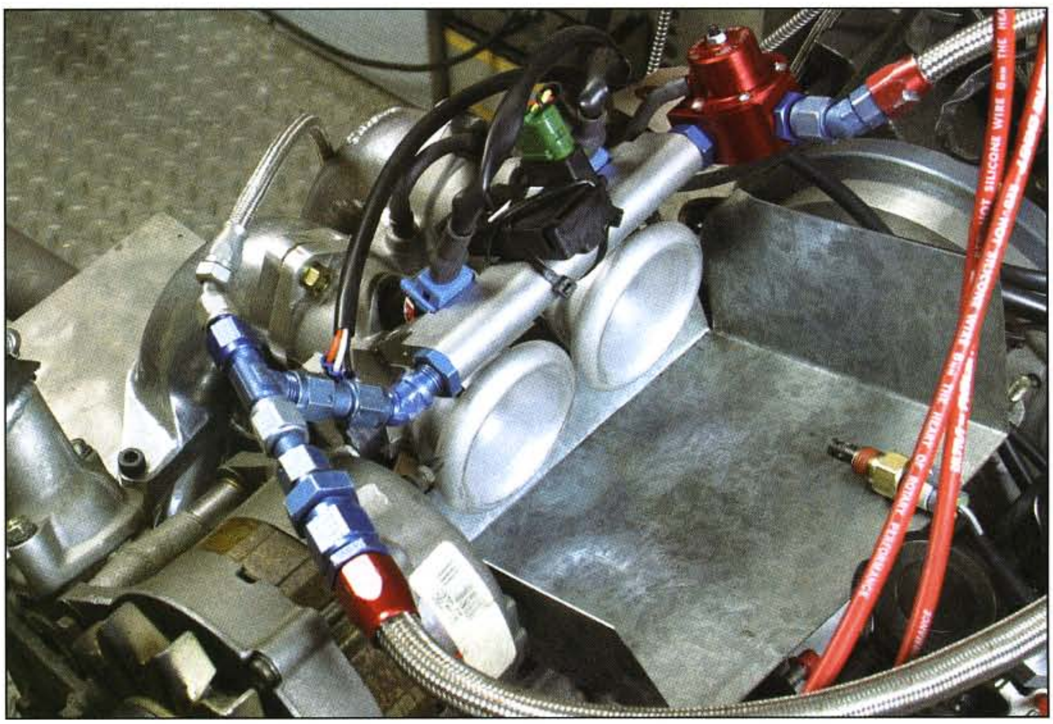
CARBURETOR VS. FUEL INJECTION

WHO WILL WIN ON THE DYNO?

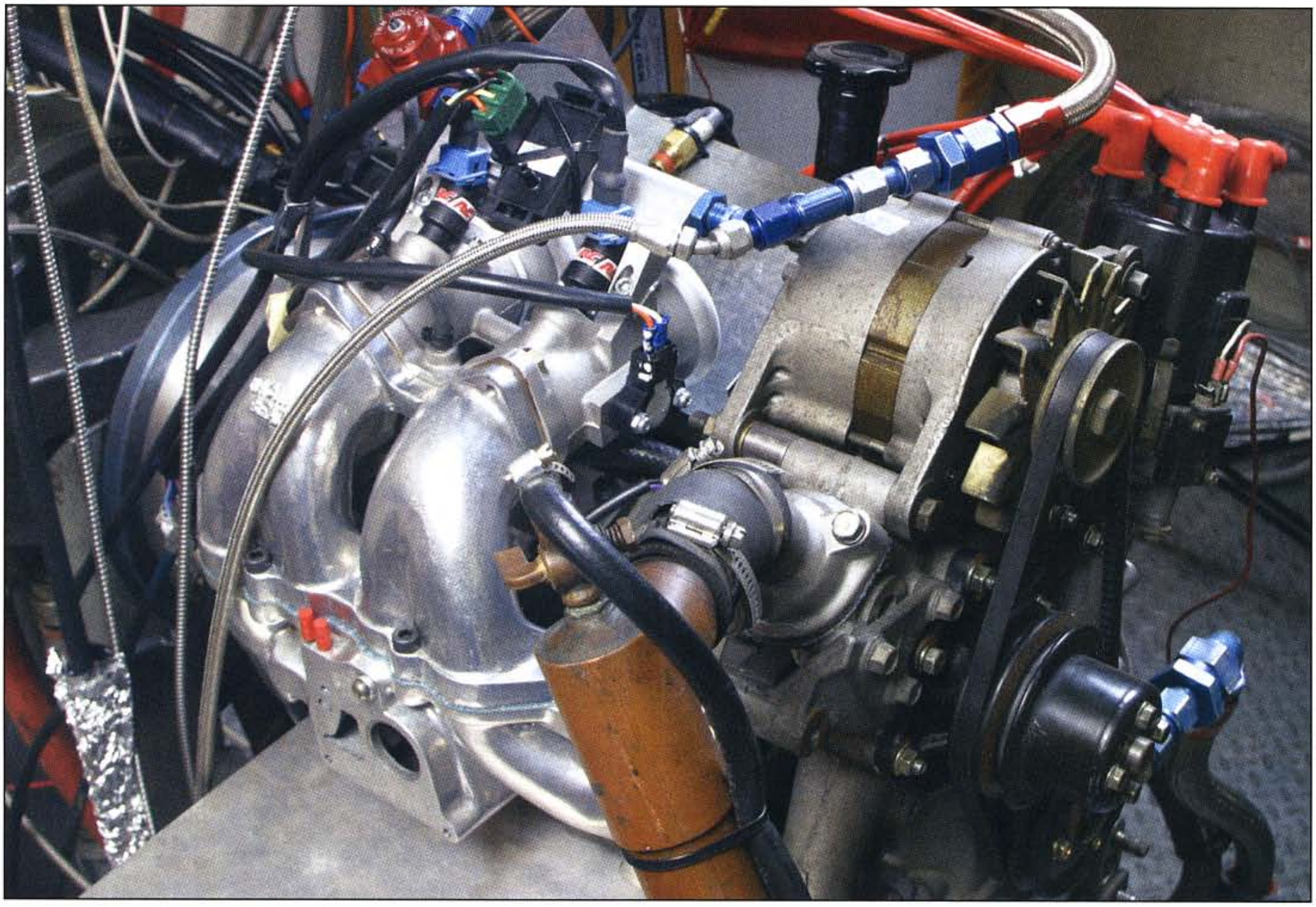
By Jim Mederer / Assisted by Damon Wong / Photos by Jim Langer

Michael Ferrara (aka the Publisher of DRAG Sport) is at it again. After the last article (three different carburetors on a street-ported 6-port 13B), he asked us to go one more step with the engine - fuel injection. Shortly thereafter, we received a TWM Induction throttle body complete with fuel rail and pressure regulator, four 750cc/min Bosch fuel injectors from R.C. Engineering and a Haltech F10 ECU (Version 7.08) with harness.



The Throttle Body

The TWM 50mm throttle body (p/n 2900-5002) had the bore spacing and bolt pattern to fit in place of a Weber (or Dellorto or Mikuni) sidedraft 2-barrel carburetor, so it fit right on the manifold we used previously. However, there is one thing to note about the TWM throttle body: the overall length of the throttle body was either 4.82 or 5.38 inches (depending on the air horn selected), while the Dellorto and Mikuni we had used previously were about 6.65 inches overall. As you will see later, overall length does affect the power output. This was demonstrated best



with the TWM throttle body when we tried both lengths (25mm and 50mm air horns) with interesting results. As you see in the pictures, two injectors, along with the fuel rail and pressure regulator, are all part of the assembly. TWM also offers the throttle bodies with four injector bosses.

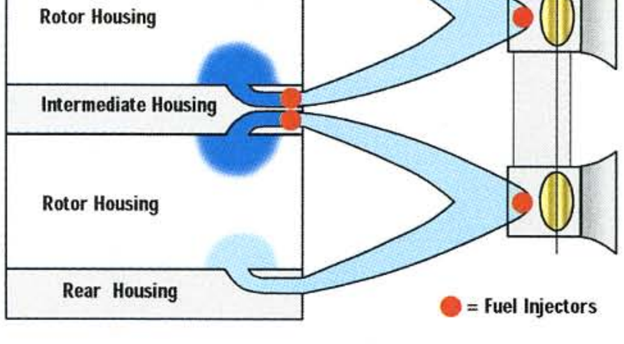
The Injectors, Fuel Flow & Horsepower

The RC Engineering injectors Part # PB8X-750, flow checked at 750cc/minute at 43.5 psi. Actually, at this point, we had determined that the cart was quite some distance ahead of the horse. You should first calculate what components you need, then order them. Of course, there are very knowledgeable people who can advise you on component selection, but they often don't have all the information, and that can lead you astray.... My point here is that you might assume that the best way to run the engine would be to run the engine on four injectors - two in the throttle body and two in the intermediate housing, where Mazda normally mounts their primary injectors. Trouble is, the fuel wouldn't be distributed uniformly in the air. True, all the fuel still goes into the appropriate rotor housing, but the charge may well be "stratified," that is, not mixed uniformly, and therefore not burn smoothly (see Figure 1). For this reason, I was interested in the possibility of running only two injectors in the throttle body and none in the intermediate housing. So we will take a moment and look at the mathematical situation. Could we only use two of these injectors and still have enough fuel to feed the engine?

Figure 1 - Schematic View of Intake Fuel Flow

The use of two injectors in the throttle body gives uniform fuel distribution in the air. Adding two injectors in the intermediate housing adds fuel to the mixture entering the intermediate housing, causing it to be excessively rich. Therefore, it seems better to use only two injectors in the throttle body, if possible.

Figure 1 - Schematic View Of Intake Fuel Flow



Fuel Flow Requirements

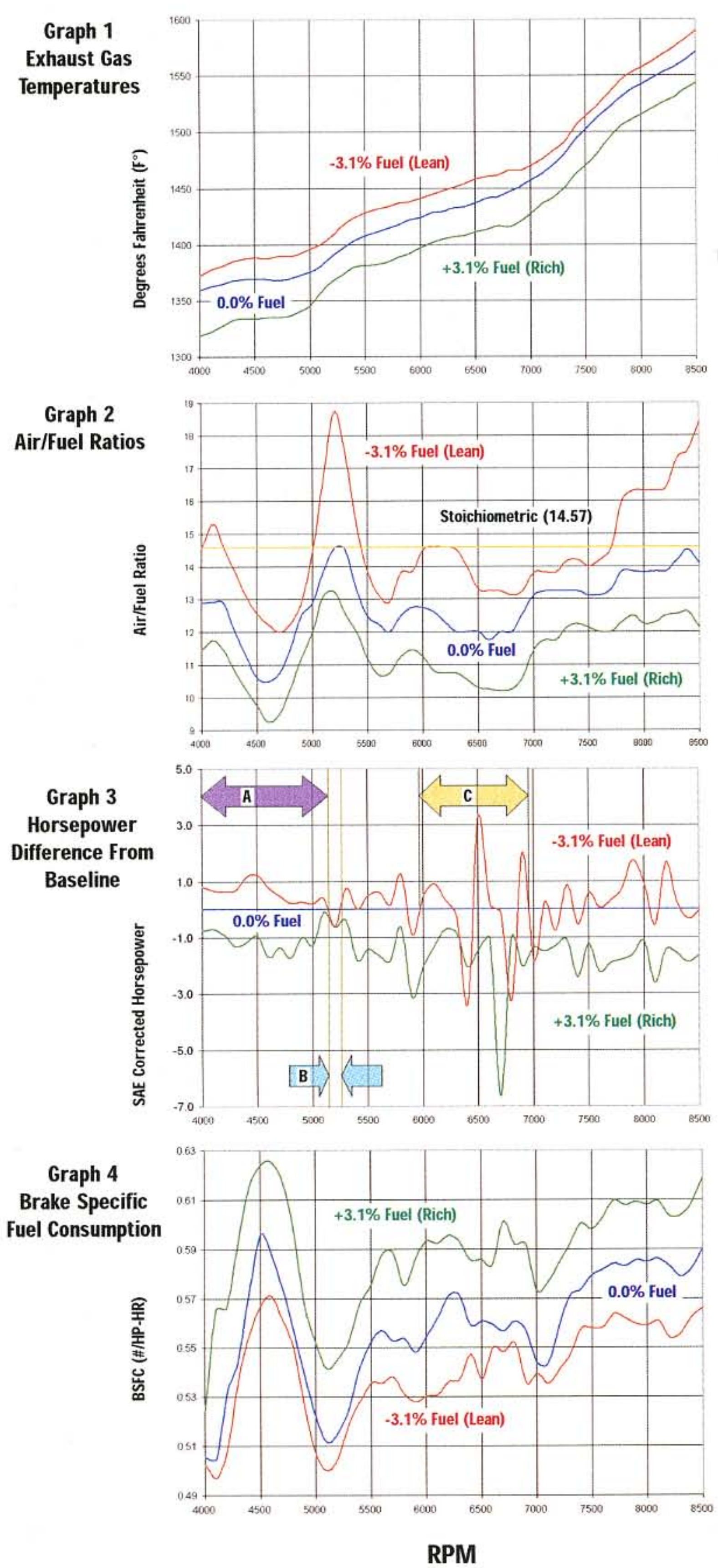
First, we needed to determine the amount of fuel required. To solve this equation, you must know the maximum power you expect to produce and also the "Brake Specific Fuel Consumption" (BSFC) of the engine. Since we had run the engine before, we knew the peak would be about 225HP at 8500 RPM. We also knew that the BSFC for this type of engine is probably .53 to .55 pounds of fuel per horsepower per hour (#/HP-HR). Therefore, we chose the higher rate of .55 to be on the safe side.

$$225\text{HP} \times \frac{.55 \text{ lbs fuel}}{\text{HP hr}} = 123.75 \text{ lbs fuel/hr}$$

Multiply the two together and you get:

Don't round off numbers until calculations are finished. (For those of you with reciprocating engines, the calculation is similar, but you should use a BSFC of .50 #/HP-HR.) Next, you compare the required fuel flow above to the flow of a single injector. Actually, RC Engineering gave us that number as 750 cc/minute. It's only necessary to convert this number into "Pounds of Fuel per Hour," The factor for gasoline is 5.7 pounds per 3785.4 cc, so:

750 cc/min x 60 min/hr x 5.7



All of the graphs on this page show the same (3) dyno runs. All are "sweeps," that is, continuous full throttle runs starting below 4000 rpm and ending past 8500 rpm.

Graph 1 shows the steady rise of EGT with RPM and leaned mixture. The EGT's shown are well below what you would see if the engine were held at one RPM long enough to "heat soak" the jacketed thermocouples. Because the rate of acceleration is NOT the same between runs or during runs (it is controlled by my sweaty hand on the water brake valve), some errors arise.

Graph 2 shows why an "Oxygen Sensor" has limited value in tuning a rotary at high power. Mapping an engine to ANY one number would result in a map with serious errors. Judging from Graph 3 (Horsepower), the "red" run (leaned 3.1%) has, on average, the best power of the three - and it ranges from 12:1 to over 18:1 while doing it! On top of that, the "ideal" Air/Fuel ratio varies from one engine to another!

Graph 3 offers a guide to what changes should be made to the basic fuel map. In Range A, the red mixture (-3.1%) is best. in Range B, the blue (0%) is best, and so on. Range C demonstrates some of the confusion that arises in dyno testing. The large excursions from the baseline are probably not primarily due to mixture errors, but instead are due to operator inputs on the dyno water valve. In this range, the torque is rising a bit faster and it would probably be better to do a little "steady state" running while changing mixture to get the map just right.

Graph 4 is actually telling you the efficiency of turning fuel into power - lowest number WINS! This number is calculated from the fuel flow and the observed (not corrected) power.

parameters listed would not supply enough fuel. However, there was another possibility. Raise the pressure. Two injectors could flow more than their original flow rating if the supply pressure to the injectors was increased beyond the original flow-rated pressure of the injector.

Flow increases roughly in proportion to the square root of pressure increase factor. From experience, we have seen that 60 PSI is usually an acceptable operating pressure for these components.

60 psi / 43.5 psi = 1.379
(pressure increase factor)

The square root of 1.379 = 1.174
(flow increase factor)

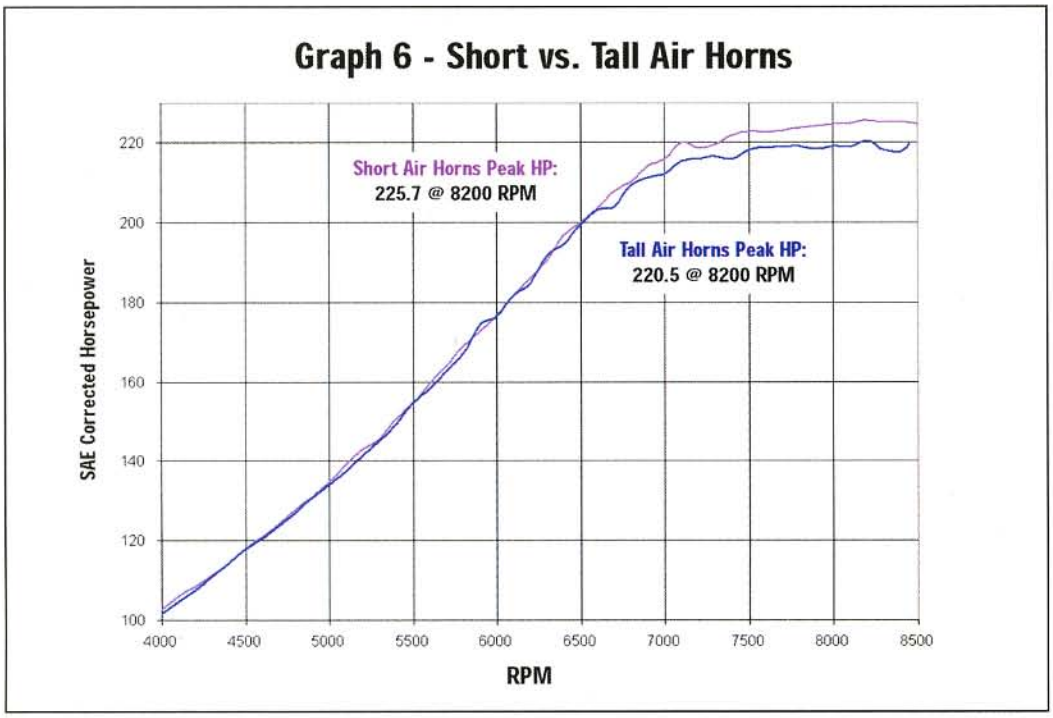
Therefore, one injector running at 80% and 60 psi will deliver:

54.21 lbs/hr x 1.174 = 63.67 lbs/hr
and two injectors will deliver:

2 x 63.67 lbs/hr = 127.33 lbs/hr

(The total fuel flow for two 750cc/min injectors at 80% and 60PSI)

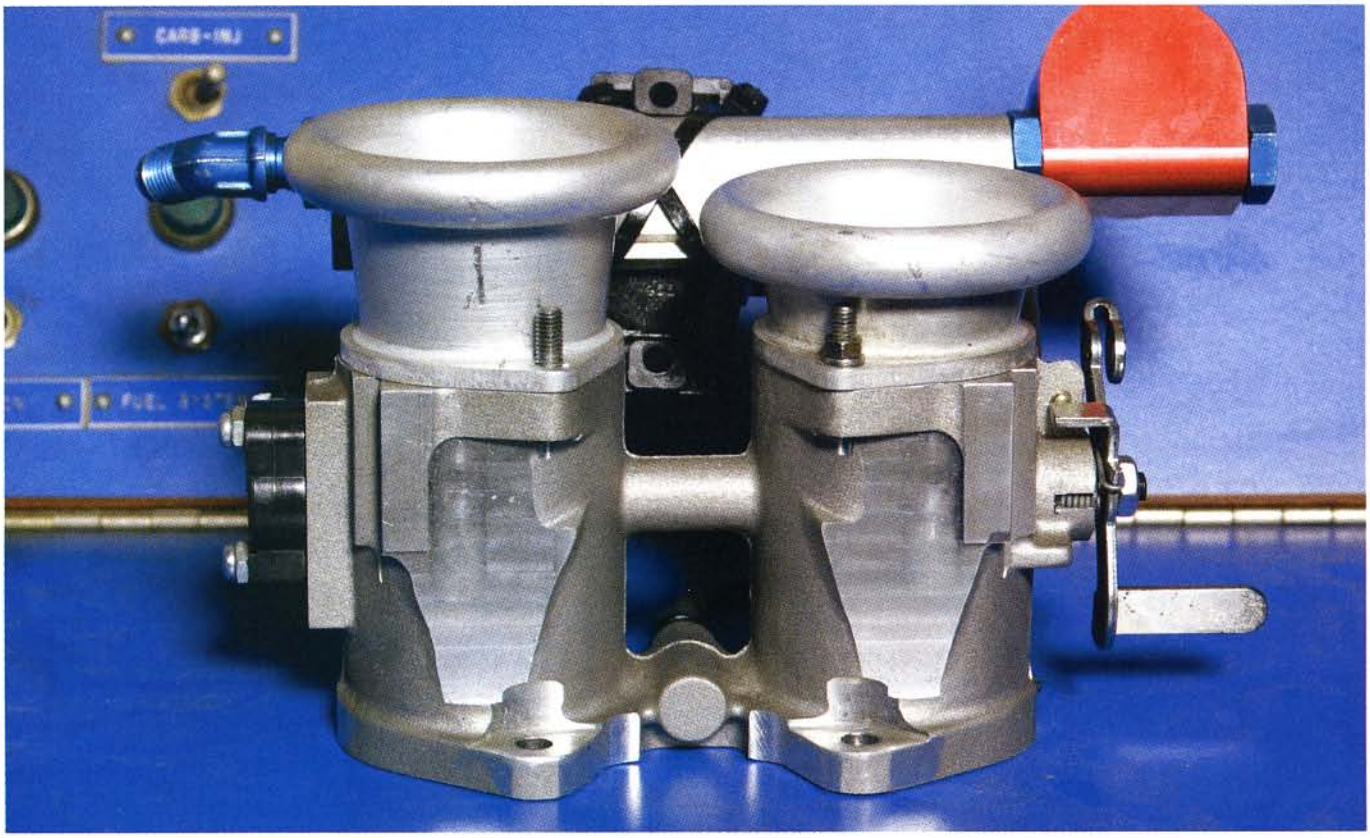
Problem solved. This is enough to get the job done! By raising the supply pressure to 60 psi (instead of the 43.5 pressure the injectors were originally flowed) we could meet the engines fuel demands with just two injectors, and they will run near the ideal on-time at maximum power. This solution is also simpler, less costly, lighter, has less plumbing and takes less power to operate. There are other considerations, but these were enough to make us want to try two injectors at 60PSI.

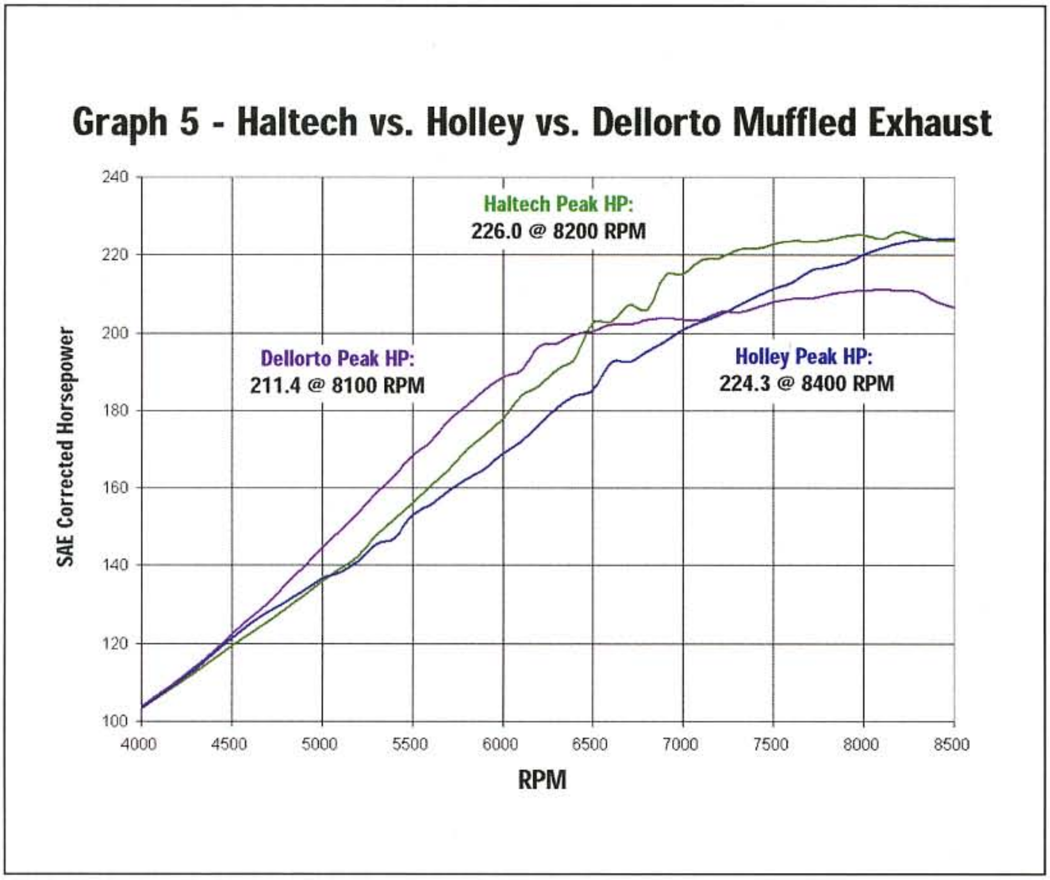


Fuel Injection Considerations

One other item to consider is the fuel pump, as well as its relationship with the fuel pressure regulator. You must select a pump that will flow the required amount at the planned pressure. As a rule, as the pressure goes up, the flow capacity goes down. Thus, a pump that flows, let's say, 130

Long vs. Short Air Horns





pounds of fuel/3785.4 cc = 67.76 pounds/hour (lbs/hr).

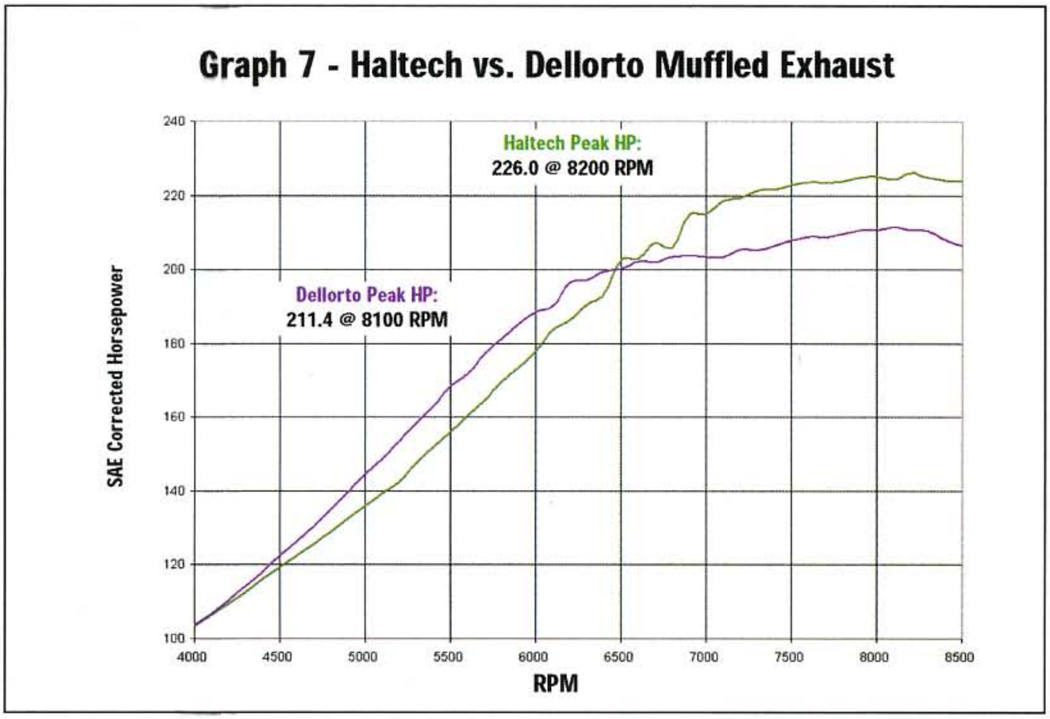
This is the flow of one injector, open 100% of the time, at 43.5 psi rail pressure. However, there is a catch. If an injector goes to 100% in an engine (or even near 100%), you loose control of the injector. You see, fuel is metered by time, and to get this control, the injector must "open" and "close," it happens that, for most injectors, the practical limit at high RPM is around 90% open time, and the wise tuner doesn't push this limit. Over time people have found that, for normally aspirated engines, 80% is a reasonable factor. (For turbos, a smaller factor is wise since it is common for boost pressure to move around - for instance, when making a quick shift - and if the "on" time rises into the 90% area, fuel flow won't increase and detonation may occur.) With this in mind:

67.76 lbs/hr x .80 = 54.21 lbs/hr for one injector at 80% and 43.5 psi.

Comparing this number with the fuel required for 225 HP (123.75 lbs/hr) and it is clear two injectors are not enough:

123.75 lbs/hr divided by 54.21 lbs/hr= 2.28 injectors required.

Thus two injectors under the



lbs/hr at 43.5psi might seem OK for this job, but in our experience, if it is run to 60 psi, the flow capacity will drop substantially. To make matters worse, pumps usually decrease in performance with age. On the other hand, if you get a pump that is excessively large, your fuel pressure regulator may not handle the flow well and the differential fuel pressure will change excessively with load and RPM (some change - one or two PSI - is common, though not desirable). The best I can suggest is to order both the pump and the pressure regulator from the same knowledgeable, reliable source - and then test them on the engine!

The Installation

With the plan established, we proceeded to assemble the parts on the engine. The throttle body fitted up nicely once the pressure regulator was swapped to the other end of the fuel rail. The short air horns were used in all tests except for the runs comparing the long and short air horns. The only easy location for the water temperature sensor was in the stock position on the back of the water pump. However, there is now no place for a dash-mounted water temperature gauge (sorry, Michael, I'm sure you'll find a suitable location when you stuff this engine into your RX-2). The throttle position sensor (supplied on the throttle body) did not match the Haltech harness, so we had to improvise that connection. We connected the Haltech RPM/sync input to the output of the leading ignition ignitor. We did not wish to use the Haltech ignition drivers because they would be another "change" which might affect power - easier and better to just leave the ignition as it was for the previous runs. We chose to run the ECU "throttle based" as opposed to "manifold pressure based" because it is quicker to map on our engine dyno. It is my impression that most guys on the street use "manifold pressure based" because it can be more forgiving in some circumstances - especially low rpm/light load. In any case, there is no difference in full throttle power, regardless of which mapping choice you make. However, since we chose "throttle based," we left the pressure input to the pressure sensor open to sense atmospheric air pressure. Actually, the best place to connect its pressure input would be inside the air filter - but one wasn't supplied, so "open" was the next best thing. The rest of the connections went well, as did loading the software and addressing the ECU with a laptop.

The Haltech F10 Setup

As for the ECU configuration settings, here is a summary:

Main Setup:

Cylinders	4
Load sensing by	Throttle
Map sensor	1 Bar
RPM limits	8800
Units	US
RPM mode	10500rpm

Fuel Setup:

Ign/by	1
Injection mode	Multipoint

Trigger Setup:

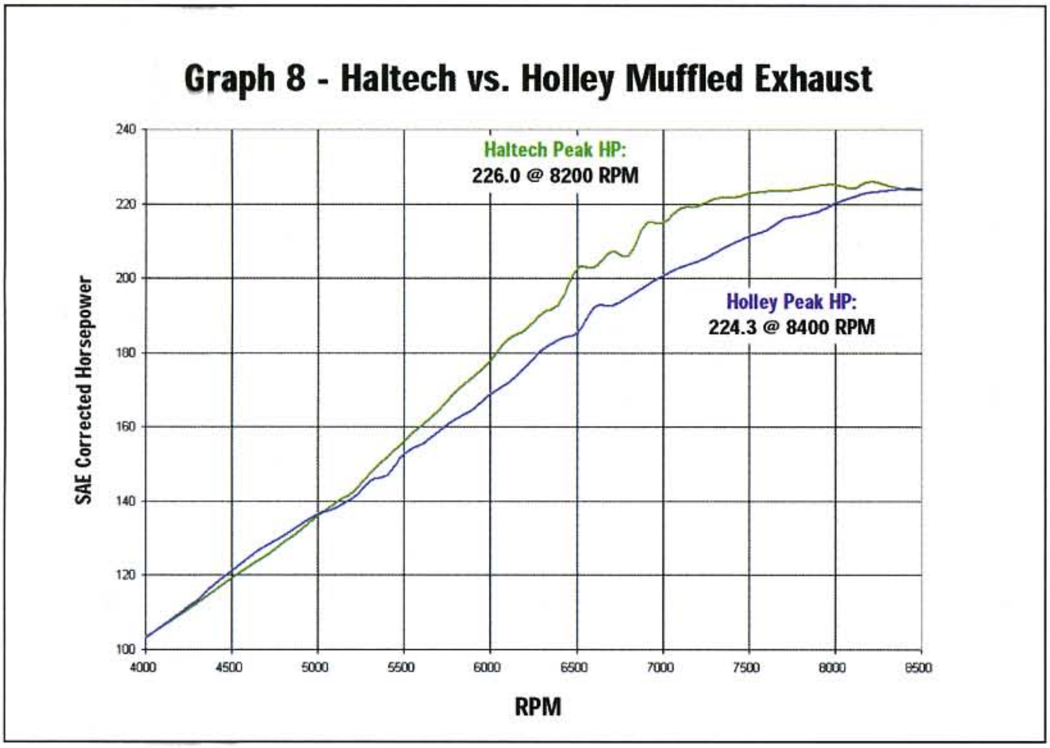
Switch 1	Off
2	Off
3	On
4	On
5	On
6	On
7	High
8	3.4V

Everything in software setup not specifically required for our running was disabled.

The "starter map" was largely useless due to our configuration choices, so it took a while to get running. Once the engine was warm, we proceeded to refine and expand our map. The logical place to start is at one of the lower rpm and throttle positions, and map to higher and higher rpm at a fixed throttle setting until you reach maximum rpm, then carry that same number of milliseconds off the high rpm side of the array.

Suggestions with Mapping the ECU

At this point, we'd like to offer a few suggestions: Do not try this with a fresh engine - you will delay break-in because you can't run at higher rpm and load due to the lack of a correct map. Break in the engine on a carburetor, if



necessary, or build a good map on an older engine to get the map close before switching to the fresh engine. We also believe that it is painfully difficult to build a map from scratch on the street or on an acceleration dyno. Only a dyno with a controllable load is appropriate for the job. If you have an excellent starter map, you may be OK, but otherwise; you will probably just beat up the engine by the time you get a functional map. Accurate mapping is tough so don't expect to breeze through it.

Optimizing the Fuel Map on a Rotary

Now for a few words on the criteria for adjustment of the fuel map: We have found that, in the higher power and RPM ranges, an Oxygen Sensor is of very limited value and exhaust gas temperature readings are of no use at all. This is different from most reciprocating engines, where "150 degrees rich of peak EGT (exhaust gas temperature)" or ".86 Lambda" or "12.5:1 Air-Fuel Ratio" pretty well define the "best power" mixture. In our experience, these "rules of thumb" will give you a substantially rich mixture in a rotary at full throttle. Why? Darned if I know. I just do what the engine tells me.

EGT, in our experience, doesn't peak until the engine begins to misfire from a lean mixture (see Graph 1). Short of the point of misfire, the EGT just rises with increasing load and RPM and decreasing fuel. Almost as bad, "Best Power" Air-Fuel ratios wander all over the map (see Graph 2). So what do you use as a guide in tuning a rotary? POWER. It is the only arbiter of "best mixture" at high rpm and load. One of the problems with this situation is that "best power" occurs across a small RANGE of fuel flow - usually 3% to 8% - so how do you choose a fuel quantity? At very low RPM and load, we select a "middle" or slightly rich setting for idle stability and better clutch engagement. As RPM and load increase, we tend toward the leaner side of the "best power" mixture for cleaner running and better mileage. Finally, at full throttle, we do "sweeps" with the "Data

Acquisition" engaged from low to maximum RPM (once a rough map has been established), first at the baseline setting, then about 3% rich, then 3% lean (see Graph 3). By analyzing the power increases and decreases at each load site, you can glean information to refine the map still further. This is NOT SIMPLE, nor is it easy, but it is the best technique we have found. As you see in Figure 3, the lines don't always line up

Haltech power compared to previous tests of the Holley and Dellorto carburetors. Considering that the manifolding is the same in both the Haltech and Dellorto tests, the TWM throttle body seems to flow notably better than the Dellorto at high RPM's, but also managed to do reasonably well in the mid range. Graph 6 shows the effect of changing from the "short" to the "long" air horns. Clearly, "short" is

just where you would like, but there is valuable information there. You must repeat the process several times to validate the changes you make, but the end result is worth it.

Graph 4 shows the final full throttle "Brake Specific Fuel Consumption" (BSFC). You may recall that, in early calculations, we used a BSFC of .55 # fuel/HP-HR based on past experience with many other intake systems. The graph shows that this engine is actually using .555 # fuel/HP-HR at maximum power. This observed BSFC corresponds well with our earlier assumption of .55 #/HP-HR.

Power Increase?

So, what power did we find? Pretty good, actually. Graph 5 shows the

better than "long" in this application. The results do suggest that it would be interesting to try an even shorter air horn than the "short" model we tested, but those we ran were near the practical limit of attachment to the throttle body.

Room for More Improvements

While studying the throttle body / injector assembly, we found something interesting - when the injector fires, about 40% of its spray hits the injector boss bore and doesn't immediately enter the air stream. This is the result of the choice of injector angle and position relative to the throttle bore. To be sure, all of the fuel still ends up in the appropriate rotor housing, but it is not as well atomized as it might be, causing a bit poorer mileage and requiring more "Accelerator Pump" fuel. According to TWM, a swap to a different manufacturer

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Anaheim, CA 92807
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RC Engineering
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Torrance, CA 90501
(310) 320-2277

TWM Induction
325D Rutherford Street, Dept. DS04
Goleta, CA 93117
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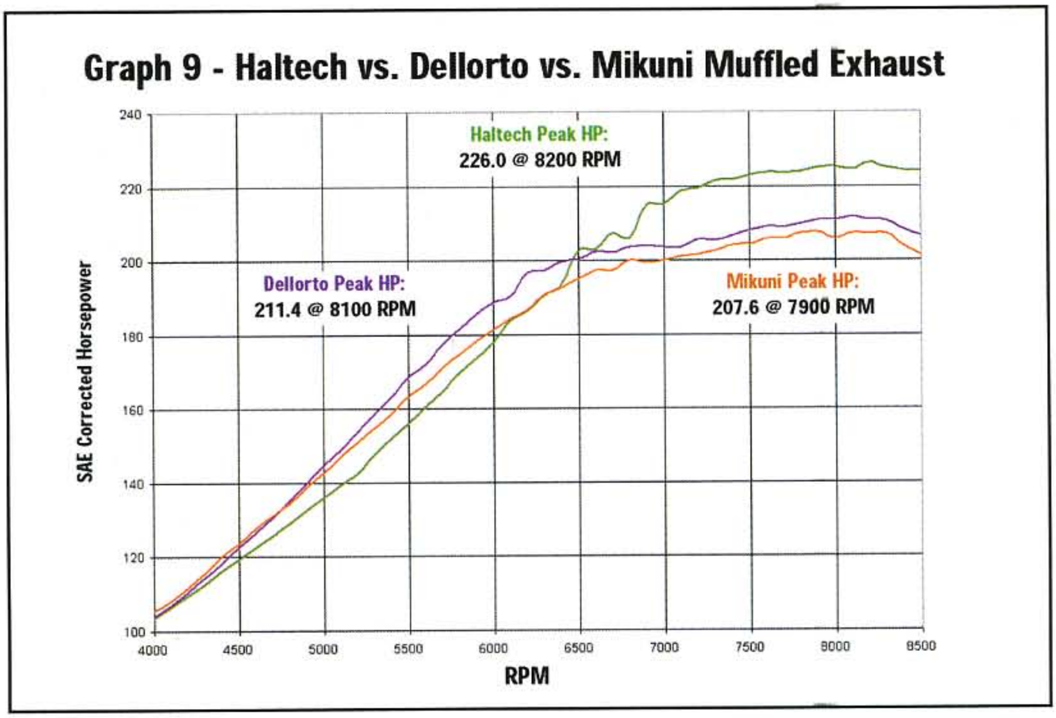

of injector may solve the problem (perhaps we'll solve this in the future).

The Bottom Line

So there it is, a full-throttle comparison of carburetors versus injection on a 6-port, street-port engine. Digital fuel injection works, although it requires a lot of effort to refine it to the best it can be. Truth is, to do a thorough job of mapping on the dyno, we would have had to spend several more days - and then some additional tuning would still have been necessary to get "driveability" right. Don't try this at home unless you are prepared for the effort. On the other hand, it sure is fun when it works well!

OK, Michael, time to pick up your darned engine!