



MAX POWER ON PUMP GAS & WATER INJECTION

By Martin Musial of AMS (www.automotosports.com)

There's nothing better than the smell of sweet race gas and your boost gauge pegged at 30psi. Gobs of horsepower are waiting to be unleashed under your right foot and that 116 octane fuel will keep detonation from trashing your motor. What if you could do all this without spending \$8/gallon on race fuel and just be able to run regular pump gas? You'd save a lot of money and you wouldn't have to remember about switching ECU maps and carrying 5 gallon drums of race fuel around. There are tuning tricks that let us make some very impressive horsepower

on regular pump gas but it's a fine line that we walk and have to be very careful in what we do. Detonation is a harsh beast waiting to rip the internals of your engine apart. A solution that lets us make more horsepower safely is water injection. Water injection is very interesting and contrary to what most people think its been used since WWII and was patented in the early part of this century. Water injection is beneficial to any engine that has high compression on the verge of detonation but most advantageous to forced induction engines.

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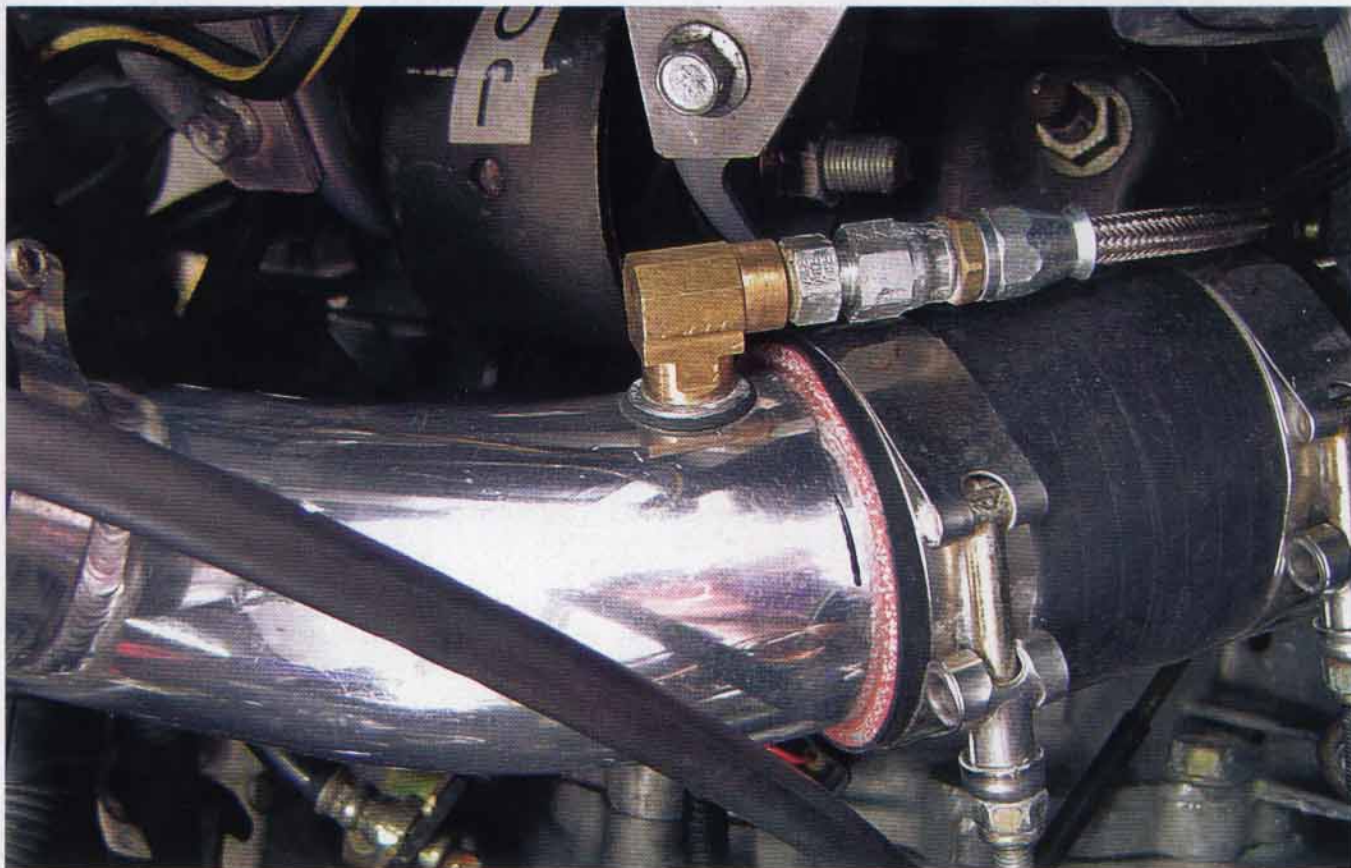
WHAT IS DETONATION?

Hopefully most of you haven't experienced detonation and if you have you might know it has some dire consequences. Detonation is a little complex to describe and understand but one of the most important things to know when tuning for maximum horsepower. During a normal combustion process the piston is reaching the top of the compression stroke and the spark plug ignites the mixture anywhere from 40 to 5 degrees before top dead center (TDC). A normal combustion process is a controlled burn, not an explosion. Even though it happens very quickly there is what's called a flame front that starts at the spark plug and moves into the combustion chamber outward. As this flame front travels, the cylinder pressure is also rising at a controlled rate. This cylinder pressure is what pushes on the top of the piston and gives the engine torque. Ideally this pressure peaks after the piston has reached TDC and is moving down the bore (combustion stroke). Detonation occurs when this controlled burn becomes an uncontrolled explosion and this results in a large pressure spike. This pressure spike is higher than the peak pressure during controlled combustion and is very sudden and violent.

There are varying degrees of detonation severity and it can become so violent that it will be heard during engine operation (sounds like marbles in a tin can). Detonation and the resulting pressure spike can crack pistons, pop head gaskets and eventually knock out rod bearings. There are several factors that contribute to detonation and different modes of how it propagates. Pre-ignition can lead to detonation and is caused by the fuel igniting in another spot besides the spark plug. A hot spot in the combustion chamber or pistons can cause this and then you have two flame fronts traveling towards each other. End-gases (gases left over from the previous combustion stroke) contribute to detonation because they dilute the intake charge with left-over hot exhaust gas. Pressure and thus temperatures raise suddenly as these flame fronts approach each other and can cause the air/fuel mixture to suddenly explode/detonate. Air/fuel charge temperatures can also be too high and cause sudden detonation. When more pressure and heat is applied to the air/fuel mixture the tendency to detonate increases. Too much spark advance increases cylinder pressures and can also cause detonation. As you can see, there are numerous causes for detonation and there are solutions to prevent each one.

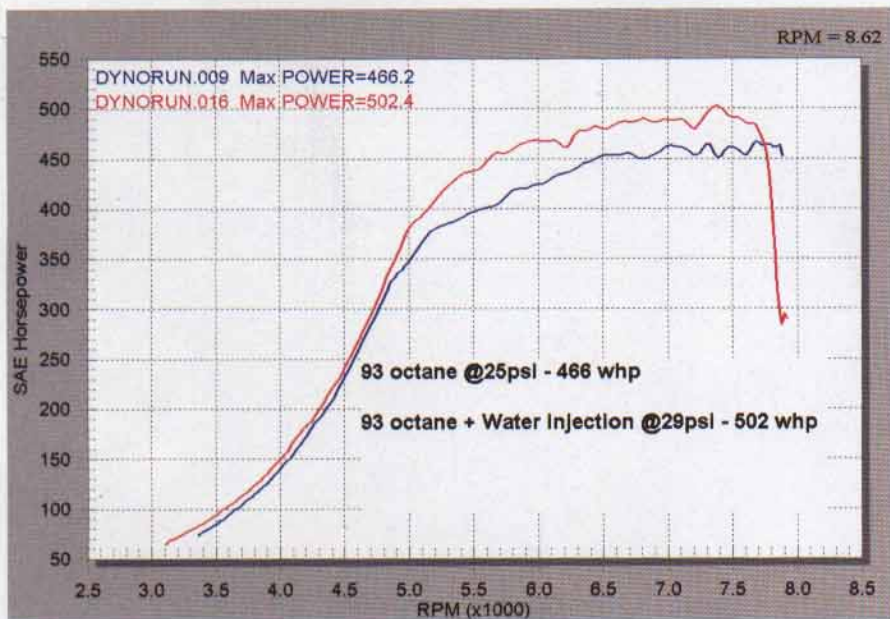
MAKING MORE HORSEPOWER

Before we dive into water injection it's important to know why a higher-octane fuel is needed and what makes an engine more prone to detonation. In this example we'll take a simple boosted motor under set conditions and alter components and boost and see why we are making more horsepower and what it does to the octane requirements. To keep things simple we'll talk about a factory stock 2.0L turbocharged engine. The manufacturer has already equipped this engine with lower compression pistons and has the fuel and timing curves set to keep this engine running safely. In factory tune we see that this engine is capable of making 250 horsepower and 250 lb-ft of torque on premium pump gas. The easiest way to make horsepower on a boosted engine is to turn up the boost. Providing the fuel system is adequate, we can turn the boost up and in turn make more horsepower and torque. This added boost packs more air into the engine and produces more cylinder pressure on each combustion stroke. Keeping in mind our previous discussion on detonation, we will reach a point where we have too much cylinder pressure and this can detonate on our premium pump gas. Turning the boost up



also has the effect of raising the intake charge temperatures. A turbo compresses the air and raises the charge density. Compressing the air also raises the temperature of it, thus the more boost the higher the intake charge temperature. By turning the boost up, we do two things to increase the chances of detonation, one is raising cylinder pressures and the other is raising intake charge temperatures. In our theoretical (example) motor we raised the boost from 10psi to 15psi and our horsepower jumped from 250hp to 300hp. Let's say this boost and horsepower increase has brought us right to the edge of detonation. Anything past this boost level will cause detonation and the slight horsepower gains (provided the stock ECU does not have knock control) will be offset by eventual engine damage or failure. Some performance modifications will make more horsepower and can actually help prevent detonation. Upgraded intercoolers lower intake charge temperatures and can lower pressure drops in the intake letting the turbocharger put less heat into the charged air. Any exhaust upgrades that free up the flow path will leave less end-gases (which can contribute to detonation) in the combustion chambers and raise the volumetric efficiency (more torque and hp). Anything from a header, downpipe, or exhaust system

will do this but one overlooked aspect is the turbo itself. An upgraded turbocharger with a larger exhaust wheel and larger turbine housing flow more exhaust gas and lets more exhaust gas out through the engine making more horsepower and leaving less hot end-gases in the cylinders. Cams can have a profound affect on cylinder pressures and detonation limits. Cams with little overlap and high dynamic compression at low engine speeds will make good low end torque with high cylinder pressures at low RPM but have a much lower detonation threshold. A set of cams tailored for higher RPM use, which reduce low speed dynamic compression and move the power curve up, will have lower peak cylinder pressures. The lower peak cylinder pressures mean a lower tendency for detonation but also less torque at lower RPMs. ECU modifications that raise the ignition timing bring a slight torque and horsepower increase but at the same time can put you over the detonation threshold. Timing is best left alone or reduced when trying to increase horsepower on a pump gas street machine. A complete book can be written on engine modifications and tuning in regards to cylinder pressures and knock thresholds. This is only intended as an intro to give you some idea of how and why detonation occurs.



HP GRAPH

Shown here are the WHP results of two pulls, one with water injection which netted 502whp and the other without which netted 466whp.



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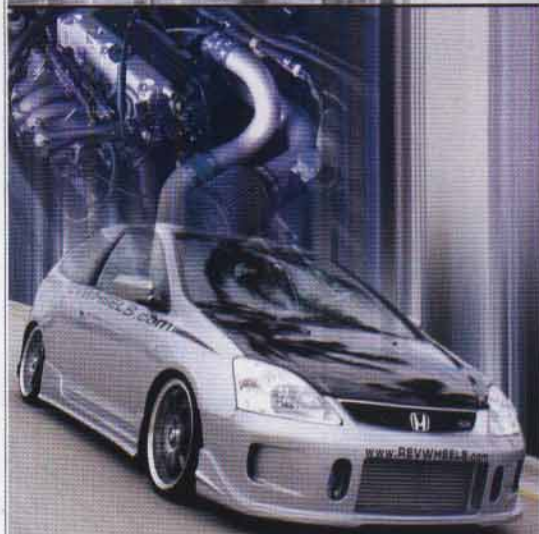


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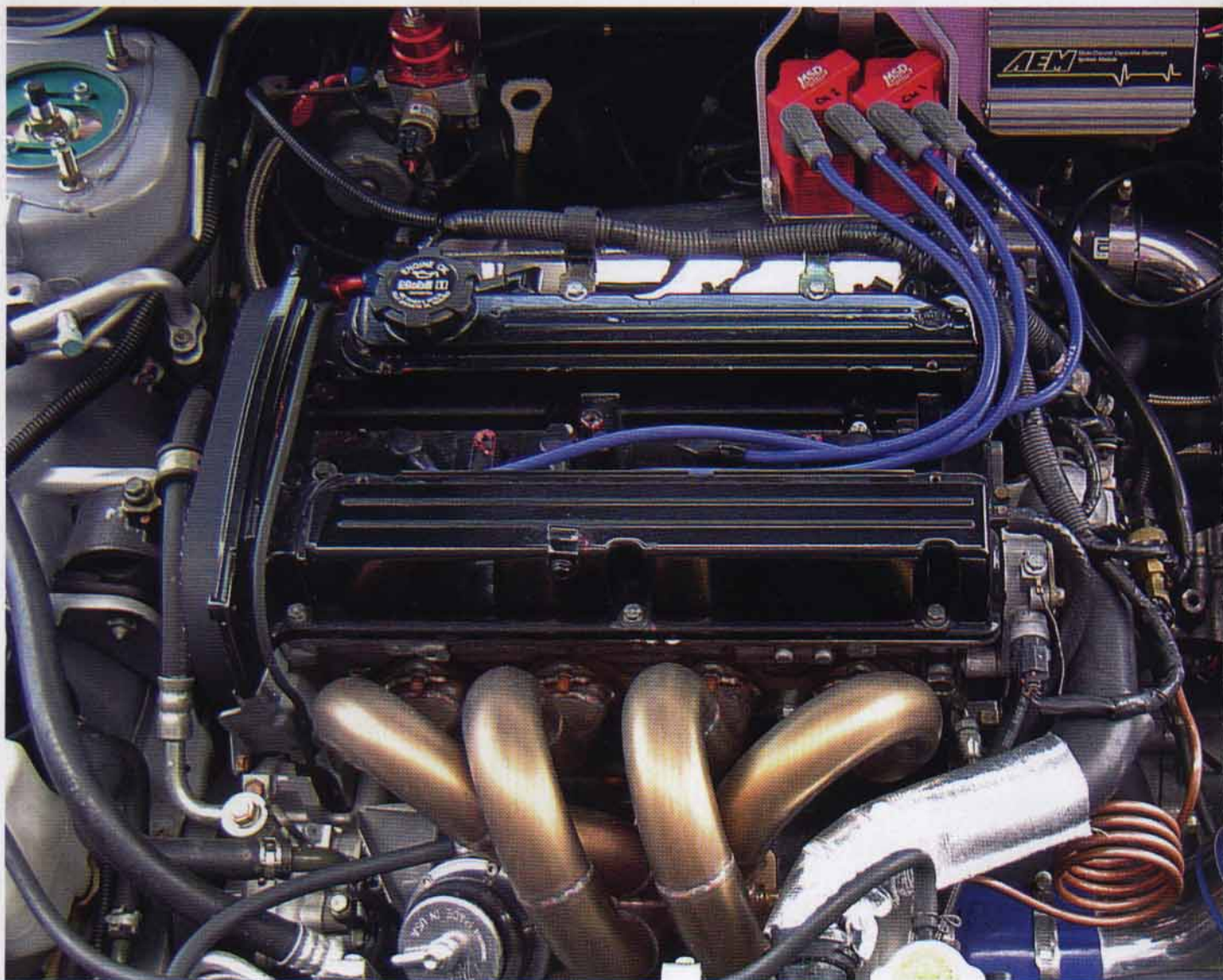
COMMON WAYS TO AVOID DETONATION

There are some tuning strategies and component choices that will reduce the chance of detonation. Obviously a higher-octane fuel can be used which has less tendency for pre-ignition or detonation. The main ways to reduce the chances of pre-ignition and detonation is reducing cylinder temperatures, reducing end-gases, and lowering peak cylinder pressures. Changing turbochargers and intercoolers can help in reducing intake charge temperatures and thus increasing the knock threshold. Using excessively rich fuel mixtures helps reduce detonation and pre-ignition by cooling the charge. The extra fuel acts to cool the charge temperature and also the internal components of the cylinder (valves, piston top, cylinder walls, spark plugs, etc.). Many OEM turbocharged vehicles will run very rich under WOT conditions for just

this reason, safety. Another and better way to cool things down is water/alcohol injection. We'll talk more about this a little later. Increasing engine VE and more specifically the exhaust flow will leave less end-gas. More efficient and complete combustion will also leave less end-gas in the cylinder. Piston and combustion chamber design can help reduce the amount of end-gas by forcing the charge into the center of the combustion chamber. Reducing peak cylinder pressure is most commonly done with less ignition advance or reduced boost and compression ratios. I have found that increasing the boost and reducing the ignition advance can make more power. There is a limit in which too little timing advance can increase combustion chamber temperatures and increase chances of pre-ignition. It's important to monitor knock sensor activity, air fuel ratios, and read the spark plugs if tuning near the knock threshold.

WATER INJECTION

Water injection is a very effective method of suppressing detonation and pre-ignition. A water injection system consists of a control system, water/fluid reservoir, pump, and injection nozzle. The most effective way to control the water injection is to increase the flow as boost pressure rises. Water under high pressure is injected as a fine mist before the throttle body. Water serves two purposes. It reduces charge air and cylinder temperatures thus reducing the chance of pre-ignition. It also acts as a buffer during the combustion process and prevents detonation. Water has a very high specific heat, meaning it absorbs a lot of heat energy without a big temperature change. Water is very good at reducing charge air temps and it also helps to cool down the valves, piston tops, cylinder walls, spark plugs, etc. When charge air

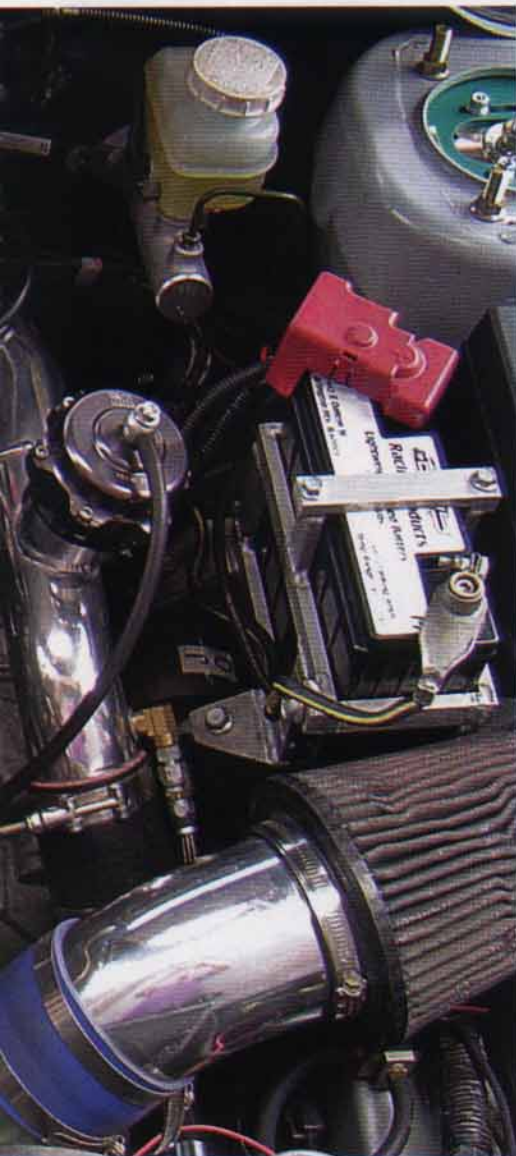


temperatures are reduced the density increases, thus packing more charge air into the cylinder (just what an intercooler does).

Water also acts as a buffer and slows the flame front thus slightly reducing the peak cylinder pressure. A higher average pressure offsets this reduced peak cylinder pressure across the power stroke (higher MBEP). The cooling effect and buffering also reduces the chance of the end-gases pre-igniting the compressed air fuel mixture. A properly setup water injection system works and has been proven and tested from WWII aircraft to modern day World Rally Challenge cars.

WATER INJECTION TESTING

During testing of the water injection system I strived to keep every variable constant and repeated the test results to gain an accurate



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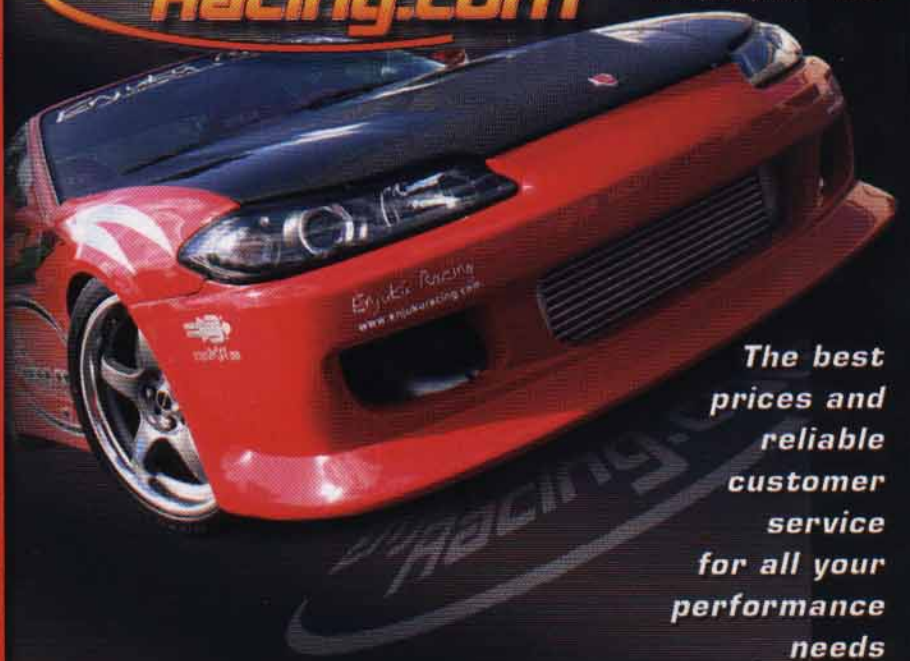
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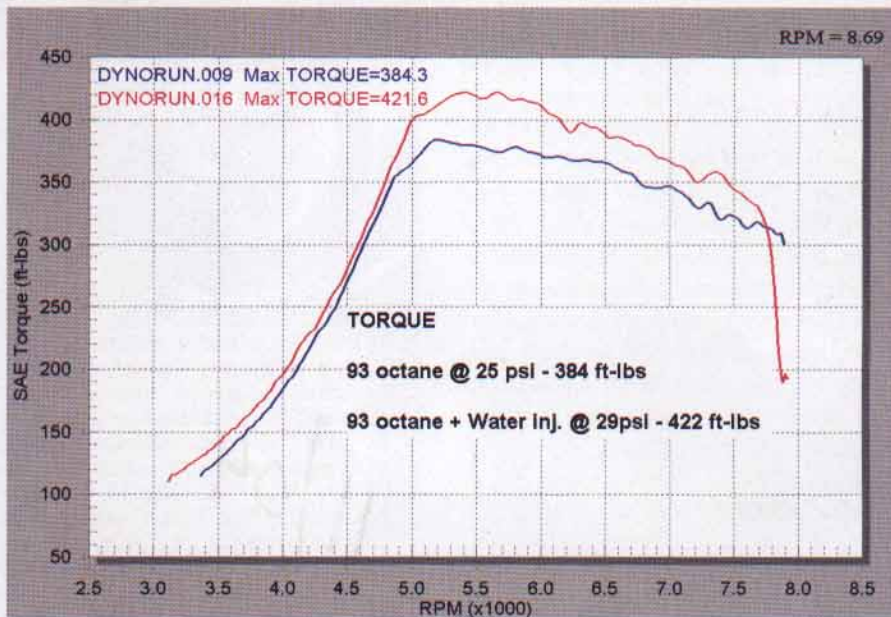
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TORQUE GRAPH

A peak gain of 38 lb-ft of torque was also obtained with the use of water injection. The graph shows a steady gain across the entire torque curve, which is always a good thing.

representation of what was happening. The test vehicle is our shop Mitsubishi Evolution VIII. Extensive modifications have allowed us to make 667whp on VP racing C16 race fuel. Now it was time to see what it would do on local 93-octane pump gas. During the whole process I was datalogging and monitoring the knock sensor activity with an AEM EMS. After each run I also checked the spark plugs and with a magnifying glass inspected the ceramic and electrode for telltale signs of detonation. Each run resulted in increased boost and reduced timing. After about 50 dyno pulls I reached a plateau in which adding boost and reducing ignition timing did not make more horsepower. The final result was 466whp and 384 lb-ft of torque at 25psi of boost. Activating the water injection system, I started with the pump gain (power level) at a medium setting. Slowly I raised the boost and noticed I didn't have to reduce as much timing as I thought necessary. Since water was doing most of the cooling I brought my air fuel ratios closer to 12:1 instead of almost 11:1 as it was on pure pump gas. Peaking out at 29psi of boost the dyno displayed 503whp and 422 lb-ft of torque. Knock sensor activity was actually slightly lower at this boost level with the water injection than at 25psi and on pump gas. The water injection pump gain was adjusted so that knock noise was kept at a low level but the engine would not bog down or misfire due to a large percentage of water being injected.

The next step was to mix varying percentages of water and methanol to see if it would allow even more boost and horsepower. The only problem was the stock ignition. Under these demanding conditions it was starting to become unreliable and any more boost resulted in misfires and I could not pull off a clean run.

Water injection has proven itself in the past and in this real life dyno test. It allowed us to run another 4psi of boost and make 37whp more than on pump gas alone. The system is safe and has a low fluid level sensor and multiple inline filters to prevent nozzle clogging. Water injection is a great bang for the buck modification but has to be used with caution and tuned accordingly to extract its benefits. I'm in the process of upgrading the ignition now and will be testing water and alcohol mixtures to find the most potent pump gas horsepower recipe. ■■■

