VersaTuner™ Tuning Guide

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VERSATUNE®

Introduction

Welcome to VersaTuner, the user friendly automotive performance tuning solution. VersaTuner is intended to make improving the performance and drivability of your car easy to understand and easy to do.

VersaTuner will allow you to make the most of your engine configuration and any modifications you might have. Whether you have a stock engine that you want to get a little more performance from with a minimal effort, or you have an all out race engine that you want to get every last bit of performance from, VersaTuner will make it easy.

The purpose of this guide is not only to explain how to use VersaTuner, but also to educate you about performance engine tuning. That way, the decisions you make when using VersaTuner are informed decisions and not just hopeful guesses.

Tuning Fundamentals

Before we jump in to making changes to your car, let's look at what we will be changing and why.

What is Tuning?

What exactly is changed when tuning an engine?

In the old days, engine tuning meant turning the distributor a few degrees or swapping carburetor jets, running the engine hard, and "reading" the spark plugs. It used to involve a lot of trial and error and usually took a lot of experience interpreting sights, sounds, smells, and vibrations in order to be successful.

Tuning in the modern era of computer controlled electronic fuel injection (EFI) usually means modifying the Engine Control Unit (ECU)'s preconfigured operating parameters in order to increase engine power output and/or drivability. Now, it's done with a computer keyboard, not wrenches.

Modern ECU's are powerful computers running real-time operating systems which are purpose built for automotive engine control. ECU's use multiple sensors to obtain data about engine conditions prior to and after combustion. They are very capable of handling a wide range of operating conditions. For example they can go from sweltering hot desert valleys below sea level to frigid mountain tops with thin air and still deliver smooth and reliable operation of the engine. In order to accommodate these various conditions, the ECU has many pre-defined parameters and performs *MANY* calculations on the fly. The following is a list of the general areas of engine control:

Air flow, temperature and pressure measurement

Fuel metering

Electronic Throttle Control (in drive by wire applications)

Boost control (in turbocharged applications)

Ignition timing

Valve timing (in variable valve timing applications)

Emissions control

RPM and vehicle speed limits

Engine load targeting

Pre-defined operating parameters are stored in the ECU's flash memory. They are sometimes single numeric values like the Vehicle Speed Limit, or very large 3D tables like Air/Fuel Ratio Targets and Ignition Timing Advance.

By manipulating these parameters, we can free up hidden potential and extend the operating limits of the engine. In advanced tuning applications, the core logic of the ECU can be changed in order to get different behavior from the engine and to accommodate new hardware that was not originally equipped.

Harnessing Untapped Potential

Why is there unused power hiding in my engine?

Modern automobile manufacturers are faced with many conflicting design requirements. Among them are legislated tailpipe and noise emissions and fuel economy standards, manufacturing cost reduction, reliability and warranty cost reduction, model placement for marketing reasons, insurance cost to owners, drivability, and overall owner satisfaction.

Depending on which of these areas you are willing to change, there can be significant gains to be had. Some are controlled by the ECU, others require engine modification.

Emissions - For racing applications, tailpipe and noise emissions are not a concern. Some increase in noise can be within legal limits but beyond the comfort level of some people. Exhaust equipment modifications usually affect tailpipe emissions and noise levels.

Fuel Economy – Government legislation requires auto manufacturers to meet strict corporate average fuel economy (*CAFE* in the US) standards. More power requires more fuel, so manufacturers will often sacrifice power for fuel economy. If you are using that newly found extra power when you drive (leadfoot!), your fuel economy will reflect it. This is a universal tradeoff based on the laws of physics. If you choose, however, you can tune for economy at the expense of performance. With VersaTuner, the choice is yours.

Manufacturing costs – Often a manufacturer will share a common engine across multiple vehicle platforms to reduce costs. In this case ECU tuning is usually used to match the output of the common engine to the design goals for each vehicle. Exotic materials and complicated manufacturing processes are too expensive for use on a vehicle marketed to a price sensitive consumer. If money were no object, we would all drive a 1,000HP super car! As individual vehicle owners, we have the power to decide which performance parts are worth the investment, not some far away accounting department.

Reliability – This comes down to how much you are willing to risk engine failure in order to gain performance. Auto manufacturers *really* don't like replacing engines under warranty, so they tend to be very conservative with their tuning. They need to develop products for use by a wide range of consumers in a wide range of environments. Typical long term 250,000 mile reliability can be sacrificed if you are willing to accept the consequences. Caveat Emptor! Know the limits of your engine before you start making changes!

Marketing - Manufacturers often limit power with tuning to prevent a midrange vehicle from outperforming a top of the line vehicle. Tuning can certainly reverse this decision.

Insurance costs – Manufacturers also try to stay under certain thresholds set by insurance companies in order to reduce total cost of ownership. This is another artificial power limit that tuning can undo.

Drivability – Manufacturers strive to deliver smooth, wide, and flat torque curves. In order to obtain that, they chop the peak off of the torque curve with tuning. In vehicle applications with limited traction, power is often reduced to enhance drivability. With minimal effort, that hidden power can be added back.

For unmodified engines, there is usually room to improve power output. Highly modified engines will typically benefit more from tuning, since the original tune was not developed for the modified engine.

Engine Performance Basics

How to make more power?

Now that we know why there is hidden power, we'll have a brief discussion about the basics of engine performance before we get to how VersaTuner sets that power free.

More Air! More Air! – Increasing Airflow

You're probably already aware that a four stroke internal combustion engine is at its most basic level, an air pump. Based on the measured mass air flow and current operating conditions, fuel is metered by the ECU to provide the desired air-fuel mixture. Generally speaking fuel flow is not the limiting factor in power output. So, in order to make more power, our goal is to get more air to flow through the engine.

First, a note about air mass and air volume. We need to flow more air molecules (oxygen molecules really) to make more power. Because of this, we measure air flow by Mass rather than Volume. A given mass of air will always have the same number of molecules, while its volume may change wildly with temperature. Mass Air Flow is typically measured in grams/second (g/s) or pounds/minute (lb/min). The goal is to increase Mass Air Flow, not Volume Air Flow. Keeping air temperatures low improves MAF. More MAF = more power.

A key point to understanding air flow is this - Air flow through an orifice is determined by the following primary factors:

area of the orifice

pressure differential across the orifice

shape of the orifice

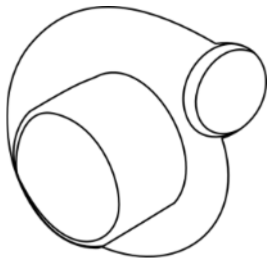
temperature (density) of the air

Your engine is a series of orifices that the air must pass through in order to be mixed with fuel and burned to make the power that moves your car. These orifices are, in order, the air filter, air intake pipe, turbocharger inlet pipe, turbocharger compressor, intercooler inlet pipe, intercooler core, intercooler outlet pipe, throttle body, intake manifold – including VCTS flaps, cylinder head intake ports, intake valves, exhaust valves, cylinder head exhaust ports, exhaust manifold, turbocharger turbine, downpipe, catalytic converters, exhaust pipes, resonators/mufflers, tailpipes. That's a lot of opportunities for restriction. Or, in other words, a lot of opportunities to make more power by improving flow.

With VersaTuner, we have control of the following items which control orifice area – electronic throttle opening and intake valve timing. The remaining items require engine hardware changes to improve the airflow potential. For example, a larger air filter increases the area of the orifice. A bigger intercooler reduces the temperature of the air and increases the density of the air. A larger turbo can have larger orifices and increase the boost pressure, etc.

Obviously, the more modifications that improve overall airflow through the engine, the more potential there is for power gains from tuning.

Pump it up! – Increasing Air Pressure



Now that we've dealt with restrictions to air flow due to orifice area, let's look at pressure differentials. ECU's measure and report pressure in kilopascal (kpa). Atmospheric pressure at sea level is roughly 100 kpa, or 1 bar, 14.7 pounds per square inch, 29.9 inches of mercury, etc. On a normally aspirated engine, atmospheric pressure is the main force we use to push air into the engine, and the force that we must push against to get exhaust out of the engine. Slight improvements can be made with velocity tuning on the intake side and scavenging on the exhaust side, but these are minor compared to the substantial pressure differential that forced induction creates.

Be sure to know the difference between manifold absolute pressure (MAP) and boost. As the *Absolute* in its name implies, MAP is referenced to an absolute vacuum. So, the MAP would be 100kpa with the engine off and the manifold at atmospheric pressure at sea level. Boost is referenced to ambient atmospheric pressure. It's the *boost* in pressure above normal atmospheric pressure. A MAP of 100kpa at the top of Mt. Everest would mean 70kpa of boost since the atmospheric pressure there is a low 30kpa.

A turbocharger increases engine power output by increasing the mass air flow of the engine. It accomplishes this by compressing the air before it enters the engine. This compressed air has a greater density and creates a greater pressure differential across the engine's orifices than air at atmospheric pressure would. This means more mass air flow through the same size orifices. The two downsides are that the turbocharger's turbine creates a restriction (reduces the orifice area) in the exhaust, and the compression of the air heats it quite a bit. Luckily, the gains greatly outweigh the losses.

All of the restrictive orifices we talked about earlier have another affect beyond their own flow restrictions. Any flow restriction creates a pressure drop. This pressure drop means that all the other orifices further downstream will have a lower pressure differential and thus lower flow.

With VersaTuner, you can control the boost pressure. Boost pressure significantly affects the pressure differentials in our engine. There are limits however to how much boost pressure a particular turbo can efficiently deliver and how much boost pressure an engine can mechanically handle reliably.

Making the most of the airflow we have

Now that we've crammed as much air into the engine as possible, let's see what we can do to get the most power we can from it.

AFR

Air-fuel ratio (AFR) is the ratio of air to fuel (duh!) by mass, not volume. It is referenced, monitored, and reported by the ECU in Lambda. A lambda of 1.000 is the representation of the stoichiometricly correct air to fuel ratio – for any fuel. This means that, in theory, when operating at a lambda of 1.000 there should not be any left over oxygen after combustion. AFR is also referred to as equivalence ratio. Lambda can be converted to more familiar AFR numbers for gasoline by multiplying lambda by 14.7. This is not exact since gasoline blends change widely and can be oxygenated at different times of the year. If you can get used to using lambda, you will be ahead of the game when working with E85 and other alternative fuels which have different stoichiometric ratios.

AFR's are controlled very closely by the ECU. This is because there is a fairly narrow range of safe, efficient, and emissions friendly operation. *When not limited by knock*, peak power occurs around .84 lambda or ~12.3-12.4:1 AFR for gasoline. In high boost turbocharged engines, knock is usually the limiting factor and the air-fuel mixture must be cooled by enriching the mixture. Mixtures as rich as 0.700 lambda (10.3) or richer can be used to control knock as long as the ignition system is powerful enough to light the overly rich mixture. Manufacturers tend to stay on the safe side of AFRs due to inconsistencies in high octane fuel availability. If you always fill up with high octane gas, you can definitely pick up some power by leaning the mixture slightly. Be aware however that operating an engine at high load and at excessively lean mixtures can burn exhaust valves and cause severe and damaging knock. That condition is to be strictly avoided!

Peak efficiency occurs around 1.050 lambda (15.4:1 for gasoline). Unfortunately that AFR causes high exhaust gas temperatures (EGTs) and can shorten the life of catalytic converters, damage the turbine wheel of your turbo, and create excessive NOx emissions. Most manufacturers tune for lambda 1.000 at light load for efficiency and emissions compliance. When equipped, exhaust gas recirculation (EGR) is used to run lean AFRs while reducing EGTs and NOx emissions. EGR is used at part throttle lean cruise and is not activated under wide open throttle (WOT) conditions. Wow that's a lot of alphabet soup. Stick with me.

VersaTuner has control over AFR targets for the various engine operating conditions.

Ignition Timing

Ignition timing plays a very important role in determining overall engine performance. If the spark comes too early (advanced) the combustion force pushes against the piston while it is still on its way up during compression. This causes excessive heat, reduces power output, and usually causes detonation also known as (spark)knock or pinging. If it is severe enough and goes on long enough, it can cause serious engine damage such as pitting of the valve faces, cylinder head chamber, and piston crown, or much worse, holes in pistons or broken piston ring lands. If the spark comes too late, (retarded) it wastes power by causing the combustion pressure to push against the piston after it is well on its way down the cylinder. The ideal ignition timing is when maximum power is delivered with the least advance and without knock.

In turbocharged applications, spark advance at WOT is usually limited by knock. For this reason and due to lack of high octane fuel in some markets, manufacturers usually do not tune for the most possible spark advance. They leave a warranty friendly safety margin. If you always use high octane fuel, you can increase ignition advance to gain additional power.

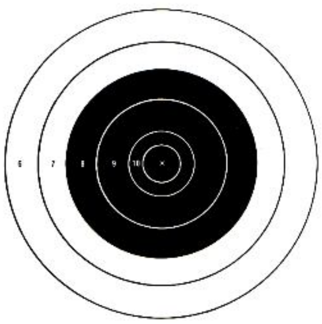
VersaTuner allows you to control ignition timing for normal operation and when knock has been detected.

EFI and Turbocharger Terms and Concepts

The following is an overview of EFI terms and concepts as they apply to the turbocharged direct injection spark ignition engine. This is the last topic before we get to using VersaTuner.

Load
It's not just a Metallica CD. Load is what the ECU uses to describe engine output. Actual load is a calculated value based on current sensor inputs. Requested load is used to describe the level of engine output requested by user inputs (accelerator pedal) or the ECU (cruise control, AC compressor engaged). It is roughly analogous to torque output. Simply put, it is how hard the engine is working or how hard you want the engine to work.

Load Targets and Limits
When you stomp on the accelerator pedal, you do not directly open the throttle. What you are actually doing is sending a *request* to the ECU to increase the load on the engine. The ECU looks at the current sensor inputs and predefined parameters and first calculates how much load is requested based on accelerator pedal position, current gear, etc. then it determines how much to open the throttle to provide the requested load. If the current load exceeds the preset load limit slightly, the throttle opening is reduced or boost pressure is reduced. If load exceeds the maximum load limit value, the fuel injectors



stop injecting fuel (fuel cut) to limit engine load. There are three dimensional tables that map accelerator pedal position to requested load, requested load to throttle position, load to AFR, load to ignition timing, etc. The important point is that load is the main parameter that the ECU is trying to manage, and that most of the tuning parameters are based on load. VersaTuner gives you the power to control load targets and limits.

Control Loops
The various operating parameters that the ECU has control over are managed with control loops. There are two types of loops Open Loop and Closed Loop. The different parameters can be controlled by different loop types. For example, AFR might be controlled with a closed loop at cruise and an open loop at WOT, but boost is always controlled with a closed loop.

Open Loop
Open loop is a simpler loop type than closed loop. Open loop operation is when the ECU is not applying changes to operating parameters based on feedback from the previous iteration of the loop. Open loop is used when the rate of change in operating conditions is too rapid for feedback learned from previous cycles to be valid for the current cycle. Moderate load to WOT operation are typical conditions where open loop operation is used. VersaTuner allows you to control the transition between closed loop and open loop.

Closed Loop
Closed loop is a much more complicated loop type. Closed loop operation is when the ECU is continuously adjusting a given engine operating parameter based on feedback from sensor inputs in order to reach a predefined target operating condition. Closed loop operation allows for more precise control of engine operation because it fine tunes each cycle based on the outcome of the previous cycle. This is an ongoing cycle of operating, monitoring, adjusting and repeating.

The cycle starts with the ECU determining the target value for the operating parameter. This target is either found in a lookup table or calculated based on current operating conditions. Next, the ECU makes a ”guess” at what should be done to reach that target condition. The guess can be obtained from a simple table lookup, or it can be calculated from several table lookups. Then the ECU operates the engine with the guess value for the parameter and measures the outcome. Based on the outcome, the ECU comes up with a correction to be applied to the next cycle to try to get closer to the target value. This correction can be a simple table lookup, or calculated from several tables. Sometimes a history of previous cycles is analyzed to determine a correction factor.

For example, AFR is often managed by a closed loop. Let's assume that the ECU has just switched to closed loop for AFR and does not know the outcome of the previous cycle. The loop starts at the beginning where the ECU looks at a table to see what the desired AFR is for the current operating conditions. It then does some sensor reads and table lookups to make a best guess at how much fuel to inject for that cycle. It runs that cycle and injects the guessed amount of fuel. Next it looks at the O2 sensor to see what the actual AFR was. It compares the desired AFR to the actual AFR and calculates based on table lookups or predefined logic how much fuel to add or subtract from the base guess for the next cycle. It then starts the loop over but applies the correction factor to the base guess. Rinse and repeat… These AFR correction factors are remembered and averaged over time and become the short term and long term fuel trims.

Duty Cycle and Pulse Width Modulation

Duty cycle is the ratio of on time to off time for a device that is capable of being switched on and off. Zero percent duty cycle means that the device is always off, and 100% duty cycle means that the device is always on. Many electronic devices are switched on and off at a high frequency in order to provide varying amounts of whatever the device does. By varying the duty cycle, we can vary how much the device does whatever it does. This process of rapidly switching something on and off at a fixed frequency with variable pulse widths to control it is called pulse width modulation (PWM). Boost control solenoids and electronic throttles are controlled with a PWM signal.

Wastegate

The wastegate is a mechanical valve used to control the output of the turbocharger. It accomplishes this by diverting part of the flow of hot exhaust gasses around the turbine wheel. The wastegate can be integrated into the turbine housing or can be external to the turbo. External wastegates are connected to the exhaust manifold and the downpipe. The wastegate is operated by a pressure diaphragm called a wastegate actuator (WGA). The WGA pressure source is connected to the turbo compressor housing outlet. An internal spring normally holds the wastegate valve closed forcing all exhaust gas through the turbine wheel encouraging the turbo to speed up and increase output. When boost pressure exceeds the spring pressure on the WGA diaphragm, the wastegate valve opens allowing exhaust gas to bypass the turbine wheel. With less exhaust flowing through the turbine wheel, the turbo slows down and reduces output.

Boost Control Solenoid (BCS)

The boost control solenoid is directly controlled by the ECU. Its purpose is to modify the boost signal seen by the pressure diaphragm in the WGA. By bleeding off some of the air coming from the turbo's compressor outlet to the WGA, the BCS is able to cause the wastegate to stay closed at boost pressures greater than the spring pressure in the WGA. The BCS is operated with a PWM signal. Changing the duty cycle of the PWM signal varies the amount of air bled off by the BCS.

By changing the duty cycle of the BCS, the ECU effectively changes the pressure seen by the WGA, and thus the boost output of the turbo. Boost control solenoid duty cycles are controllable with VersaTuner.

Bypass Valve

The bypass valve, sometimes called a blow-off valve, serves to prevent excessive pressures from building between the turbo and throttle when the throttle is closed under boost (shifting or decelerating). These high pressures can cause damaging compressor surge in the turbo. The bypass valve has a vacuum/pressure diaphragm and an internal spring that normally holds the valve closed. The vacuum/pressure source for the bypass valve's diaphragm is the intake manifold. When there is boost pressure in the intake manifold, the boost pressure on the diaphragm adds to the spring pressure and valve is further forced closed. When there is sufficient vacuum in the intake manifold, the vacuum causes the diaphragm to pull against the spring and open the valve causing the air exiting the turbo to bypass the engine and re-enter the turbo inlet in a loop.

The bypass valve is necessary since the turbo does not instantly stop when you close the throttle, nor is it desirable for it to do so. When you close the throttle to shift gears, you want the turbo to maintain speed so that there is boost readily available when you open the throttle in the next gear. The air that the turbo is pushing needs to go somewhere while the throttle is closed. The bypass valve allows that air to flow in a circle temporarily until the throttle is opened again or the turbo spins down.

When the outlet of the bypass valve is vented to the atmosphere (VTA) it does not flow the unneeded air back into the turbo. It dumps it to the open air under the hood. This is problematic in a draw-thru MAF controlled engine, because that dumped air has been measured by the MAF, and the ECU is injecting fuel based on that measured flow. This causes excessively rich mixtures when the bypass valve is open in a VTA configuration. It may sound cool, but it will make your catalytic converter very unhappy.

Tuning Overview for VersaTuner on DISI 2.3

General

When starting out with an unfamiliar tuning platform, it is best to start with a known good base tune and slowly tweak it to fit your needs. Start with either a stock tune or a pre-built tune that is developed for a vehicle with the same or very similar mods. Make only one change at a time and save a copy of each file as you go. Make notes of what you changed in each file and what the outcome was. That way it is easy to go back to the last good tune if something doesn't work out quite the way you expected. Next, be conservative. Start small and work up slowly. Don't jump from stock boost to 20 psi in one step. It's easier to tune the complimentary maps when you make small changes. This allows you to more easily see the correlations between the maps. Lastly, it bears repeating - know the limits of your engine.

Boost Control

Based on our experience and the fact that the ECU uses no less than nineteen different tables to control boost, obtaining consistently smooth boost control is the most difficult task in tuning the MZR 2.3l Turbo DISI engine. This is most likely due to the large number of factors that affect turbo boost output and the latency between when the BCS duty cycle is changed and when the resulting change in manifold pressure occurs. I will spend the most time discussing the tuning of boost control.

In order to understand how to tune boost control, we must first understand how the ECU manages boost. The ECU has two main tools to manage boost levels. The first tool is the turbocharger wastegate via the BCS. As mentioned above, changing boost level via the BCS takes some time to have an affect, so the ECU sometimes has to resort to using the second tool to manage boost - the throttle. The throttle sits between the turbo compressor and the engine. By reducing the throttle opening, the ECU limits how much boost enters the engine and creates a higher pressure zone between the turbo and the throttle plate. This higher pressure causes the wastegate to open and reduce turbo boost output sooner. The BCS is the preferred tool since it's proactive, but it is slow to act. The throttle is faster acting, but it is generally a reactive tool. Using the throttle to control boost is a bit like stepping on the brakes because you went too fast.

Boost control is managed with a closed loop. Boost targets are defined for various throttle positions. So, as the throttle opening changes, so does the boost target. The primary table for BCS duty cycle is based on RPM vs. APP. This is where the ECU gets the base BCS duty cycle from. It then applies correction factors from the other tables to come up with the actual BCS duty cycle. It applies this duty cycle to the BCS and measures the results with the MAP sensor. The ECU then calculates the difference between the boost target and the actual boost level. It then does a lookup on the Boost Correction table and determines how much to add or subtract from the BCS duty cycle to attempt to correct the discrepancy.

As mentioned above, managing boost levels in a turbocharged engine can be quite a challenge. There are a number of operating conditions where boost levels need to be closely managed. The first of which is initial turbo spool up. The goal is to achieve the desired boost level as soon as possible without overshooting. The boost level typically rises very quickly once the engine reaches sufficient RPM at WOT to support boost. Preventing a boost spike from occurring requires tuning the boost tables with knowledge of when the spike will occur if left unchecked. Reducing the BCS duty cycle and temporarily reducing throttle opening will reduce and flatten out the boost spike. The tendency to boost spike is much greater in higher gears. This is due to the fact that in higher gears, the RPMs do not rise as fast to handle the rapid increase in turbo output. This is why there are separate BCS correction tables for the different gears.

Boost spikes at low RPMs are very dangerous since they can cause excessive cylinder pressures and corresponding knock or worse – head gasket or rod failure. Bottom line - if you want to run 30 psi at 3000 RPM, get a diesel!

The next scenario where boost control is important is high RPM WOT operation. All turbos have a finite flow limit. On compressor maps it's described as the choke line. When operating a turbo beyond the choke line, the incoming air in the turbo inlet is very close to or exceeds supersonic velocity and the compressor efficiency is very low. The turbo will overspeed and can damage the turbo bearings. This is basically what happens when you put your hand over the end of a vacuum cleaner hose – the vacuum motor races with no load. Stock turbos, due to their small size, are at greatest risk of operating beyond the choke line. If you know the mass air flow rate at the choke line for your turbo, you can limit boost (and thus total flow) at high RPMs, if necessary, to prevent overspeeding your turbo.

Common boost control problems

The most common problem related to boost control is excessive boost, also called overboosting. If severe enough, it results in fuel cut. As mentioned earlier, fuel cut is a last resort self preservation mechanism that the ECU employs to prevent engine damage due to excessive boost levels. By properly anticipating how boost levels change and properly tuning boost controls, overboost and fuel cut can be avoided.

The first overboost scenario we'll look at is initial turbo spool up. If boost is spiking at initial spool up, try reducing BCS DC a little and start the reduction earlier. You can also close the throttle a little to help. Boost comes on fast at initial spool up so most of what you are tuning is proactive and not reactive. Modified engines will tend to produce boost earlier than a stock engine. The stock tune will need to be changed to accommodate the onset of boost at a lower rpm and the steeper boost slope.

The next most common overboost scenario is WOT at high gear and low RPM. Under these conditions, boost can rise quickly since the engine is not rapidly increasing RPM's to consume the increased output from the turbo. Close attention to the BCS tables and if necessary, the throttle tables will help here. Note that there are separate tables for the different gears. That is because the engine will behave differently with different work loads on it.

Increasing the boost correction aggressiveness can help too. Be careful not to overdo it. If boost correction is overly aggressive, boost will oscillate above and below the target and give a pulsating feeling to the power output.

Another overboost scenario is boost creep. This occurs when the wastegate cannot flow enough exhaust to reduce the speed of the turbo. This causes the turbo to speed up and increase boost. This condition occurs when a small turbo is used on a large engine with an undersized wastegate. The proper fix is to increase the size of the wastegate. A temporary workaround is to use the throttle to reduce peak engine flow to below the max flow capability of the wastetgate.

Drive By Wire Throttle

The MZR DISI 2.3 engine is equipped with a drive by wire (DBW) throttle. A DBW throttle does not have any mechanical connection to the accelerator pedal. The ECU controls the DBW by changing the PWM DC of the electronic throttle. There are several tables to control DBW throttle opening. An undesirable feature of the stock tune is that it partially closes the throttle at higher rpm. Using VersaTuner, we can overcome this to unlock significant performance increases.

It is important to note that the maximum throttle opening is reported as ~75-76% relative throttle position. You will not see higher than that no matter what you use for DBW throttle DC.

Ignition Timing

Ideally, fine tuning ignition timing should be done on a dyno. It is hard to feel the subtle differences that one or two degrees of timing can make. It is also possible that advancing the timing will reduce power even though knock is not detected.

Start off conservatively and gradually increase timing as long as there is a measurable power increase and there is no knock detected. If increasing the timing does not increase power, back it off. Use the VersaTuner Dashboard to datalog and see if knock retard is occurring. If it is, reduce spark advance gradually in that part of the map until it does not occur.

Be consistent with the fuel you run. The factory tune is conservative to account for variations in fuel. If you are tuning your car very close to the knock limit, you need to be very consistent with your fuel. Seasonal fuel blends and changes in ambient temperature can affect performance. Be sure to check how your tune is performing as the seasons change.

AFR

Tuning AFR is not as simple as value X for power and value Y for cruise. For this discussion, we'll assume that gasoline is the fuel being used, so gasoline AFR numbers will be used. Generally speaking, cruising AFR is 14.6-14.7 for emissions reasons, and WOT AFR is 11.8 - 12.2 for maximum power. There are exceptions. Under high boost conditions, very rich mixtures near 10.0:1 are sometimes used to cool the mixture and help prevent knock. A combination of timing adjustment, cooling effect of rich mixture, and boost control must be experimented with to get the most power without knock. Another exception is low RPM off boost WOT operation. The AFR can be leaned out a bit here to raise EGT and help spool the turbo. A small change from 14.7 to 14.9 can cause a large increase in EGT – use lean AFRs with caution. Prolonged operation with high EGTs can damage exhaust valves, turbos, catalytic converters and O2 sensors. Fine tuning of AFR is best done on a dyno with a pyrometer to measure EGTs.

Fuel Pressure

VersaTuner gives you the ability to control the direct injection fuel pressure. The mechanical pressure relief valve is designed to open at around 1885 PSI (13MPa). Unless you have installed an upgraded pressure relief valve, do not request fuel pressure above 1850 PSI (12.75 MPa).

Due to the short injection times in direct injection engines, high fuel pressure is used to deliver fuel quickly and in very tiny droplets. These tiny droplets vaporize quickly, burn faster, and burn more completely. This improves power, fuel economy, and emissions. When fuel pressure drops, fuel droplet size increases. This slows combustion reducing power and increasing fuel consumption. The factory high pressure fuel pump (HPFP) has a limited flow capability. It can supply enough fuel for mildly modified engines, but as mass air flow approaches ~270g/s the fuel pressure may start to drop at low rpm and high load. Individual components can vary, so this is a rough guideline. Monitor your fuel pressure with the VersaTuner dashboard. If fuel pressure drops below 1200 PSI at WOT, you should strongly consider a HPFP upgrade. Your AFR's may still be good, but much of the combustion will be happening late, and you will be losing power and using excessive fuel.

Tuning Walkthrough with VersaTuner

Start with a solid foundation

The first step in performance tuning is to ensure that you have a solid foundation to work with. Make sure that your engine is in proper working order and that it passes all health checks. It is a complete waste of time to try to develop a tune for an engine that operates in an unreliable manner.

If you have any doubts about the health of your engine, check for any DTCs, visually inspect the air intake hoses for leaks or loose connections, perform a compression test, check and gap the plugs, check and clean or replace the air filter, clean the MAF sensor, etc.

You can not "tune your way around" a defective part or sick engine.

The remainder of this document assumes you have installed VersaTuner Tune Editor*.

Calibrate the MAF

This is very important, especially if you are running a modified air intake system. If your MAF calibration is off, the ECU will not provide the desired amount of fuel. Depending on how far off the MAF calibration is, it could cause persistent knock or high fuel consumption. A seriously miscalibrated MAF will usually throw DTCs relating to Bank Lean or Bank Rich conditions. Aftermarket air intakes typically skew the MAF calibration to the lean side. This is done deliberately. Did you really think that adding a Cold Air Intake yields a 10% horsepower increase from the additional flow alone? A large part of the power increase is from the leaning of the mixture. Some intakes provide more accurate MAF readings than others. In order for the ECU to do its job well, it needs accurate inputs from all of its sensors.

MAF Calibration Step 1 – Drive your car.

Simple enough. Just make sure that you have driven the car long enough and over its total operating range to allow the ECU to build its Long Term Fuel Trims. The LTFT values are stored in RAM in the ECU. When the ECU is reset by disconnecting the battery, or by a software reset as part of a reflash operation, it loses its LTFT data. Therefore, you need to drive several drive cycles covering at least 50 miles or 80 km in a variety of rpm and load conditions to rebuild the LTFT data after a reset.

MAF Calibration Step 2 – Datalog

Log using the VersaTuner Dashboard MAF Calibration Preset (PIDs: Engine RPM, MAF Volts, Absolute Load, Relative Throttle Position, LTFT, STFT Primary, Actual Equivalence Ratio, Desired Equivalence Ratio). Find a safe place to do some part throttle and full throttle 2nd and 3rd gear acceleration while logging. Also log while cruising at various speeds and at idle. This should cover the complete operating range of the engine. The goal is to create flat spots at various MAF voltages in the log where the engine operates at a steady state.

MAF Calibration Step 3 – Log Analysis

What we are looking for here is what fuel trim was required to get to the desired AFR or, if the actual AFR was different from the desired AFR due to the fuel trim limits being exceeded.

Find places in the log where the MAF volts are steady for at least 1 - 2 seconds and add the corresponding STFT and LTFT to get the combined fuel trim. Record the MAF volts and the net fuel trim for as many points as possible. Note that the ECU goes open loop at ~3.25 MAF volts, so no trims are reported above that. Also, the ECU turns fuel off when decelerating. This will appear as a sharp dip in the AFR to max lean when the throttle is closed and the engine is decelerating.

MAF Calibration Step 4 – Adjust MAF Tables

Open VersaTuner Tune Editor* and adjust the MAF tables as needed to increase or decrease the g/s to match the net fuel trim percentages from the log analysis step. Apply smoothing as needed and save the tune.

Flash the new tune to your car, and repeat as necessary. Depending on how long you let the LTFTs build and how many data points you used to modify your MAF tables, you should only have to go through one or two iterations.

VersaTuner Tune Editor* Table Reference

Coming Soon

*VersaTuner Tune Editor is currently in Beta Release status. Final functionality is subject to change.

Glossary

AFR – Air Fuel Ratio

This is the Air to Fuel ratio. Numerically higher AFR's are leaner. Numerically lower AFR's are richer.

APP – Accelerator Pedal Position sensor

The APP sensor reads Volts. The ECU calculates pedal position percent.

BARO – Barometric Pressure

BAT – Boost Air Temperature

The temperature of the air in the intake manifold after being heated by the turbo and cooled by the charge air cooler or intercooler.

BCS – Boost Control Solenoid

The Boost Control Solenoid is rapidly switched on and off by the ECU. This allows some of the boost signal to the WGA to be bled off allowing the turbo to provide more boost pressure than the preset WGA spring rate.

Boost – Increase in manifold pressure above ambient barometric pressure due to turbo or super charging

BOV – Blow Off Valve

A valve that vents unused turbo pressure to the open air when the throttle is closed under boost. This type of valve will cause problems with draw-thru MAF readings when it opens.

BPV – Bypass Valve

A valve that feeds unused turbo pressure back to the turbo inlet when the throttle is closed under boost. By recirculating the air, the MAF reading is not affected.

CAC – Charge Air Cooler

The intercooler. This is a heat exchanger that cools the incoming air charge after the turbo and before the throttle.

CAN – Controller Area Network

The serial data network that connects the various control modules in a vehicle. US EPA mandates that all vehicles 2006 or newer must support CAN communications for diagnostics and emissions module programming.

CKP – Crank Position Sensor

CL – Closed Loop

CMP – Cam Position Sensor

COP – Coil on Plug

An ignition system design that places the ignition coils directly above the respective spark plug. This eliminates the need for high tension spark plug wires and reduces resistance in the high voltage circuit. Individual ignition coils also allows for individual cylinder miss detection.

CPP – Clutch Pedal Position

CR – Compression Ratio

DLC – Datalink Connector

The vehicle diagnostic port. Sometimes called OBD-II port.

DBW – Drive By Wire

The accelerator pedal is not directly connected to the throttle. The ECU has direct control over the throttle, not the driver.

DC – Duty cycle

The ratio of on time to off time for any device that can be switched on and off. Applies particularly to pulse width modulated devices.

DISI – Direct Injection Spark Ignition

DP – Down Pipe

The exhaust pipe that connects to the turbocharger exhaust housing outlet and travels vertically down to the exhaust tunnel under the vehicle. This pipe also contains the warm-up catalytic converter.

DTC – Diagnostic Trouble Code

Error codes reported by the ECU. These may or may not light the Malfunction Indicator Lamp (MIL) also called the Check Engine Light (CEL). These codes are reported when the ECU detects a component or subsystem that is outside of defined normal operating conditions.

ECT – Engine Coolant Temperature

ECU – Engine Control Unit

The main control module for the engine.

EFI – Electronic Fuel Injection

EGR – Exhaust Gas Recirculation

A system of reintroducing exhaust gas into the combustion chamber. EGR can reduce knock at part throttle, reduce emissions, and increase fuel economy.

EGT – Exhaust Gas Temperature The temperature of the exhaust gas as it exits the combustion chamber.

Flash (noun) – The non-volatile memory of the ECU that stores the firmware which the ECU boots from and runs on.

Flash (verb) – The process of rewriting the firmware stored in the ECU’s flash memory.

Fuel Cut – A last resort employed by the ECU to prevent damage caused by excessive boost or load. The ECU completely stops injecting fuel into the engine until the boost level or calculated load reaches a safe level again.

HO2S – Heated Oxygen Sensor

IAT – Inlet Air Temperature

J2534 – SAE standards document describing the method for communicating with the ECU for reprogramming and diagnostic purposes.

J2534 PassThru – A device which meets the J2534 specifications for PassThru programming (flashing) of ECUs.

Knock – Spark knock.

Premature ignition of the end gasses in the chamber as a result of low fuel octane or excessive ignition advance. This causes a sharp rise in cylinder pressure that causes the engine to ring resulting in a knocking or pinging sound. Knock occurs after the normal start of ignition by the spark plug.

KR – Knock Retard

The amount of timing the ECU subtracts from the normal ignition timing as a result of detected knock.

KS – Knock Sensor

The sensor that detects the vibrations in the engine block caused by knock.

Load – Describes the relative power output of the engine. Expressed as a value from 0 to 4 where 0 = no power output and 1 = power output at WOT with manifold pressure equal to atmospheric pressure.

LTFT – Long Term Fuel Trim

The adjustment to the amount of fuel injected based on the long term averaging of the oxygen sensor feedback. It is expressed as a + or – percent.

MAF – Mass Air Flow

The measurement of the mass of air flowing in to the engine. The MAF sensor reads Volts. The ECU calculates g/s or lb/min based on lookup tables.

MAP – Manifold Absolute Pressure

The measurement of the absolute pressure of the intake manifold. This pressure is relative to a complete vacuum. The MAP sensor reads Volts. The ECU calculates kPa or psi based on lookup tables.

NBO2 – Narrow Band Oxygen Sensor

Narrow band oxygen sensors are designed to precisely measure air fuel ratios near the stoichiometrically correct lambda of 1.000 or an AFR of 14.7 for gasoline. They cannot measure AFRs very far from that point. On vehicles equipped with a wideband oxygen sensor, the narrow band sensor is used to fine tune the fuel mixture at idle and low load cruise conditions and monitor catalytic converter efficiency.

OBD-II or OBD2 – On Board Diagnostics version Two

US EPA mandated vehicle diagnostics interface.

OL – Open Loop

Pre-Ignition – An ignition event initiated by a source other than the spark plug. Hot spots in the combustion chamber caused by lean operation are often the source of pre-ignition. Depending on the crank angle when the pre-ignition occurs, the results can be catastrophic for the engine. Pre-ignition during the compression stroke can cause bent or broken rods, head gasket failure, holes in pistons, etc.

PWM – Pulse Width Modulation

A method of providing variable control to an on/off device – typically solenoids. The ECU rapidly switches the device on and off at a fixed frequency. By varying pulse width of the on signal, the device can be made to provide a variable action corresponding to the pulse width of the signal. For example, the flow of a solenoid valve is proportional to the pulse width of the PWM signal used to control it.

STFT – Short Term Fuel Trim

The adjustment to the amount of fuel injected based on the short term oxygen sensor feedback. It is expressed as a + or – percent.

TB – Throttle Body

TC - Turbocharger

TPS – Throttle Position Sensor

The TPS reads Volts. The ECU calculates throttle opening percent or degrees.

Tune – The combination of all configurable engine operating parameters which determine how an engine will operate and perform.

VTCS – Variable Tumble Control System

A system of flaps in some of the intake runners which are activated a low RPMs to increase air velocity and turbulence in the combustion chamber. This reduces emissions and increases low speed torque. Sometimes called intake manifold runner control (IMRC).

VSS – Vehicle Speed Sensor

VVT – Variable Valve Timing

The ECU is able to adjust the advance or retard of the intake camshaft. This allows for a broader torque curve and reduced emissions.

WG – Wastegate

The valve connected to the exhaust manifold or turbine housing that allows hot exhaust gasses to bypass the turbocharger in order to control boost levels.

WGA – Waste Gate Actuator

A mechanical device with a spring and a pressure diaphragm that uses boost pressure to open the wastegate.

WB02 – Wideband Oxygen Sensor

Wideband oxygen sensors are able to measure the air/fuel ratio over a wide range of operating conditions. The front oxygen sensor is a wideband type.

WOT – Wide Open Throttle This is when the engine power output is not restricted by the throttle. Maximum power output is requested by the ECU.