



# **An Intro to Subaru Tuning**

**By Bad Noodle**

**Compiled as Word Doc  
By Wideboy**

**Based on posts by**  
Tea Cups / merchGod  
mickeyd2005  
Tgui  
clark turner  
Freon  
And others...

# An Intro to Subaru Tuning

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# An Intro to Subaru Tuning

## Forewords

### BY BAD NOODLE

First and foremost, I am NOT a tuner. I only have experience with my car; none of this information is guaranteed to be accurate. I wanted to learn to tune and have done lots and lots of reading regarding the topics. I put this document together mostly for myself and later decided to share with the community when I saw there was a need. The information presented here is not my own, it is information I found in various posts, articles, and books. I simply put it together in one document.

### BY WIDEBOY

I gathered all the information together from the forum posts and updated the original text with comments from later postings. I have tried to remove the typos and clarify what seems confusing. Same rules apply. I am not a professional tuner I do not guarantee anything to be correct in this document.

### DISCLAIMER

While every endeavour has been made to ensure accuracy of the information:

**DO NOT** use this document as a definitive resource for anything.

**DO NOT** tune your car using the information contained herein as the definitive resource.

**DO** your own research.

Make your own judgements.

# An Intro to Subaru Tuning

## What you need

### TOOLS AND SOFTWARE

Before you can tune, you need to have the following:

- Nice virus free laptop
- Power converter for the cigarette lighter (in case laptop batteries die while logging)
- RomRaider with latest definitions
- ECU Flash with latest definitions
- Old version of ECU Explorer (only for reading trouble codes and resetting ECU)
- Wideband O<sub>2</sub> sensor/meter (must work with RomRaider)
- Tactrix cable
- Airboy's spreadsheet

## What you need to be comfortable with

### WARNINGS

Before you can tune, you need to know what ROMs are and how they are flashed to your ECU. The information can be found at: [RomRaider/Ecuflash getting started FAQ](#)

**You also need to be OK with knowing that a bad flash can kill your car.**

**There is no guarantee that flashing your car won't fry the ECU.**

**It is very unlikely, but there have been instances.**

**So every time you flash your car, you are taking a risk.**

**Note:** Tactrix.com now offers an ECU recovery service for drive by wire ECUs. It's much cheaper than a new ECU and has gotten good reviews. Something to keep in mind.

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## Which tables to tune

When you first see all the tables in the ECU through RomRaider, you might wonder what they do and which ones you need to change. Luckily, there are descriptions for each table. Open the table and look at the description under **View→Table Properties**. The table descriptions included in this article are not the exact descriptions that are in RR. You can't copy/paste table properties, so these are paraphrased to give you an idea of what the tables do. I included these tables in the writeup just to reference while reading the description of how each system works. The tables listed in each section are not the only important tables, there are many others. Check the RR tables for the details as they are often updated.

### BASIC TABLES TO START WITH

- Target Boost
- Boost limit fuel cut
- Initial Wastegate Duty Cycles
- Max Wastegate Duty Cycles
- Turbo Dynamics Immediate
- Turbo Dynamics Integral Positive/Negative
- Primary open loop fueling
- Failsafe open loop fueling
- Injector Flow Scaling
- Injector Latency
- MAF Scaling
- Base Timing
- Timing Advance Maximum
- CL to OL Delay
- AVCS

The tables you will need to change usually correspond to the parts you are trying to tune for. For example, if you switched out an intake, you would need to rescale your maf. If you switched out your stock boost controller for an after market one, you would need to change the wastegate and turbo dynamics tables. If you got new injectors, you would need to change the injector flow scaling and latency as well as the maf. For a basic tune, you would normally change the tables that are directly related to the new parts you put on the car. Not all parts are directly related to tables though. For example, if you switched out your top mount intercooler for a front mount intercooler, that is usually done to run more boost, a leaner AFR, and possibly more timing. So for the intercooler, you would need to change several tables to gain the advantages of the part and make it run correctly. The best practice would be to know exactly how the part you're tuning for will help you make power and how it fits into the big picture. Understanding this will help you know what tables to tune. The best way to find this information is to do some research on the forums.

Before we talk about tuning techniques, we need to know what tables do, how they are related, and their effects on the car. The following is background research. It is meant to be a simplified overview of the concepts and show how they are applied to your car. This is not meant to be a definitive guide on how the ecu works, what type of material works best for an intercooler, or anything that specific; as new information is always being found about those topics. The best place to find gritty detailed descriptions of each process or component would be the forums. What I attempted to do here is provide enough information about the fundamentals to help you with a basic tune. So this is simply a newbie start up guide. More detailed info is available else where.

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## Boost

Boost is simply a positive air pressure in your intake manifold created by your turbo. The turbo pushes more air into the engine than the engine can process, so the extra air builds up pressure as more air gets squeezed into the manifold. Boost is good because having more pressure in the intake manifold means that when the intake valves opens, more air will be pushed into the cylinder. We start with boost since it lays down the ground work for the rest of the tuning process. Changing boost, changes everything else which is why it must be dealt with first.

### **ABOUT BOOST:**

Most of the info about boost and boost control comes from the Cobb Tuning Guide where they explain the Subaru stock boost control system. There is no need to repeat the information here, and therefore I suggest that you read the article before going any further.

The article is available here: [Cobb Tuning Guide](#)

Another great article: [Turbo dynamics and boost control explained](#)

After reading the article, I had some unanswered questions, mostly about how to relate the information found there to the RomRaider tables that control boost. The next section is written as a Q&A and attempts to bridge the gap.

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## HOW TO PICK TARGET BOOST VALUES

In the Target Boost table you will tell the car how much boost you want to make. You can enter any numbers you want in this table and the ECU will do what it can to help you to reach these numbers.

### ***So why not just enter 10000psi across the board and be done with it?***

A turbo has two sides; the hot side, which is connected to the exhaust and a cold side, which is connected to the intake. The cold side of the turbo compresses the ambient air and is therefore called the compressor. Now, each turbo has something called a compressor efficiency map. This is a visual graph that shows what kind of pressures the compressor is capable of. Let's take a look at the compressor map for a TD04-13G turbo:

The pressure ratio on the y-axis is how much ambient air pressure is compressed. At sea level that's 14.7psi. So if you look at the inner most ellipse at 200cfm on the x-axis, you see a 1.8. That means  $1.8 * 14.7 = 26.46$  psi, now subtract out the 14.7 and you get 11.76, which is what you would see on your boost gauge. So you can see 10000psi is a little unrealistic.

### ***What do those circle thingies mean?***

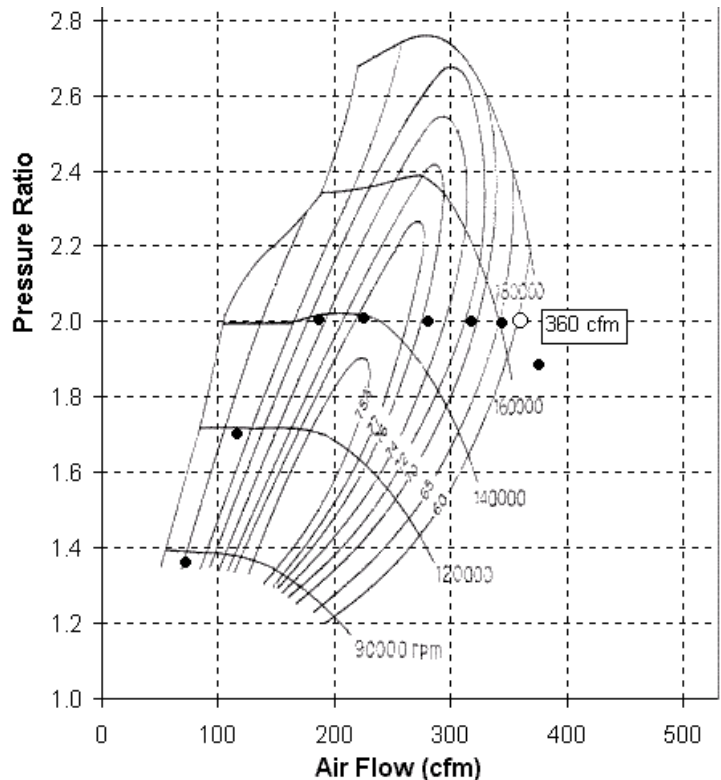
Those are a measure of how much of the energy input into the compressor is being used to compress the air and how much is used to create heat. So if you look at the inner most ellipse you see 75%. That means 75% of the energy is being used to compress the air and 25% is used to create heat.

### ***What does that mean for me?***

It means that the more psi you try to run, the hotter the air will be.

### ***So what?***

Well, the hotter the air is, the less of it there will be per cubic foot. So even though you're moving 200cfm in the 75% efficiency range at 11.25psi and 65% efficiency range at 17.7psi, there will be more air molecules per cubic foot at the 75% efficiency range because the air is colder and therefore denser. In other words, you are moving more air (mass) at the lower psi because of the higher efficiency range.





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**But won't an intercooler cool the air and make it denser? So therefore I can run more boost at a lower efficiency?**

Yes, but it can only remove so much heat. So let's do some math for a minute here to show why it's better to run a lower psi and stay at a higher efficiency range.

Here is the equation used to calculate the mass for air that is moving into your engine:

$$n(\text{lbs} / \text{min}) = \frac{P(\text{psia}) \times V(\text{cuft} / \text{min}) \times 29}{10.73 \times T(\text{deg R})}$$

P = absolute pressure coming into the engine (so atmospheric pressure + boost)

V = CFM from the map (we'll use 200 as an example)

T = Air Temp at throttle body + 460

So the only thing we don't know is the Air Temperature going into the throttle body. To figure this out we need to figure out:

- 1) What the air temperature will be after the compressed air leaves the turbo
- 2) How much the intercooler cools the air?

To figure out the air temperature after the turbo we use the following:

$$T_{out} = T_{in} + \frac{T_{in} \times [-1 + (P_{out} / P_{in})^{0.263}]}{\text{Efficiency}}$$

T<sub>in</sub> = ambient air temp + 460 (F)

P<sub>in</sub> = atmospheric pressure - intake resistance (Psi)

P<sub>out</sub> = atmospheric pressure + boost psi

efficiency = efficiency of the compressor. (%)

For our example we have:

$$T_{in} = 70F + 460F = 530F$$

P<sub>in</sub> = 14.7psi - 0.5psi (guessed on the intake resistance)

P<sub>out</sub>/P<sub>in</sub> = either 1.8 for 75 % efficiency and 2.2 for the 65%

Efficiency = .75 and .65 respectively

So now

$$\text{LowBoost}T_{out} = 530 + \frac{530 \times [-1 + (1.8)^{0.263}]}{0.75} = 648R - 460 = 188F$$

$$\text{HighBoost}T_{out} = 530 + \frac{530 \times [-1 + (2.2)^{0.263}]}{0.65} = 717R - 460 = 257F$$

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The next step is to find the thermal efficiency of the intercooler so we can estimate how much heat will be removed. To do this we will have to use the following formula:

$$\text{ThermalEfficiency}(\%) = 100 \times \frac{T_{in} - T_{out}}{T_{in} - \text{Ambient}}$$

Here is where we get lucky. TurboXS actually went out and tested the capabilities of the stock intercooler with the following results:

14psi max; Temp into IC 92.5C; Temp out 41.5C; IC Efficiency 73.4%

16psi max; Temp into IC 106C; Temp out 49.5C; IC Efficiency 68.1%

18psi max; Temp into IC 103C; Temp out 50C; IC Efficiency 66.3%.

**Note: I've seen posts claiming that the stock unit is only about 56% efficient. So these numbers are debatable.**

So to figure out our final air temperature going into the throttle body we just rearrange the equation to:

$$T_{out} = T_{in} - \frac{TE}{100} \times (T_{in} - \text{Ambient})$$

So we apply this to our high and low boost numbers and get:

Lo boost  $T_{out} = 101.86\text{F}$

Hi boost  $T_{out} = 133.58\text{F}$

Now that we have all the parts, let's see what the final mass of air going into the engine is at both conditions:

$$\text{LowBoostMass} = \frac{(14.7 \times 1.8) \times 200 \times 29}{(10.73 \times (102 + 460))} = 25.5 \text{ (lbs/min)}$$

$$\text{HighBoostMass} = \frac{(14.7 \times 2.2) \times 200 \times 29}{(10.73 \times (133 + 460))} = 29.5 \text{ (lbs/min)}$$

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**Well, you can see that I'm wrong about my assumption that low boost is better. Apparently the intercooler makes a big difference with the numbers. So now the question becomes, when is it better to turn down the boost and when to leave it high?**

To figure this out, I made the following →

What I did here is I took those equations and applied them to the entire compressor map. What I was looking for was the lbs/min to start decreasing at a certain point, but as you can see it didn't. What this means is because of the intercooler, the more boost you make the more lbs/min will be pushed into the engine. The underlying assumption is that the intercooler efficiency is what I guessed it to be in the table. I could not find any more information on efficiency so I interpolated the data turboXS posted. Keep in mind that IC efficiency will change with location, material composition, pressure, humidity, and tons of other variables.

**Ok, so I'm gonna run 22 psi on my td04! It looks like it can be done.**

No, wait, there are other factors. On turbo charged cars, the air entering the throttle body should be about 110° and a max of 130. You can go over this limit, but you will have to compensate with running richer fuel mixture and less timing, which will actually cost you power. Not only that but your turbo can only spin to about 190k rpm and can withstand a temperature of 950°. If you try to run 22psi, the turbo is likely to fail quickly.

**Oh damn, what the hell should I do then?**

There never seems to be a good answer!

This is where you will have to experiment since each setup is different. But first, we should look and see what the max psi we should run is. Looking at our post IC temp chart, we see a CR of 2 around the 100 degree mark. (This is a max of 14.7 psi) But we could also try a 2.2 CR (17.5 psi) since that seems to be in the acceptable range. (Note: If you assume a 56% IC efficiency, only a 2 CR will be acceptable. The Tout for a 2.2CR will be about 160F) When making this decision, keep in mind that the intercooler will be less efficient on hot days and therefore you will exceed the 130 degree mark very easily running a 2.2CR. So the "best choice" would be to run a 2.0 CR (14.7PSI) so that you will be ok once it gets hot outside as well.

(Note: If you assume a 56% IC efficiency, only a 2 CR will be acceptable. The Tout for a 2.2CR will be about 160F) When making this decision, keep in mind that the intercooler will be less efficient on hot days and therefore you will exceed the 130 degree mark very easily running a 2.2CR. So the "best choice" would be to run a 2.0 CR (14.7PSI) so that you will be ok once it gets hot outside as well.

**This seems like a lot of work to figure out one number, can't this be easier?**

It can, just pick whatever CR is at the tips of the two inner most efficiency ellipses. But the better choice would be just to ask around on the forums if you don't know.

Compressor Map							
	2.6			65	70		
	2.4		60	72	74	65	
	2.2		65	72	77	74	65
	2	60	70	76	77	74	60
CR	1.8	65	74	78	76	70	
	1.6	72	78	77	72	60	
	1.4	77	77	70	60		
		127.152	169.536	211.92	254.304	296.688	339.072
		0.06	0.08	0.1	0.12	0.14	0.16
				CFM			
Tout - Pre IC							
	2.6			302.9514	286.312		
	2.4		298.7061	260.5884	255.4374	281.1133	
	2.2		257.8897	239.6226	228.6082	235.0382	257.8897
	2	246.6414	221.4069	209.4537	207.6426	213.2227	246.6414
CR	1.8	206.3134	189.7348	183.5945	186.5839	196.5768	
	1.6	166.8542	159.4039	160.565	166.8542	186.2251	
	1.4	133.6865	133.6865	140.0552	151.7311		
		127.152	169.536	211.92	254.304	296.688	339.072
				CFM			
Intercooler efficiency							
	23.52	52	52	52	52	52	52
	20.58	59	59	59	59	59	59
	17.64	66	66	66	66	66	66
	14.7	73	73	73	73	73	73
	11.76	80	80	80	80	80	80
	8.82	87	87	87	87	87	87
	5.88	94	94	94	94	94	94
Tout - post IC							
	2.6			181.8167	173.8298		
	2.4		163.7695	148.1412	146.0293	156.5565	
	2.2		133.8825	127.6717	123.9268	126.113	133.8825
CR	2	117.6932	110.8799	107.6525	107.1635	108.6701	117.6932
	1.8	97.26269	93.94696	92.71891	93.31677	95.31535	
	1.6	82.59105	81.62251	81.77345	82.59105	85.10926	
	1.4	73.82119	73.82119	74.20331	74.90386		
		127.152	169.536	211.92	254.304	296.688	339.072
				CFM			
lbs/min of airflow							
	2.6			40.929	48.35221	76.14179	
	2.4		32.39475	39.87269	46.68025	52.43798	
	2.2		24.95168	31.51922	38.06564	44.24426	49.90335
CR	2	17.48927	23.59733	29.66436	35.62792	41.45579	46.63804
	1.8	16.31741	21.88678	27.41926	32.86756	38.20748	
	1.6	14.89657	19.89761	24.86508	29.79313	34.59808	
	1.4	13.24863	17.66484	22.06526	26.44363		
		127.152	169.536	211.92	254.304	296.688	339.072
				CFM			

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## WASTEGATE

Before we talk about the tables, let's talk about how the car controls boost. The wastegate controls how much exhaust gas is not used to create boost. If all the exhaust gas was always used to create boost (you didn't have a wastegate) then the turbo would always be spinning as fast as possible and making outrageous boost. You'd probably see upwards of 25 psi on a td04. Now, the stock engine isn't designed to make take that much boost, there isn't enough fuel available to be used with that much boost, the air going into the throttle body would be too hot, and the turbo would fail quickly. So the wastegate bleeds off extra exhaust gas to try and keep the turbo in its efficiency range. So at lower engine speeds the wastegate is closed to try and bring the turbine up to speed (spool), but once it's up to speed, the some of the exhaust gases are directed around the turbos exhaust wheel so the turbo doesn't make any more boost.

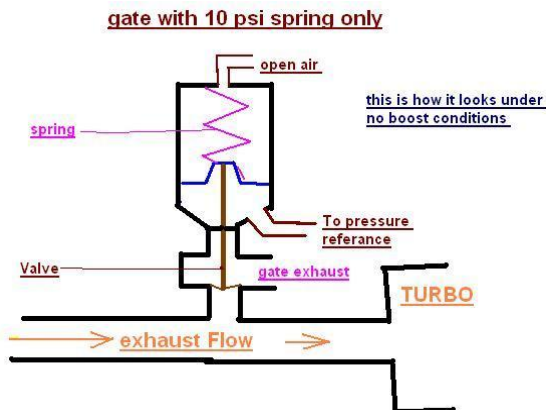
A wastegate is controlled by 2 things. A spring and a diaphragm. The spring has tension on it that keeps the wastegate closed and the diaphragm helps to overcome the tension of the spring and open the door. The springs are rated for a psi value required to overcome the tension. The OEM spring is rated for 7 psi usually (it varies). What that means is that while you're making less than 7 psi of boost, the wastegate will always be closed. Once you exceed 7 psi, say 7.1, the wastegate will crack open, some exhaust will be bled off, and the pressure will drop to 6.9 psi. So the wastegate will close now and pressure will start building up again. This is done really fast to maintain an average pressure of 7 psi.

So how do you build more than 7 psi of boost and control it? The spring in the wastegate will allow you to build unlimited boost. The diaphragm keeps this from happening. As you build boost, the positive pressure referenced from the compressor pushes the diaphragm that pulls on the spring while the exhaust gases push the wastegate door open. These two things overcome the spring tension and allow the wastegate door to open and relieve some exhaust gases.

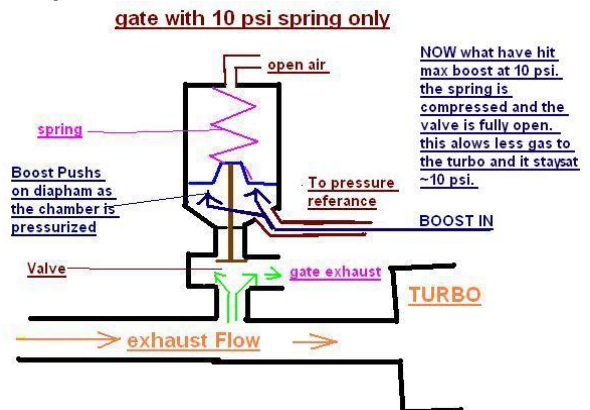
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Confused? Here are some pictures:

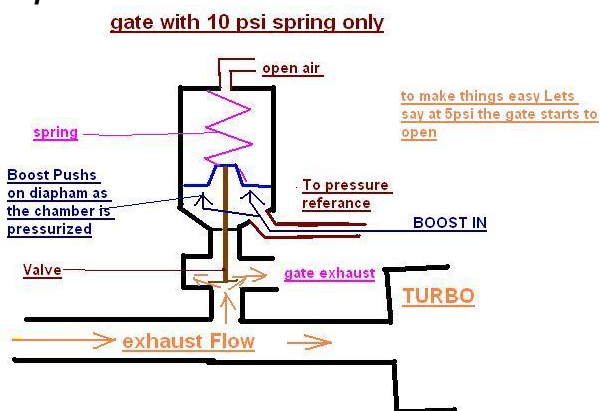
## 1. No Boost



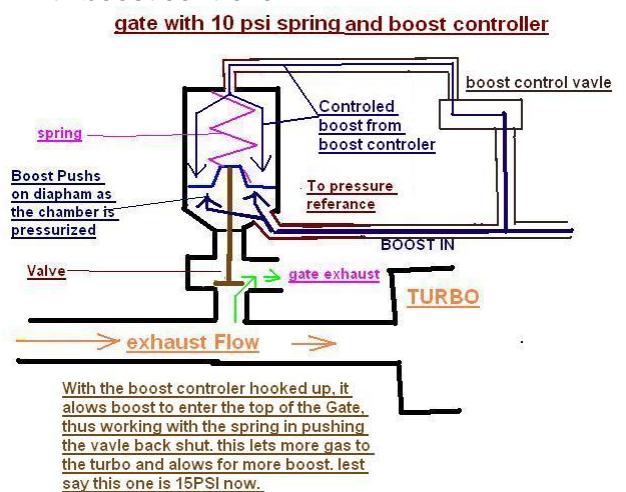
## 3. 10 psi boost



## 2. 5 psi boost



## 4. With boost controller



## ELECTRONIC BOOST CONTROL

So now that electronic part of boost control comes in (this is what we tune). Since we want more boost, we lessen the pressure on the diaphragm to keep the wastegate closed longer. Once we reached our desired boost value (say 16psi) we want more pressure on the diaphragm so it pulls the spring harder, which allows the wastegate to crack open and release some exhaust gas, thus lowering our boost pressure. The best way to allow this to happen is to flip a switch that lets the diaphragm see vacuum when we want to make boost and the boost pressure if we want to lower boost. If we flip this switch really fast, that will allow us to keep a constant pressure of 16psi that we wanted. This switch is the boost controller (gm, stock, whatever).

This finally brings us to what a wastegate duty cycle is. A WGDC is simply a percentage of a set amount of time (say a couple of milliseconds) that the wastegate diaphragm will be exposed to the vacuum intake pressure rather than boost pressure. So higher wastegate duty cycles means the wastegate will stay closed longer, thus making more boost.

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## **TURBO DYNAMICS (32 BIT)**

In an ideal world, you would setup your WGDCs to reach your target boost at all times, but that doesn't always happen for a variety of reasons, so this is where TD steps in. TD adds to or subtracts from the initial WGDC when you are not reaching your target boost values with the wastegate duty cycles you have assigned. TD comes in two forms and fixes two types of errors.

1. Immediate boost error is corrected by TD Proportional.
2. Continuous boost error over time (milliseconds) is corrected by TD Cumulative.

So when the ECU sees a boost error (say you're not making enough boost) it adds a TD value to your post compensation initial WGDC to get the WGDC amount applied to wastegate. If you're overboosting, it subtracts the TD value to try and get the boost back down.

Keep in mind that if  $\text{initial WGDC} + \text{TD} > \text{Maximum WGDC}$ , then Maximum WGDC will be applied to the wastegate since it's the capped limit.

TD Proportional is simple, if your boost error is X, then add Y. TD cumulative is a little different. Say we are not making target boost. The ECU looks at the boost error and sees it's positive, so it says I see boost error of 5, I'll add 2%. Looks back in a couple milliseconds and says, damn! I still have a boost error of 2, I'll add another 1% to try and reach target boost (3% total now). looks back again, and either keeps adding more, doesn't add anything, or resets the value to 0 if the conditions are no longer met.

The way TD works is when you first see a boost error, a lot of immediate correction will be applied and almost no cumulative correction. As time goes on and you continue doing your pull, the cumulative correction will start to add up, and the immediate correction will get smaller. Finally, most of the TD will be cumulative correction and you will have little immediate correction. This is what I've seen on my car when I have my WGDC dialled in correctly to make the boost I want. If can't reach your target boost, you will see both corrections max out. If you hit target boost immediately (somehow), the cumulative will not have time to build up and you will see little of both correction.

It would seem that TD is like a Band-Aid for poorly tuned boost. It would make sense that if you dialled in your boost correctly, then you would never need to use TD. This is not the case. Boost is affected by temperature, humidity, elevation, air density, and a huge load of environmental conditions. TD is meant to correct for these conditions. Therefore, in an ideal world where the car is at sea level, it's 70deg outside, and the sun is shining, you would not need TD. But during realistic driving conditions, it keeps your boost steady in a variety of weather conditions.

Boost tables have their compensations and limitations. The ecu has the ability to adjust the Target Boost, WGDC, and TD based on environmental conditions. Things like intake air temperature and relative air pressure need to be adjusted for in order to keep a known mass of air going into the engine. There are also thresholds that the ecu sets before certain tables can be activated. Like there is a minimum boost error and rpm thresholds that need to be met before TD is applied. The best place to find info on these limitations is the RR link at the top of the page as well as by viewing table descriptions in RR.

## **SOME BOOST TABLES WE TALKED ABOUT**

### **TARGET BOOST**

This table holds the target boost values your car will try to make at each rpm and load point.

### **BOOST LIMIT (FUEL CUT)**

If somehow your car over boosts, anything past this boost level will cause a fuel cut causing the engine to cut out in an attempt to save the engine.

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## **BOOST COMPENSATION (VEHICLE SPEED)**

Change in target boost while in 1<sup>st</sup> gear and while below the Boost Compensation (vehicle speed) Disable.

## **BOOST COMPENSATION (VEHICLE SPEED) DISABLE**

Speed, above which, the above is disabled. These are used to give you more control over boost while in 1<sup>st</sup> gear.

## **BOOST CONTROL DISABLE (IAM)**

If your car is knocking and the IAM drops below the left value, boost defaults to minimum possible value. It doesn't return to normal until the right value is passed.

## **INITIAL WASTEGATE DUTY**

This table specifies the starting values used when calculating the final WGDC applied.

## **MAX WASTEGATE DUTY**

This is a cap for precompensation WGDC that can be used. It's usually 8% above the IWGDC. I've also seen 5% across. It should be a big enough difference that full Turbo Dynamics can be applied to the initial and the total is below this value.

## **TURBO DYNAMICS PROPORTIONAL**

This is the immediate amount WGDC correction applied to the initial WGDC.

## **TURBO DYNAMICS INTEGRAL POSITIVE**

This is the WGDC correction that will accumulate for all positive Boost error values over time.

## **TURBO DYNAMICS INTEGRAL NEGATIVE**

Same as above, but with a negative boost error (this means you're over boosting)

## **INTEGRAL CUMULATIVE RANGE (WGDC)**

The most integral correction you will be able to add or subtract from the WGDC.



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## Fuel & Air-Fuel Ratios (AFRs)

### REFERENCE

Most of this info comes [Closed Loop to Open Loop fueling transition explained on RomRaider](#)

I found it difficult to understand so I rewrote it and added information I found in other posts and forums

### DEFINITIONS

Stoichiometry is the measurement of ratios of reactants in a chemical reaction. In the case of an engine it is the ratio of air to fuel which will burn and leave no residual air or fuel. For gasoline the stoichiometric ratio is 14.7 masses of air to 1 mass of fuel; for other fuels this ratio will vary. Less than 14.7 air will result in a rich mixture and more than 14.7 is a lean mixture. In this document the term is abbreviated to stoich.

Lambda is an alternative way of representing AFR as a multiplier of the stoichiometric ratio. A stoichiometric AFR will always be 1 for any given fuel. A lambda less than 1 will be a rich mixture and more than 1 will be a lean mixture

Examples:

For gasoline:	lambda 1.0	= (1.0 x 14.7):1	= 14.70:1 AFR	(stoich)
	lambda 1.1	= (1.1 x 14.7):1	= 16.17:1 AFR	(lean)
	lambda 0.9	= (0.9 x 14.7):1	= 13.23:1 AFR	(rich)

### INTRODUCTION

Before we get to the tables, we need to discuss air fuel ratios, fueling, and air intakes. Target AFR for gasoline is 14.7:1 or 1 lambda. A 14.7:1 AFR is normally considered the best trade off between emissions, fuel economy and power production.

Unfortunately you can't run that mixture all the time. At that ratio, the air fuel mixture is very energetic. So doing things like forcing the mixture into a crammed spaced at 15 psi might have some negative consequences. It could pre-ignite or explode rather than burn. But of course the cooler the air (better intercooler), the higher the octane of gas (octane is the resistance of gas to spontaneously ignite or explode) the more abuse the AF mixture can take before something bad happens. So the closer you can get to the stoich AFR, the less abusive you can be to the air fuel mixture.

This brings us to the logical conclusion that we should try to run that stoich mixture when we're being gentle with the AF mixture (cruising on the highway), and something less energetic when we're trying to cram the most amount of air/fuel possible into the cylinder (under boost). This is the idea behind closed loop/open loop fueling.

Subaru decided to only equip our cars with a cheap wideband O<sub>2</sub> sensor on 32-bit ecu cars and narrowband on older 16-bit models. That means that the sensor can tell if you're running a 14.7 AFR accurately, but if you try to use it for any other AFR, it's very inaccurate and just about useless for tuning as the guys on iwsti demonstrated [here](#). Even if we put a better wideband sensor in place of the stock sensor, that wouldn't help much because the ECU wouldn't know how to interpret the signal. That means that if we want to run the stoich AFR, we use the sensor (closed loop fueling) and if we want to run some other AFR, we ignore the stock O<sub>2</sub> sensor and find another way to get the correct AFR (open loop fueling).

### CLOSED LOOP

Let's start with closed loop fueling. The goal of closed loop fueling is to have the car run the stoich AFR or 1 lambda. It does this, like it does everything else, by using guess and check. As you drive, a known amount of fuel is being used. After it is burned, the exhaust gases are analyzed by the O<sub>2</sub> sensor to see if there is any oxygen left in the exhaust. If there isn't, the ECU thinks you are running rich (too much fuel and not enough air, AFR lower then 14.7) so it lessens the amount of fuel it is squirting into the engine. When it sees oxygen in the air, it thinks it's running lean (AFR higher then 14.7) and adds more fuel. It



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does this really fast and only adjusts the fuel a little bit as needed thus giving you an average 14.7 AFR. Easy.

## Note:

For those that have wideband O<sub>2</sub> sensors, you will notice that your AFRs bounce around a bit (+-0.6) while you're in CL fueling. This is normal behaviour and is meant to help the catalytic converters.

## Note 2:

The CL system was designed to run a 14.7 AFR on gasoline. If you're on e85, the stoich AFR will be different and a 14.7 would be bad.

## OPEN LOOP

There are times when we want our car to not run the stoich AFR. This would be when we are trying to make a lot of power by compressing the air/fuel mixture as much as possible before the spark plug ignites it. So what AFR should we run? A 12:1 AFR is good for power, but dangerous to the engine. It would be good for an aggressive tune on a car that you won't mind if the engine goes. The more reliable AFRs of 10.5:1 to 11:1 for a TMIC and 11:1 to 11.5:1 for an FMIC are usually used on a daily driver. The tricky part is figuring out how much fuel you need since there is no feedback. This is where your Mass Air Flow sensor comes in. The MAF is just a heated wire. The ECU tries to keep that wire heated to a certain temperature, but as air flows over the wire, it cools it. So the more air that is sucked into the engine, the more voltage will be required to keep the wire at the set temperature. So that voltage can be mapped to a given amount of grams of air per second going into the engine. So, for example, if the MAF sees 2.6 volts, then the ECU knows the engine is eating 126 grams of air per second. Knowing this, the ECU looks at what AFR you want to run; takes into account any necessary compensation; and determines an injector pulse width to give you the AFR you're looking for. The pulse width is the amount of time the injector is open and (along with the fuel pressure) determines how much fuel gets squirted into the engine. As you can see, the ECU never knows what the real AFR is while in open loop. It's up to the tuner to determine what AFR the car should be running and setup the ECU parameters to make the actual and requested AFRs match up.

## CL / OL DELAYS & TRANSITIONS

The ECU is designed to only transition to OL fueling if some conditions are met over a period of time. There's no real explanation on why there is a delay, but emission requirements have been pointed out as being the culprit. To make things worse, this transition process has been responsible for some hesitation/drivability issues seen with the WRX. The ECU determines if it should go to OL fueling by using a counter and a couple of threshold values. Once the counter exceeds the *CL to OL delay* value, the transition starts. The easiest way to look at it would be in pseudo code:

### CL TO OL TRANSITION PSEUDO CODE:

```
While (counter < CL_to_OL_Delay) {
  If (currentThrottle > CLtoOLTransition_Throttle_threshold) {
    Counter = Counter + 1;
    Break;
  } else {
    If (currentBasePulseWidth > CLtoOLTransition_BPW_threshold) {
      Counter = counter + 1;
      Break;
    } else {
      Counter = 0;
    }
  }
}
```

So as you can see, if one of the conditions to get to OL is exceeded, the counter gets incremented. On the next check, if the condition is still being exceeded, increment the counter again. If it's no longer

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being exceeded, are any other conditions exceeded that would increment the counter? If not, reset the counter to 0. Finally, when the counter passes the CL to OL Delay value, the transition process starts. Well almost, there are certain extreme conditions that if exceeded, you skip the whole delay process and start the transitions. These are dictated in the max/min maps. So if the ECU does not see these extreme conditions, it follows the code above, if the extreme conditions are met, the code above is skipped.

The last roadblock in the transition is the current value in the Primary Open Loop Fueling table (POLF) as well as the minimum primary open loop enrichment value. The transition will only happen if the desired AFR from the POLF table is richer than the Minimum transition to OL value. (This value is usually 14 and isn't changed). If all that checks out, we go to OL fueling. So, we add these two parts to our Pseudo Code to get:

## GETTING PAST THE DELAY COUNTER

```
While (counter < CL to OL Delay) {
    If (currentThrottle > CLtoOLTransition_Throttle_threshold) {
        Counter = Counter + 1;
        Break;
    } else {
        If (currentBasePulseWidth > CLtoOLTransition_BPW_threshold) {
            Counter = counter + 1;
            Break;
        } else {
            Counter = 0;
        }
    }
    If (any of the extreme conditions met) {
        Forget the counter and start the transition
    }
}
```

## THE TRANSITION

```
If (desiredPrimaryOLValue isRicherThan minRequiredValue) {
    Welcome to OL fueling
} Else {
    Go back to CL fueling
}
```

***So now we are in OL. Let's sum up how the ECU operates in terms of fueling. The ECU takes the following steps in each ECU cycle:***

- Reads the MAF voltage
- Looks at the MAF scaling to determine how many g/s of air are going into the engine.
- Looks up the target AFR
- Adjusts the AFR for environmental conditions
- Determines how much fuel it needs to output to give you the target AFRs
- Looks at the injector flow scaling to figure out how long the injectors need to stay open to get the right amount of fuel into the engine.
- Determines an initial pulse width
- Applies injector latency time to the pulse width
- Applies voltage to injector for duration of the pulse width and hopes for the best

### ***Notes (based on comments by Tea Cups) (A more in-depth view):***

The above is not entirely correct as Tea Cups pointed out. It was written to keep it simple and understandable. The thing that is incorrect is the steps about the Target AFR and corrections. Even though you have a Primary Open Loop Fueling map in RomRaider, the ecu does not have the same map. Rather than having a Target AFR, it has a Base Injector Pulse Width. The RR software lets you set a Target AFR, but translates it to a fuel injector base pulse width when it talks to the ecu. All fueling

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corrections and compensations in the ecu are just modifications to the base pulse width. This is true as well when talking about CL and OL fueling. The ecu does not distinguish between OL and CL fueling. OL Fueling is seen as a correction to the Base Pulse Width. So when you are in CL the ecu looks at A/F learning & A/F corrections (interpreted feedback from the AFR sensor) and adds them to the base pulse width. When you are in OL, the short term corrections are tuned off (feedback from AFR sensor is turned off) and the OL fueling compensations (from the POLF map) are added to the Base Pulse Width. So when you are tuning the OL Primary Fueling map, you are really just dictating how much longer the injector should stay open or how much time to add to the base pulse width to give you the AFR you want. When you are tuning the CL/OL transition, you are determining when to stop listening to the stock O2 sensor feedback and start adding OL corrections. The Base Pulse Width is related to Load and injector scaling in the following manner:

$$\text{engine load g/rev} = \text{base pulse width table value} / (2707.090 / \text{Injector Flow Scaling})$$

## SOME FUEL TABLES WE TALKED ABOUT

### CL TO OL DELAY

This table holds the counter values that need to be exceeded before the CL/OL transition happens. These will vary by year and ECU.

### CL TO OL TRANSITION WITH DELAY (THROTTLE)

This table hold the throttle data, that once exceeded, increments the counter

### CL TO OL TRANSITION WITH DELAY(BASE PULSE WIDTH)

This holds the pulse width value (calculated from injector flow scaling and load) that once exceeded, increments the counter.

### CL DELAY MAXIMUM ENGINE LOAD

This holds the load, which once exceeded, the counter gets incremented. If load drops below the lower value, the other conditions are looked at to determine the transition.

### PRIMARY OPEN LOOP FUELING

Desired fueling to use when in open loop mode (no feedback)

### PRIMARY OPEN LOOP FUELING (FAILSAFE)

Use this fueling when IAM drops below the threshold. (Engine is now happy)

### INJECTOR LATENCY

Dead time of an injector (like PE would be different from stock)

### FLOW SCALING

Estimated CC/min for the injectors being used

### THROTTLE TIP IN ENRICHMENT

An extra injector burst when the throttle position changed by a given amount. So if your throttle plate opening angle changed x% since the last time you looked at it, fire an additional pulse width of y(ms)

### MAF LIMIT - MAXIMUM

This is the max g/s that can be interpreted by the ECU. If the actual value exceeds this limit, the ECU won't know it and think it's at this maximum value.

### MAF SENSOR SCALING

This is where the relationship between volts read by the MAF and g/s or air coming in is specified.

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## Timing

Majority of this comes from [Subaru's knock control strategy explained \(RomRaider\)](#)

*I again paraphrased a lot to make it easier to read and added information I found in other places.*

### **KNOCK**

Knocking (also known as pinging or detonation) is when the AF mix explodes in the cylinder. Fuel isn't supposed to explode, but rather burn quickly creating an even pressure wave that drives the piston. When a car knocks, the AF explosion creates a pressure spike, whose pressure exceeds anything our engines were built to withstand. In order to withstand detonation, you'd need a cast iron engine block + a crank and bearings that can handle it = diesel car. So when the car knocks, the pressure spike is driving the piston downward much harder than it's meant to. This knocks the crank into the bearings, scoring them. Then you need a new short block. Not saying your engine will blow if your car ever knocks, but give it one good knock and it could be toast.

A better way to look at it is with an analogy. Say you had a fragile vase glued to a skateboard and wanted to move it as far as possible with one push. (Stay with me here) If you punch the vase, the skateboard won't go anywhere and the vase will break. If you give the vase a smooth push, the skateboard will go rolling away and the vase will stay intact. So the goal is to give the vase as hard of a push as possible, without it breaking, to make the skateboard roll away as fast as possible. The punch is like knock while the push is like regular combustion.

To get the most power out of the engine, we need the maximum pressure in the cylinder to occur once the piston is 15° past TDC (top dead center, or the 12 o'clock position.) To accomplish this, the AF mixture is ignited early on, usually before TDC. It then gets a little more compressed as it reaches TDC, accelerating the burn. Then, after TDC, the majority of the combustion occurs, pushing the piston.

When we tune timing, we are setting the number of degrees before TDC that we want the sparkplug to ignite the AF mixture. The more advance, the sooner the AF mixture is ignited. Yes, a lot can go wrong here. Luckily, Subaru has an advanced/complicated knock system to prevent catastrophe.

One more note on knock. The knock sensor is an audio sensor. That means it actually listens for a certain sound in the engine. The engine can be a noisy place, so it filters out almost all sound except certain frequencies that are characteristic of knock. So if the sensor hears a sound with the specified frequency range, it reports knock. Yes, the knock sensor can pick up false knock. There have been cases where someone dropped a bolt by the sensor and didn't know it. As they drove, the bolt rattling made the knock sensor think the car was knocking like crazy. This does not happen often and it does not mean you can ignore a knock signal. This is just a limitation of the knock sensor.

### **SUBARU KNOCK CONTROL**

Rather than having just 1 table for the timing value, the ECU has several that it combines to come up with the final value. The reason for this is that it gives the ECU the ability to reduce or advance timing in response to information it receives from its sensors as well as feedback it gets from the knock sensor. Therefore, we need to examine the various parameters that make up the final value. The final value is computed in the following manner:

$$\text{Total Timing} = \text{Base Timing} + (\text{IAM} * \text{Timing Advance}) + \text{Corrections} + \text{Compensations}$$

*Base Timing:* Value in the Base Timing look up table for the specified RPM/Load cell

*IAM:* Current value of the ignition advanced multiplier stored in ram.

*Timing Advance:* Value of Timing Advance look up table for specified RPM/Load cell

*Corrections:* Value the ECU learned from previous experiences & feedback.

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*Compensations:* Adjustments made for variables such as intake temperature, ECT per cylinder, etc.

Let's look at where each of these parameters comes from and how they are determined. Base Timing comes from the base timing map in the ECU. The tuner has full control of this map. The Timing Advance value comes from a similar map, which the tuner can change as well. So why the need for two maps if their values are just going to be added together? The answer is the IAM value. The Ignition Advanced Multiplier is there to add the full TA to the base timing if the engine is happy and only part of the TA if the engine is not too happy. Your engine is happy if the knock sensor is not hearing any knock. You, as the tuner, could very easily put in all 0s in the TA and make the Base timing Value = Base Timing + Timing Advance. This wouldn't be a problem at all if your engine is always happy, but it's "safer" to have the two separated. They are separate just in case your car runs into trouble. In that case, the ECU can lower the IAM and thus add less TA possibly saving your engine.

IAM is also known as "Rough Correction". This is because if it is lowered, only part of the TA will be applied, and thus timing gets pulled across the board. If you IAM is lowered, your car will use less timing for all rpm/load ranges. Another way of saying this is if the car only knocks in one combination of rpm and load and the IAM is lowered, you will still not get full TA once you get out of the "danger zone." There needs to be a better way to compensate for knock that only happens in certain places.

This is where the other corrections come in. The other corrections are Feedback Knock Correction (FBKC) and Fine Learning Knock Correction (FLKC). FBKC is a timing correction that is applied mostly during WOT (wide open throttle) pulls and FLKC is usually applied during cruise. Let's take a look at our revised equation first.

**Total Timing = Base Timing+(IAM\*Timing Advance)+FBKC+FLKC+Other Compensations**

## **HOW DOES THE ECU DETERMINE CORRECTIONS?**

Simply, the ECU adjusts one form of correction at a time through trial and error. This means we have 3 forms of correction (FBKC, IAM and FKLC) and we can only adjust one at a time. So how is this done? The ECU is set up with parameters that dictate which correction the ECU will be adjusting at any moment. To generalize, FBKC is the default correction, but if certain conditions are met, the ecu switches to one of the two other corrections. If conditions are stable (small changes to load and rpm), the ecu can switch to FLKC mode. This usually happens while cursing on the highway. And as long as certain load and rpm conditions are met, the ecu keeps adjusting the FLKC. However, once these conditions are no longer met, the ECU switches back to FBKC. If the ECU is adjusting FLKC and there are huge corrections (-4° or more) to be made, the ECU decides it's not happy and switches to IAM correction. This is done because the ECU thinks there is something wrong with the car and this pulls timing across the board to protect the engine. This is why people say the IAM is a measure of how happy the ECU is.

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Let's try to sum this up with some more pseudo code:

```
If (in FBKC) {
    If (Engine Conditions are stable) {
        Goto (FLKC)
    }
} else {
    Keep Listening for knock and make corrections.
    Stay in FBKC correction mode
}

If (in FLKC mode) {
    While (engine load and rpm are steady) {
        Check for knock and pull timing if needed
        If (pulled more than 4° or the ECU is unhappy) {
            Goto (IAM correction)
        }
    }
    Else {
        Go back to FBKC
    }
}

If (in IAM correction) {
    Find optimal IAM
    Go back to FLKC mode
}
```

The ECU is set to rough correction initially. This makes sense since it finds it's optimal IAM first, then moves on to adjusting the FBKC and stays there until the IAM needs to be recalculated or FLKC can be learned. Another thing is that the ECU seems to give FBKC priority over the other modes. So since this is the case, we'll start with that.

## FEED BACK KNOCK CORRECTION

FBKC is active during the values specified in the "feedback knock correction range". During that time, the ECU is constantly listening to the knock sensor waiting to hear a knock activity. If there is no knock activity, FBKC will stay at 0. However if the ECU hears a knock event, the FBKC gets the Feedback Correction Retard Value subtracted from it. This value could be anything, but is usually, 1.4°. So once the first knock event is heard, FBKC = -1.4. This means that 1.4° are now subtracted from your final timing value. The ECU goes back to listening. If the correction helped, the ECU won't hear any more knock, and at that point it will slowly start adding timing back in. That means your FBKC value start going back towards 0. It only returns a little bit at a time, not the whole amount. So say pulling that 1.4° did the trick, therefore as time goes on, the ECU will raise the FBKC to -1°, then -.6°, then -.2°, then back to 0°. But if at any point in time, the ECU hears another knock event; it will subtract another 1.4° from whatever the current value of FBKC is. So if it hears another knock right after the first, your FBKC = -2.8°. If it hears another knock a little later on when FBKC = .6°, then your FBKC = -2°. It does this over and over as you drive.

At this point it would seem like a good idea if the ECU just learned when to pull timing automatically. The learning should depend on how the engine is doing. If the engine is doing poorly and it hears a lot of knock, it should pull timing everywhere to be safe. If it only hears a little knock here and there, it should concentrate on the areas where it hears the knock to clear them up and leave the rest alone.

That is a good idea, but in order to learn the ECU needs to get out of FBKC mode and into one of the other modes. To do this, there is a list of conditions that must be met. This list of thresholds ensures that engine conditions are steady enough that whatever knock you hear is not a fluke.

They are:

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- Coolant temp is greater than 140F
- A/C is off or A/C was not just turned on
- load and RPM are within the "Rough Correction Ranges" or "Fine Correction Ranges"
- Immediate change in load is less than about +/- .05 g/rev.
- ECU is not in test mode
- ECU is not in limp-home mode due to the triggering of specific groups of CELs.
- An unknown timing compensation based on throttle change is not active (i.e. no compensaton).

These are not guaranteed to be accurate. They are often updated and therefore the RR link is the best source for an updated list. I mentioned them here to give you an idea of what it takes to get out of FBKC.

## FLKC MODE

Let's assume engine conditions are steady and we enter FLKC from FBKC. FLKC is meant to make adjustments to the timing for particular load and rpm combinations rather than applying corrections across the board like rough correction. The learned values stored in RAM are applied in all modes, but adjustments to the values can only be made if

- Currently in fine correction mode.
- FBKC is disabled.
- Engine speed and load are within the ranges specified by the 'Fine Correction Range' tables.
- Limp-home mode is not active.

If those conditions are met, the ECU listens for knock. If there is no knock, the ECU can do nothing or it can add a positive correction (advance timing further). The ecu will do nothing if your IAM is maxed out. The ecu can try and add timing if you had your IAM was lowered at some point. The idea is to advance timing as much as possible in knock free rpm/load combos, even though timing was pulled across the board. So rather than add timing across the board, the ecu tires to only advance timing in certain rpm/load ranges. To do that, the following conditions must be met:

- (FBKC and/or negative FLKC was NOT applied during the last execution)
- If above is true, then the previous FLKC load/RPM range also has to be the same as the last range before this execution.
- The current FLKC table load/rpm range is the same as the last range.

Like the other corrections, there is a delay before which an FLKC table value can be increased ('Fine Correction Advance Delay'). This is based on a counter, which is incremented when there is no knock and is cleared when FLKC table adjustments are made or the knock signal is set.

If the above are met and the counter is passed, then the FLKC value for the current load/RPM cell is increased. However, it cannot be increased if  $(\text{Timing Advance Value} * \text{IAM}) + \text{FLKC}$  is greater than the current value in the "Timing Advance (Maximum)" table. Again, FLKC will only be positive if your IAM is not at 100%.

If the ECU hears knock, the fine correction in the current FLKC cell is decreased by about 1° ("Fine Correction Retard Value").

So if everything is good, the IAM is at 100% and the FLKC are all 0's. However, if there are big problems and knock activity is abundant, there is always the potential to enter back into rough correction mode. To do this, the following conditions need to be met:

- Engine speed and load must be within the ranges specified by the 'Rough Correction Range' tables.

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- Timing advance (maximum) map value is greater than  $4.9^\circ$ .
- Some FLKC value change (positive or negative) occurred last execution.
- The last FLKC applied value ( $|x|$ ) is greater than  $3.9^\circ$  (that is, the absolute correction  $\rightarrow$  ex.  $-4 = 4$ )
- The last FLKC raw difference ( $|y| * 2.84$ ) is greater than last timing advance (maximum) map value.
- ( $IAM > 1$ ) or ( $IAM \leq 1$  and last applied FLKC was positive).

Before we got onto Rough Correction, let's sum up the FLKC with some pseudo code:

```
If (conditions for adjustments are met)
{
    Listen for Knock
    If (Knock) {
        Set Counter to 0
        Subtract Fine Correction Retard Value from current RPM/Load cell
        If (totalCorrection < -4) {
            Transition to Rough Correction
        }
    } Else //no knock {
    If (IAM < 100% max value)
        If (No knock for period of 'Fine Correction Advance Delay') {
            Increment Counter
            If (Counter > Delay Target && (TA*IAM)+FLKC < TAmmaximum) {
                Add Fine Correction Advance Value to RPM/Load Cell
                Set Counter to 0
            }
        }
    } else //IAM is maxed out {
        Do nothing
    }
}
```

## ROUGH CORRECTION / IAM CORRECTION

So let's assume we enter IAM (rough) correction mode. We get here because we either just rest the ecu or the engine is hearing lots of knock. Once we're in, we can either adjust the IAM or not. If the following conditions are met, the IAM can be adjusted

- Current timing advance (maximum) map value  $> 3.9^\circ$  ("Rough Correction Minimum Timing Advance Map Value").
  - ECU Limp-home mode not active (IAM would already be 0 in this case)
  - ECU FBKC is disabled.
  - ECU IAM step value  $> 1$
- (again, check the RR link for these conditions)

So now, let's assume that the IAM can be adjusted, in order to do this, we need to do the following first (but only once every time we enter rough correction):

- Set ECU IAM is set to the 'Advance Multiplier (Initial)' value
- Set ECU IAM step value is set to 4 ("Advance Multiplier Step Value")
- Set ECU IAM learning delay counter set to 0
- Clear the FLKC table

This is done to make sure that we are not working with any previous corrections.



# An Intro to Subaru Tuning

So now, we calculate the new IAM value by listening for knock activity. This can be summarized with the following pseudo code:

```
If(conditions for adjustment are met)
    IAM = initial Value (usually half the max)
    IAM Step Value = Max Step Value
    Counter = 0;

While (IAM Step Value > (1 or .25)) {
    Listen for knock
    If (Knock) {
        Set Counter to 0
        Decrease the IAM step value in half
    } else { // There is no knock
        If (No knock for period of 'Rough Correction Learning Delay') {
            Increment Counter
            If (Counter > Delay Target) {
                Increase IAM by Advanced Multiplier Step Value
                Set Counter to 0
            }
        }
    }
    If(IAM = max or IAM = 0){
        Go back to FLKC
    }
}
}
```

## **SOME IMPORTANT TIMING TABLES WE TALKED ABOUT**

### **BASE TIMING**

This is the starting value used in the calculations. All corrections & compensations will be applied to this value. This value is lower than the final value.

### **TIMING ADVANCE MAXIMUM (TA)**

The ECU will try to add this value to the base timing.

### **ADVANCE MULTIPLIER (INITIAL)**

Initial value the IAM will be set to.

### **IAM STEP VALUE**

The amount to adjust the IAM initially. This value drops later on as the IAM is calculated, but this is the starting value.

### **FEEDBACK CORRECTION RETARD VALUE**

This is the amount to decrease to pull in FBKC mode if a knock even is heard.

## **SOME IMPORTANT VALUES STORED IN RAM**

### **IAM (IGNITION ADVANCE MULTIPLIER)**

In short, this is the percentage of the TA that will be added to the base timing. If your car is happy, this value is 100% and all of the TA will be used.

### **FBKC (FEEDBACK KNOCK CORRECTION)**

This is the amount of timing subtracted from the total timing based on short term feedback from the knock sensor.

### **FLKC (FINE LEARNING KNOCK CORRECTION)**

Amount of timing subtracted from the total timing based on long term steady feedback from the knock sensor.

# An Intro to Subaru Tuning

## AVCS (active valve control system)

The basic idea behind AVCS is simple; it's just a way to open the intake valve on the cylinder earlier. The higher the AVCS value is (degrees) the more advance the intake valve is given. However, the length of time the valve stays open is still the same. So what is the point of doing this? According to the Subaru article, it's to smooth idle at low engine loads, better emissions at mid engine loads, and get more power out of high engine loads. So Subaru tells us right there what to do with AVCS. At low loads, turn it off (set to 0) and at high loads turn it up. Then taper that through the middle loads.

Now, if you look at the stock WRX AVCS map, you'll notice a big jump (40°) in a couple columns near the lower rpm low load range. That is there for emissions. According to Subaru, having some of the exhaust gasses flow back into the intake reduces harmful oxides in the exhaust. Furthermore, the s202 and other JDM maps don't even have that spike. So we can eliminate that right away.

What the Subaru article doesn't talk about is the relationship between AVCS and RPM. The OEM AVCS map is a 3d map broken down by engine load and rpm. So we know that the min advance should be 0 and occur at the left and max advance at the right, but what about top to bottom (low to high rpm) what happens there?

This is where things get complicated. That all depends on your exhaust/intake/turbo setup. The reason AVCS can make good power is because it increases the Volumetric Efficiency of your engine. VE is the percentage of air that is going into the engine / the amount of air that could fit. So in other words, it's how easily air flows into the engine. Another way of saying this is how much resistance the air has going into the engine. In a turbo application, the psi measured in the intake manifold is a measure of how much air is not going into the engine. So that means if the turbo is pumping out the same amount of lbs/min or air, having a lower psi is actually better since more air gets into the engine since there is less restriction.

So now this brings a problem, reversion. This is where if you give AVCS too much advance, the exhaust gases come back into the intake manifold and "pollute" your intake charge. Not only that, but they cause an extra restriction so it's harder for the turbo to move air since the pressurized exhaust gases are moving in the opposite direction of the intake charge.

This brings us to our point. The bigger your turbo and the less restriction there is in your exhaust, the more advance you can run into the higher RPM ranges. This is because the bigger turbo pushes the air harder on the intake side and the better exhaust lets the air move more freely on the exhaust side.

The key to tuning AVCS is figuring out when advancing AVCS causes more of a restriction than it helps move air into the engine. (We'll talk about this when we get to practice)

*(Oh and since it changes your VE, your fuel and timing are affected....)*

# An Intro to Subaru Tuning

## Tuning the car

When tuning the car, what you are really doing is finding the limits of the engine. Finding how much boost the turbo can push, how lean a fuel mixture the engine can run, and how much timing advance the engine can take. So keep in mind that the closer you come to any of these thresholds, the more likely you are to break your car. But the trade off is you'll make more power. A lot of people say the car felt the best (made most power and whatever else that means) right before the engine blew. So whatever margin of error you leave is completely up to you.

Another thing to keep in mind is that each car is different. What works for one car, might not work for another. This is why a custom tune is usually far superior to any off the shelf tune. The tune really has to be suited to the vehicle. While the practices and theory remains similar, the actual numbers will vary.

When tuning the car, you can judge progress by a number of different ways. Your goal might be max power, max usable power, quickest turbo spool, or the most boost.

Max Power: Getting the dynamometer to give you the highest possible point on your power curve.

Max Usable Power: Getting the most area under the power curve

Quickest turbo spool: Getting the turbo to push air as fast as possible as soon as possible.

Most Boost: Sacrificing all to claim you can push the most air on your turbo.

***Clark Turner always says that your priority should be to tune for the most amount of usable power.***

Why? Simply because that is what will make your head fly into the back of your seat and keep it there. Another way of looking at it is to compare it to audio components. The most expensive/best sounding speakers are the ones that have the highest RMS values, which is a measure of usable power. It's the power available to push the speaker. So we want the same thing, we want the most power available to push the car and that means getting the most area under the power band. (Anyone who's ever bought a cheap pair of speakers claiming they're rated at some awesome wattage will understand this analogy. You get them home, hook them up, and they sound like crap. No bass, terrible treble, total waste of money) So usable power will make your car move, while the other stuff just looks pretty on paper and is great for internet bragging.

When tuning, you never have complete control of all the variables being process by the ECU. You are constantly negotiating with the ECU to get the car to do what you want. So the general format is you tell the ECU what you want the car to do (set up the base tables), tell it how to do it (set up values that make the car reach the desired values), then tell the ECU how to adjust for unknown environmental conditions. Then you test the setup and make sure you see the results you were looking for. If not, adjust.

***Enough BS, let's get to the tuning.***

First, we need to set up the basics. These are turning off any CELs and finding the correct values for fuel injector scaling, latency, tip-in, and the MAF table. The reason you do this first is so that you have established a proper relationship between air and fuel from the beginning. Once you have the relationship setup, tuning the rest will be a lot easier. So we will tune in the following order:

- 1) Establish Air and Fuel relationship
- 2) Tune boost
- 3) Tune Fuel
- 4) Tune timing
- 5) Tune AVCS
- 6) Retune fuel and timing

# An Intro to Subaru Tuning

## ESTABLISHING THE AIR AND FUEL RELATIONSHIP

This needs to be done if anything has changed with the way fuel is delivered or the intake. Meaning if you threw on an intake, fuel pump, or fuel injectors, you will need to do this. The intake and the fuel systems are "tuned" to work together to give you a proper AF relationship, so changing one means, you need to update the relationship values. So if you changed something in the fuel system, you need to update the fuel parameters, if you change your intake, you will need to rescale your MAF, if you did both, you'll need to do both. That is the more difficult case. This is because if you try to tune for both at the same time, you'll be chasing your tail and will never get it done. This is because while tuning for each, you're looking at changes in the same parameters and you're never sure if the intake or fuel injectors are making those changes. Therefore, you can only tune for 1 at a time. There are 2 ways of doing this:

- 1) Throw on the stock intake and tune the fuel, then put on the aftermarket intake and tune the MAF.
- 2) Put in theoretical values for fuel, and compensate for the difference from actual values while tuning the MAF.

Ideally, you would do 1, but that can't always happen in cases where your stock air box will no longer fit in the original location. In that case you would do 2.

So let's say you have the stock intake on. If we didn't, we would just put in theoretical values and skip to the MAF tuning.

## INJECTOR FLOW SCALING:

How many cc's/min our injectors will flow

- 1) Find the theoretical values for your injectors. They can be found on the forums, from your manufacturer, or from Cobb's database. Cobb's db is a good starting point, but it lists the raw ECU values rather than the cc/min that RomRaider wants. Luckily, you can use the following to convert:  $2707090 / \text{Cobb Value} = \text{RomRaider Value}$ .
- 2) Let the car come up to temperature.
- 3) Once that's done, reset the ECU. You're doing this to flush any learned fuel values.
- 4) Turn the car back on and let the car idle and watch the AF correction #1 and AF learned correction. The sum should be  $\leq \pm 5\%$ .
- 5) If it's not, positive numbers mean the ECU is adding fuel; negative means the ECU is pulling fuel. Therefore, you just adjust the values as needed (up or down) by a little bit at a time.
- 6) So check total correction, adjust the map, flash map, idle again and watch the sum. Rinse & Repeat.

## INJECTOR LATENCY

"Dead" time of the injector that is based on battery voltage and fuel pressure. Do the same thing as you did for your injector scaling, but do it for the entire MAF curve. This is why it's so important to have the stock intake. If you had a different intake, that means your MAF values will be off and you can't be sure if the MAF or the injectors are causing fuel corrections. So drive around under many different conditions. While driving, you need to avoid sharp throttle movements to avoid extra fuel being added due to tip in enrichment. Keep adjusting the trim values until you get the sum of your fuel corrections within 5%.

It's been said that if you have a constant error through the MAF curve, it's an injector scaling problem. If you see a lot of error on the bottom of the MAF curve and less on top, it's an injector latency issue. This makes sense since as boost rises; fuel pressure rises so the latency would have less of an effect. Wave like errors will need to be compensated for by scaling the MAF. Keep in mind that MAF will probably need to be adjusted anyhow.

# An Intro to Subaru Tuning

The above steps can be followed to get the injector latency and scaling. The easier thing to do would be to use the RomRaider injector scaling tool. You can find it in the logger, there's a little tab in the lower left hand corner. Keep in mind that you will need a lot of good data. When using the scaling tool, if your data is constantly off from the line, it's an injector scaling problem. If the data had a different slope from the line, it's a latency issue. If the data has lots of scatter, it's a MAF scaling issue.

## TIP-IN-ENRICHMENT

As the throttle angle changes suddenly, there is an extra burst of air that enters the engine, so you need extra fuel to deal with the extra air. This table compensates for that.

- 1) Try to stay in closed loop fueling as you drive
- 2) Log the throttle position, throttle angle change, a/f correction #1, a/f correction learned.
- 3) If for a particular throttle angle change the sum of the 2 corrections is large, take the % correction, half it, and multiply it by the current value.  
So if the correction is 20%, then you would multiply the current value by .90 if you want to remove fuel and 1.10 if you want to add.
- 4) Rinse and repeat until the sum of all corrections < 14%. The lower the better.

## TIP-IN-ENRICHMENT (BOOST ERROR)

This is the extra fuel added to tip in enrichment at a particular boost error (so it's 'tip in enrichment' enrichment). This will only need to be adjusted if you added larger injectors or a FMIC.

- 1) For a FMIC, set all cells to 0 (the much longer intercooler piping eliminates the need for this table)
- 2) For larger injectors on a TMIC, multiply each value by (new injector size / original injector size)

## MAF SCALING

Here we adjust the correlation between MAF voltage and the mass of air being pulled into the engine. For now, we will do this only up to 2.6 volts (or closed loop fueling), we'll adjust the rest after we tune boost.

- 1) Log AF correction and AF learned, MAF voltage, CL/OL status, Throttle position
- 2) Drive around collecting data under lots of different condition.
- 3) Sort you data and get rid of any data where there is a "large" change in throttle position. This is to eliminate tip in enrichment effects.
- 4) Sort the data so you can see what sum of the a/f corrections is being applied at what MAF voltage under closed loop conditions for what cell
- 5) Then any cell that has a >5% error, multiply the value by a correction factor. For example, if the sum was +10%, then multiply the value of that cell by 1.10. If it's -10%, multiply by .90.
- 6) Rinse and repeat.

That is the "quick and dirty" way of doing it. If you want to be more accurate, follow the steps outline in:

[HOWTO: One Man's Way of Scaling a MAF \(Nasioc\)](#)

And

[Spreadsheet to scale Closed Loop MAF Table and Injectors \(RomRaider\)](#)

Easiest way to scale your MAF is to use the MAF scaling tool in RomRaider. Use is outlined at:

[How do you use the MAF calibration tool? \(RomRaider\)](#)

# An Intro to Subaru Tuning

## TUNING BOOST

There are two ways to get started:

- 1) Get a boost map from someone else and tweak it to your car.
- 2) Make your own boost map from scratch.

We will go with 2 since it's more involved and 1 is just a short cut for 2 anyway.

You will need to tune your Target Boost, and WGDC, while watching your Turbo Dynamics.

## FIND YOUR MECHANICAL PROPERTIES

- 1) Remove 2-4° of timing from your timing map in the WOT area. That's the high load area of the map. It's roughly a triangle from the top left cell to the bottom right cell.
- 2) Set your fuel targets in those areas to something conservative like 10.5 or even 10 in those areas.
- 3) Set all your WGDC to 0. You are doing this to test the mechanical efficiency of the turbo and wastegate first. So we want to see how the turbo and wastegate behave without any help from the ECU.
- 4) Drive around logging your RPM, Throttle Position, and Relative Pressure. The goal here is to try and see how your car behaves in each cell (Each RPM and throttle position value.)

From this info, you should have a pretty good idea of how the mechanical system behaves. You can use the info to create a base map that you will tune from. The idea behind this is since your turbo changed, your stock map no longer matches the turbo so you can't start from it and since you need a starting point, this is a good one. Keep an eye on your boost gauge to make sure you're not somehow exceeding the wastegate pressure.

## TUNE TO REACH YOUR TARGET BOOST

The best thing to do for now would be to look through other people's boost maps for the turbo you are running. This is just to get a general idea of what other people are doing. Not that you will follow their lead, but you want to look through a couple maps and notice the different patterns. Like where they make max boost, what their max boost is, and the general flow of the map. It's just to give you insight into how your boost map will likely progress.

- 1) Take the info you created from the information you got from your logging session above and create a boost map out of it. This means just enter the boost value you achieved at each cell as your boost target. Your boost map will now match your mechanical settings.
- 2) Now, we will slowly try to achieve the higher boost values you want. So pick a spot in the 100% load column and guess what RPM you want full boost at. Bigger turbos spool later, but for now, this is just a guess.
- 3) Enter about 75% of your target boost in that cell.
- 4) Then interpolate the table horizontally and vertically so that your target boost values are a smooth progression to your max boost.
- 5) Add a little bit of WGDC to your tables. You can make this almost like 2D map for now. So in the 0 TP load have 0 WGDC and in the 100% you can start off with 10% and interpolate horizontally.
- 6) You will not reach your target boost, but go out and log the same parameters and see how far off you are. Then add a little more at a time to the 100% column of your WGDC and interpolate horizontally and vertically.
- 7) Once you reach your target boost (this was set at 75%) then you can raise your target boost slowly and match the WGDC as before to try and meet your theoretical target boost. Keep doing this until you can achieve your target boost or you find that your theoretical target boost is unattainable.
- 8) During your pulls you will log Throttle Position, RPM, WGDC, TD Cumulative, TD immediate and FBKC.

# An Intro to Subaru Tuning

## THINGS TO WATCH FOR

- 1) **Boost spikes:** These are just what they sound like, momentary spikes in your boost. The boost system control is fast, but not instantaneous. So sometimes it responds late causing your boost to rise rapidly until it can be controlled. This is usually caused by having too high of a WGDC too early causing you to overshoot your boost targets. Say you logged a boost spike at 4000rpm: that means that you have too much WGDC before 4000 rpm. Find the conditions that caused the boost spike (boost and throttle position cells) and lower the WGDC in cells prior to them. If you switched to a different boost controller, you can also try lowering your TD correction values. I noticed that on the GM, I first multiplied the each cell by 0.66 and then the inner cells by 0.75 after. The GM is more sensitive than that stock and this helped to calm it down.
- 2) **Compressor Surge:** Trying to make too much boost too soon can cause your compressor to surge. The surge region is on the left hand side of the compressor map. The turbo is spinning too fast and not pulling as much air as it should causing it surge or oscillate air pressure. It happens on spool up and can be heard from inside the car. If this happens, lower your target boost in that area and lower your WGDCs as well.
- 3) **Compressor Stall:** Sounds like surge, but when you lift off the throttle. This happens when the BPV or BOV vents the pressure in the intake. It happens when the BOV or BPV are not functioning correctly and don't release the air in one clean vent. It sounds like the air is vented in a couple of vents rather than one. This fluctuation in pressure causes the compressor to stall. This usually involves a mechanical fix like adjusting the BOV or cleaning the BPV.
- 4) **WGDC > 95%:** WGDCs are usually kept under 95% to preserve the wastegate. Higher values cause the wastegate to work harder and can wear out the wastegate causing it to get stuck open or closed.
- 5) **Knock:** You should not see any since we setup a rich AF and low timing, but you never know. Better be safe than sorry.
- 6) **Turbo Limit:** If you're increasing your WGDC or holding them steady and your boost is dropping, you hit the mechanical efficiency of your turbo. That or increasing boost does not = an increase in airflow (g/sec). At that point, don't add any more WGDCs since doing so will push your turbo out of its efficiency range and won't make much difference anyway.
- 7) **Watch your Turbo Dynamics.** They tell you what the ECU is doing to achieve target boost. If log negative values, your WGDC are too high and you're over boosting. If you log positive values, the WGDC are too low and you're not hitting your target boosts. Keep doing this until your target boost values and your WGDC values give you the boost you want, your TD tables are low and positive (not adding much correction) and you're not experiencing any of the problems mentioned above.

## FINE TUNING YOUR BOOST

Basically, the same idea as above, but you're trying to get your turbo to spool quicker and hold boost longer. To do this, just add little bits of boost to your target boost values before and after your max boost and adjust the wastegate values. Just do this a little bit at a time making sure you don't see any of the problems listed above. You know you're done with a particular cell in the map on the 100% TP column, when adding WGDCs does not make a difference anymore. Ideally, you would want to hold a flat boost curve as much as possible. You will probably have a spool period (a quick rise in boost), then a flat plateau where your boost is steady, then a drop off. If you have a huge turbo, you will never reach the drop off since the turbo will spool so late. Different setups will have different characteristics, but the goal here is to expand that boost curve as far as you can to the left and right of where you first hit your target boost without experiencing any of the problems listed above.

# An Intro to Subaru Tuning

## TUNING FUEL

Tuning fuel simply means setting fuel target values in the primary OL fueling map and then adjusting the MAF scaling so that the desired AFR is achieved. Cobb's access tuner spread sheet can help out with this. It's a great tool for getting started.

### SO WHAT SHOULD YOU SET YOUR AF TARGET TO?

12:1 is a good power range (prone to knocking) while 11:1 more reliable. The usual settings are 10.5:1 to 11:1 for TMIC and 11:1 to 11.5:1 with FMIC. Don't change them in the closed loop part of the fuel map, just the open loop. Also, take a look at the structure of the stock map, you'll want to follow the basic layout, but just go a bit leaner A/F at the parts where the map leans out.

### SET THE MAF MAXIMUM VALUE:

This is the highest MAF the ECU will be able to compensate for after atmospheric corrections. You want this to be about 50 higher than your max g/sec in your MAF scaling table. This just helps the ECU compensate higher MAF values in different atmospheric conditions. This is just a precaution. Raising the value doesn't change much else.

### SCALE REST OF THE MAF:

You will do the same thing you did when you scaled the CL part of the MAF, except with a wideband O<sub>2</sub> sensor. You can do this once for the middle of the MAF and again for the top part of the MAF. Or you can just do it for OL part of the MAF only. You can try both ways and see what works best for you.

The following will help you scale your MAF:

- 1) Log MAF voltage, CL/OL status, Throttle position, RPM, Load, Wideband AFR (yes you **need** a wideband to do this) and Injector Duty Cycles.
- 2) Drive around and collect Data. For scaling the OL part of the MAF, do WOT pulls. You don't need to do 5<sup>th</sup> or 4<sup>th</sup> gear pulls till redline. What you should concentrate on is the MAF voltage your car sees during the data collection instead. You want to get data for ~2.66v – top of the MAF scaling. I'm starting with 2.66v since that's where I noticed OL fueling starts on my car. Could be different on yours.
- 3) Copy your Primary OL fuel table to Airboy's spreadsheet
- 4) Use Airboy's spreadsheet to read and interpolate your log. Airboy's spreadsheet will give you the percent error at each line of your log.
- 5) Take the error at each line and decide what voltage bin in the MAF scaling the line will belong to.
- 6) Average out the percent errors in each bin.
- 7) Your correction factor will be 100% + average %error for each cell.
- 8) Apply the correction factor to each cell.
- 9) Plot your MAF curve and make sure it's a smooth progression.
- 10) Keep doing this until your dictated AFRs are close to your measured AFRs.

Remember that the CL and OL correction factors should be within 5%, but don't go crazy trying to get them to 0. Different ATM conditions and different gas will do different things to the corrections. Just make sure you have a smooth progression across the table.

The only tricky part is finding the delay between MAF voltage and AFR reading. Since the MAF is at the beginning and the AFR sensor is near the end of all the engine plumbing, the AFR and MAF readings you see in a given line in the log don't match up. You need to figure out how many cells the AFR reading is behind the MAF reading. To do this when scaling your MAF, look for an easily noticeable dip or spike in the MAF voltage and find a corresponding reaction that spike or dip would get with the AFRs. Then find how many lines the AFR reading is lagging behind the MAF voltage by matching up the cause and effect.



# An Intro to Subaru Tuning

## SCALE THE LOAD:

- 1) Do a couple of WOT runs logging your wideband AFR, CL/OL status, RPM, Load, and FBKC.
- 2) Your calculated load will probably be larger than what you set on the x-axis of your primary fuel table. You will need to rescale your load column in the primary fuel table to reflect what you are seeing in your logs. This only applies to your OL parts of the map. So look through your log and find the min OL load value and the max value.
- 3) Rescale the x-axis in your fuel map so that the min OL load value stays the same, but the max is slightly larger than what you logged. Then have a smooth progression from the min to max.
- 4) Go do some more logging to double check your work.

## SETTING TARGET AFRS

- 1) Look through the OEM map; it's a good starting point. Notice the pattern in the map. Notice where the mixture is the leanest.
- 2) Set the OL areas that are lean a little leaner to your desired AFRs. Then interpolate to smooth the progression, but only in the OL part of the map. Don't go straight to your desired afr. So if you have a 10.5 and want to go to a 11, go to a 10.6 first and make sure it's ok.
- 3) Do a couple WOT runs logging wideband AFR, CL/OL status, RPM, Load, and FBKC.
- 4) Make sure that your measured and target AFRs are close for each RPM/Load cell using Airboy's spreadsheet.
- 5) Keep doing this until your leanest part of the map is what you want. As mentioned before (between 10.5 to 12)
- 6) You might have to go back and rescale the MAF to get closer to your fuel targets.

The only trick here is how to setup the drop from a 14 AFR to an 11 AFR assuming 11 was your goal. This will depend on your turbo and where in the RPM range it spools. Some people say they like to drop a little early because the richer fuel AFR helps the turbo spool faster. If you drop it too early, your car will bog. I try to match my spool. Meaning, say I get full boost at 3000 rpm then I would try to have my AFRs hit 11 at 3000 rpm. Then I would interpolate between 3000 and the start of the OL fueling.

## WHAT TO WATCH FOR:

- 1) Knock: Make sure you're not seeing any knock. You shouldn't since you pulled timing, but if you do, it might be a good indication that you don't want to run that lean. If you do, just enrich the fuel a bit and smooth out.
- 2) Jagged MAF curve: If the MAF scaling curve is not smooth, you probably have a mechanical problem like a bad intake or leak somewhere.
- 3) Large differences in target/measured AFRs: Means your MAF is not scaled correctly. You will need to rescale again.
- 4) Larger max load: You might see a load that's larger than your max load column. If you see it frequently, you might have to rescale your load again.
- 5) Maxing out your MAF: If your MAF voltage is increasing while your MAF value (g/sec) is pegged at 300, you maxed out your MAF. The best way to fix this would be to get a larger diameter intake (Perrin big MAF). This will force you to rescale your entire MAF. What this intake would do is cause a lower voltage values to correspond to higher air flow. If in the original intake, 4.6 volts corresponded to 300 g/sec, on the new intake, 4.6v might correspond to 400g/sec.
- 6) Injector duty cycle > 95%. These need to stay under 95% to prevent injector failure from overheating.

# An Intro to Subaru Tuning

## TUNING TIMING

Here we will adjust the timing advance maximum as well as the base timing. The timing advance (maximum) table in RomRaider is the same as dynamic advance in street tuner. When tuning, the car is most likely to knock during peak torque and therefore that is where you will be able to run the least amount of timing. Timing will increase as engine speed increases to keep up with the faster moving pistons. It will also increase as load decreased since your VE is lower so you advance timing to raise it. One thing you need to decide is what table to adjust in the ECU. You can add or subtract timing from the base timing or the timing advance. There is no clear answer what table to modify; it's a highly controversial topic. You want to have enough values in the timing advance table in case your IAM drops, but not so much that the car will not run correctly if it does drop. One of the accepted methods is to smooth out the timing advance table and make the highest values slightly higher than stock. Then tune the rest using the base timing table.

Before you start, you will also need to download the ECU Learning tool from:

[Learning View \(version 0.5a 02-03-09\) \(RomRaider\)](#)

This tool will read your stored learned knock correction values.

Street tuner has a special function to do this as well.

- 1) Make sure you have your conservative timing map loaded. We pulled 4° last time from the base map.
- 2) You will be logging RPM, Engine Load, Timing Advance, IAM, base timing, total timing, current applied FLKC, current FBKC, and Throttle Position
- 3) Before you do anything, make sure your IAM is at 16 (16bit) or 1 (32 bit). If it's not, your engine isn't happy and you need to fix it. That means you have a mechanical problem, are running too much boost, AFR too lean or too much timing. It means your engine is knocking as it is.
- 4) Rescale your load column in your base timing and maximum advance to match your rescaled load column from tuning the primary OL fueling map.
- 5) First, drive around logging the parameters mentioned above. You want to make sure you're not somehow knocking anywhere under normal driving conditions (mild and moderate). If you hear your car knocking (it's audible sometimes, sounds like tinny metal balls rattling in a coffee can) get off the gas. It also helps to have someone with you watching the FBKC and FLKC on the laptop so they can tell you if you're pulling timing.
- 6) Look at your correction values. If they are positive, the ECU is adding timing, if they are negative, they are pulling timing. You want to look at them to make sure they are not negative. If they are, you need to pull timing in the places where you see negative learning and add where you see positive learning. You shouldn't see any positive learning because you want your IAM to be at 100% and if it's maxed out, positive learning can not happen.
- 7) So now at this point you should be knock free just driving around town. We want to be sure the car is ok under mild and moderate conditions before we make power runs.
- 8) Now you need to figure out what the ECU is doing during the WOT pulls. So do a couple logging your FBKC, FLKC, IAM, base timing, total timing and timing advance. Make sure you're not seeing any corrections and that your IAM is 100%. Also make sure that the logged total timing is close to the theoretical total timing. (from eqs in the research). They won't match up because the ecu is compensating for environmental conditions, but they should be close. You're just making sure there are no strange corrections being added in that you're not aware of. You don't have to check the theoretical vs actual numbers every time. It's just a good idea to do occasionally to make sure everything's in line.
- 9) In cells where the ECU is happy, you can add a little timing, in cells that it is not happy, you want to pull some timing. You know the ECU is happy if it didn't knock at all for a conservative tune and knocked 2 times at most for an aggressive tune. You will usually have a little FBKC, so don't go crazy making sure it's always 0. Just like with fuel, the ECU needs the freedom to adjust the final value a little, you just don't want those adjustments to be large and negative.
- 10) When making adjustments, don't forget to smooth the map. Rinse and repeat (8 and 9 anyway).

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Most people tune to the edge of knock. That means they advance the timing as much as possible in each cell you hit during a WOT pull. Some consider this aggressive since you're just about to knock every time you do a WOT run and if something isn't right, you will knock. To me, it might seem like a good idea to pull a little bit of timing back out at this point. Just a small bit to make sure you're not always at the edge. Since most people don't tune with a loaded car or going up a hill. Having a little headroom is good.

## TUNING AVCS

This idea behind advancing AVCS is to increase your VE (volumetric efficiency). Before we start tuning AVCS, we need to figure out how to calculate VE. The accepted method can be found at:

[Speed Density FAQ \(RomRaider\)](#)

Or the Freon's formula is the following:

$$\text{VE} = \text{MAF}(\text{g/sec}) / (2.457 * A * \text{RPM} * 0.003871098 / (\text{IAT} + \text{Temp}))$$
$$A = (\text{boost pressure} + \text{sea level pressure}) / (14.7 * 760)$$
$$\text{Temp} = \text{IAT in Celsius} + 273.5$$

or in Fahrenheit it's  $(5/9) * (\text{IAT} - 32) + 273.15$

Another thing to look through is the test results from a member experimenting with AVCS.

[AVCS Research - 03" ADM STi \(RomRaider\)](#)

Those will give you a better idea on what happens when you change the values.

So now tuning AVCS becomes somewhat simple:

- 1) Reduce your timing a bit as well as add fuel. Since you are going to be increasing VE, it might cause a lean condition that leads to knocking. This is a precaution; we will fix the values later.
- 2) Rescale your AVCS table for load
- 3) Go out and Log RPM, load, MAF (g/s), boost, and IAT.
- 4) Change some AVCS advance cells a little bit.
- 5) Go out and log again and see if the change increased your VE.
- 6) Keep doing this until you get the best VE
- 7) Retune your Fuel and Timing.

This comes down to simple trial and error. Since everyone's setup is different, everyone will get different results for these values. As long as your table is smooth, you should be fine.

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## **TUNING CRUISE**

We now tuned boost, fuel, and timing to get the most power during WOT runs. Now we want to switch our focus to everyday driving.

## **GET A SMOOTH IDLE**

If you switched to larger injectors, you might want to raise the idle RPM by about 100 to keep the engine from stumbling.

You might want to also adjust your intake calibration in that area where the car idles. Do this the same way as before.

## **REQUESTED TORQUE (DRIVE BY WIRE CARS)**

This table establishes a relationship between the input from the gas pedal to the opening of the throttle plate. By adjusting this table, you adjust how much the throttle plate opens with a given input. The Target Throttle Plate Position tables have the desired throttle opening angles for different requested torque inputs. Notice that they are only scaled to a given value. Meaning on my ROM, the TTPP table is scaled only to 320. So if my requested torque is more than 320, the throttle will be open 100%. There really is no tuning method for this, just make small changes and see what kind of response you get. You're tuning for how the car "feels" while driving.

## **TUNE YOUR CRUISE VE AND TIMING**

Your cruise boost and AFRs are already tuned. You can't tune for boost since during cruise you are not making much boost and the amount you do make is dictated by your wastegate and turbo, nothing in the ECU. The AFRs are in closed loop, so the ECU is automatically trying to get them to 14.7. So now you just need to make sure you are not knocking anywhere in the map while cruising and that your VE is good.

To do this, you just use the spreadsheet made by merchGod found at:

[Spreadsheet to track Knock and VE \(RomRaider\)](#)

You just follow the instructions in the spread sheet and it will help you figure out where you need to add or pull timing during cruise and what to do with your VE.

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## All Done

I guess that should take care of most things. I've read tons of threads that I pulled bits of info out of. But the RomRaider forums are a great resource, Tea Cups, merchGod, mickeyd2005, Tgui, Clark tuner, and most of the senior guys know this stuff inside and out. So it'd probably be a good idea to read their posts and listen to their advice. I tried to keep a list of the sources that contained good amounts of info. The rest of the info I found scattered throughout posts.

## SOME MORE READING

[Turbocharger Compressor Calculations \(Turbo Regal\)](#)

[Compressor Maps \(zTechz\)](#)

[Heat Exchanger Theory and Intercoolers \(Turbo Regal\)](#)

[How intercooler's work and effect your engine \(Rap Worlds\)](#)

[Guide to boost controllers \(SPL Parts\)](#)

[Turbo dynamics and boost control explained \(RomRaider\)](#)

[Tuning Your Ford EFI System - Inside The Black Box \(Muscle Mustangs & Fast Fords\)](#)

[How Gasoline Works \(How Stuff Works\)](#)

[Closed Loop to Open Loop fueling transition explained \(RomRaider\)](#)

[Turbo Dynamics and boost control explained \(Nasioc\)](#)

[Subaru's Knock Control Explained \(Nasioc\)](#)

[Active Valve Control \(Subaru Drive magazine\)](#)

[Volumetric Efficiency \(Wikipedia\)](#)

[Let's talk AVCS tuning \(Nasioc\)](#)

[HOWTO: One Man's Way of Scaling a MAF \(Nasioc\)](#)

[AccessTUNER Tuning Guide \(Cobb\)](#)

[Emanage + GM Boost Solenoid \(3si.org\)](#)

[How to adjust the requested torque table \(RomRaider\)](#)

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## Advice Column

### TURBO DYNAMICS

#### From robbieshonda

Help with your turbo dynamics burst and continuous tables.

A lot of people get a rapid wastegate flutter. This is a way to fix this problem.

If your target boost tables is 18 psi for a given cell, and you over shoot that your ECU will pull boost by a given amount in the table. If your car is under boost targets and no knock etc. the ECU will add WGDCs to hit the target boost.

You should try taking both of those tables Burst and continuous, and multiply both by .50 which will cut the table in half.

This will generally help get rid of the rapid over boost under boost wastegate flutter.

VF series guys this can also help you as well. Yours is like mine, mainly just a weak spring but this will help smooth it out.

### AFRs

#### From williaty:

One thing I will touch on, though, is your section on AFRs. Stoich is not ideal for anything other than emissions. Stoich produces the lowest sum of hydrocarbons and oxides of nitrous. It's not the best for fuel economy (leaner than stoich is) and it's not the best for power (richer than stoich is).

The reason that richer than stoich is best for power is that, due to real-world imperfections in charge mixture, running an engine at stoich results in both excess oxygen and fuel in the exhaust stream. This is due to some of the oxygen and some of the fuel not being able to find each other in the combustion chamber. Oxygen is the thing it's hard to get into an engine so we want to be damned sure that we burn every last one of the buggers. To ensure this, we add extra fuel to make sure that none of the oxygen escapes alive.

For "normal" engines, this results in Mean Best Torque being somewhere in the ballpark of 13 to 13.5 AFR. Now, many engines, especially forced-induction engines, will have problems with knock at that AFR. By further enriching the mixture, the efficiency of the combustion can be reduced to the point that knock is easier to control.

Make sure you read that carefully, though. The increased resistance to knock is a result of reduced efficiency. So over-enrichment (richer than 12.5 or so) costs both fuel efficiency and power. However, it allows for higher boost and/or more timing. It's a trade off and different tuners will prioritize different aspects of that trade off. In the end, most theories on that compromise will end up making roughly the same power, just in different ways.

#### From 10-56

The best torque mix range is between 11.76 and 12.8.

Mean best torque is 12.28.

A good compromise Torque/Fuel Economy is 12.5

#### From brocksdad

I would like to add that even if the intake has not been changed, it would still be wise to check the MAF scaling. I have seen a couple STis that needed MAF scaling with only a stage 2 setup.

Also, I would have assumed that the SPT intake would not have needed any MAF scaling, but it actually needed quite a bit.

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## WASTEGATE

**From the suicidal eggroll (note that this has been incorporated into the write up, I made a mistake in the first version and fixed it after this post)**

Your description of how a wastegate works is incorrect, actually it's backwards. The input port on the wastegate is on the OTHER side of the diaphragm from your description, the pressure applied to this port is what opens the wastegate. Without this line attached, the wastegate would never open.

Your explanation of how to tune the wastegate duty cycle is correct, but what those changes are actually doing is again, backwards. There are three basic types of boost controllers bleed-style electronic, interrupt-style electronic and manual.

**Bleed-style electronic** - This is what the stock BCS is on our cars. The line coming from the turbo compressor outlet goes to T, one leg of the T goes to the wastegate and the other leg goes to the BCS. The other end of the BCS runs to the intake. With a wastegate duty cycle of 100, the BCS is open, allowing the air coming from the turbos compressor outlet to flow through the T, through the BCS, and back into the intake. The wastegate sees very little pressure, so it does not open. When the wastegate duty cycle is 0, the BCS is closed, forcing the air coming from the turbos compressor outlet to flow through the other leg of the T and straight into the wastegate. When the pressure applied to the wastegate is equal to the wastegate spring pressure, the wastegate will open. The bleed-style BCS controls how much pressure the wastegate sees by pulsing quickly, venting off some of the air coming from the turbo back to the intake, lowering the pressure seen by the wastegate.

**Interrupt-style electronic** - This is the Prodrive, Perrin, GM, etc. These are 3-port units (whereas the OEM is a 2-port). When the BCS is at rest, air can pass between port 1 and port 2, but not 1-3 or 2-3. When the BCS is energized, air can pass between port 2 and 3, but not 1-2 or 1-3. By attaching the turbo outlet to port 1 and the wastegate to port 2, we get the interrupt-style BCS. When the wastegate duty cycle is 0, the BCS is at rest, so air can pass freely between ports 1 (turbo) and 2 (wastegate). This means the wastegate sees the full boost pressure and will open as soon as it hits the wastegate spring pressure. When the wastegate duty cycle is 100, the BCS is energized, so air can pass freely between ports 2 (wastegate) and 3 (outside air). The wastegate sees zero pressure, and will not open. The advantage of this type of BCS is at high duty cycles, when the BCS is trying to keep the wastegate closed. In the bleed-style, the wastegate will ALWAYS see some boost pressure, the farther the WGDC is from 100, the more pressure it will see, which means it will begin to crack open pretty soon, well before you reach target boost. In the interrupt-style, the wastegate sees no boost pressure until the BCS wants it to, allowing you to build boost faster.

**Manual** - This is a very simple, very robust style boost controller. It is simply placed in the line between the compressor outlet and the wastegate (compressor outlet to BC, BC to wastegate). The BC creates a pressure drop in that line, essentially creating a pressure drop at the wastegate. This means that if the turbo is putting out 15 psi, and the BC is set at +5 psi, the wastegate will see 10 psi. The setting of the boost controller is always "+X psi", X being the amount of pressure the BC drops. They are not complicated, but they get the job done very effectively. The only downside to them is you are always set up to run the full boost that the MBC is set for. Partial throttle, 3/4 throttle, full throttle, your target boost is always the same. With a large turbo where you can control the boost pressure through the throttle quite easily this is fine, but for a small turbo that hits full boost early and easily, it can be a PITA to drive around. The EBC lets you set different target boost levels based on RPM and throttle position, the MBC does not.

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## ADDITIONAL READING

From williaty

Try **Engine Management: Advanced Tuning** by **Greg Banish** as well as the less useful **How to Tune and Modify Engine Management Systems** by **Jeff Hartmann**. Both discuss LBT/MBT/RBT. Banish does it more in terms of the theory of why you should do it that way, Hartman does it more from the perspective of finding the actual value for that car on the rollers.

Additionally, **Innovate Motorsports** has some very good whitepapers on their site about it.

## Revision History

Ver	Who	What	When	Why
0.0	Wideboy	Creation	17 Mar 2009	First version from web post
0.1	Bad Noodle	Review	24 Mar 2009	Additions and correction
0.2	Wideboy	Format	25 Mar 2009	Reformatting and clarification
0.3	Bad Noodle	Review	26 Mar 2009	Review/corrections/additions (minor)
0.5	Bad Noodle	Corrections	31 Mar 2009	Incorporated Corrections suggested by Tea Cups