How Subaru's Factory Boost Control System Works

This document is intended to assist you with the understanding of how turbo boost pressure is controlled on an internally (or externally) wastegated turbocharger through the factory boost control system. This document will show how to properly set-up or calibrate your internally or externally wastegated turbocharger so that the boost pressure can be properly controlled by the stock boost control system. This document is broken down into four chapters; Hardware, Plumbing, Hardware Function, & Mechanical Calibration. Please read the following thoroughly before you attempt to tune your Subaru with the AccessECU software. In the AccessECU StreetTUNER or ProTUNER software, Descriptions and Tuning Tips for most of the tables are provided and can be accessed by pressing the "F1" key while that table is highlighted in the Table List.

We would like to go into further detail about the safeguards and advanced tuning features that are available through the AccessECU software. The boost control system uses a closed-loop targeting system which does everything it can to make the boost control system consistent. By employing this closed-loop boost control system the electronic control unit (ECU) can use its speed to bring down boost in overboost situations and raise the wastegate duty cycles for underboost situations. The stock boost control system is much faster than any human analysis and input; we highly suggest you use it to your advantage. In some vehicles, the boost control system can set higher boost targets up to a certain miles per hour (MPH) or bring boost targets down after a set MPH. Some vehicles allow you to tune boost by the different gears you are operating the motor in. Most critical is the fact that the **ECU** (on DBW vehicles) **forces the boost control system to shut down completely** (so the vehicle runs mechanical boost pressure) **if detonation events are continuing to occur**. This bit of safeguard makes the factory boost control system far superior to any aftermarket boost control system, IMO. Once the stock boost control system is fully understood, you will find it easy to tune on internally or externally wastegated turbos.

Chapter 1 – Hardware

Turbo - An exhaust driven air compressor which consists of four basic sections or components. The compressor section consists of the compressor housing and the compressor wheel. This section acts as the inlet or intake for the turbo, compressing the intake charge and generating relative pressure (boost). Generally speaking the inlet is always in a vacuum, sucking air in and the outlet is pressurized with the intake charge. Next is the center section which contains the bearings, shaft, and the oil and anti-freeze passage ways; the compressor and turbine wheels are also attached to the shaft in this section. The third section is the turbine section which consists of the turbine wheel and turbine housing. This section also contains a machined by-pass for the wastegate valve to seat against. The last component of a turbo charger is the wastegate valve and wastegate actuator which control the wastegate valve's movement. We highly recommend that you use a turbocharger which has both an oil and water cooled center section; turbocharger longevity is compromised when only oil is used to cool the turbocharger center housing.

Wastegate Actuator - A spring/diaphragm based mechanism which controls the movement of the wastegate valve. A turbo wastegate is normally closed, forced shut by a compressed spring inside the actuator canister. As pressure is applied to the nipple of the canister, the wastegate shaft moves away from the actuator, swinging open the wastegate valve.

Wastegate Solenoid Valve - An electromagnetic solenoid which controls the air flow from the wastegate actuator to the turbo inlet. This device is normally closed when no voltage is applied. When 12V direct current (DC) voltage is applied, by the drivers in the electronic control module (ECM), to the wastegate solenoid valve, it fully opens allowing air to pass through the device. A 0% Wastegate Duty Cycle (WGDC) setting will allow the solenoid to stay fully closed; which will force the turbo to run mechanical boost pressure. A 100% WGDC setting will force the solenoid to stay fully open; which will force the turbo to run maximum boost pressure.

Vacuum Lines - Rubberized or silicone tubes attached to various components in the engine assembly. For this article we will be concerned with the six attachment point and the four sections of vacuum line plumbing and adapters which we will cover in Chapter 2.

Restrictor Pill - A small pill made of brass which contains a precision machined lengthwise hole in the center.

ECU - Also known as an ECM, PCM, EEC, EMS. The Engine Control Unit contains the processors, drivers, and logic which is calibrated to control the relative pressure (boost) via wastegate solenoid duty cycle.

Chapter 2 – Plumbing

We will break down the plumbing of the factory boost control system into four sections of vacuum lines/adapters and six attachment points. Please look at the following picture where we have four basic lengths of vacuum line and six attachment points labeled. Three of the lines are pressurized while the vehicle is under load, and one vacuum line, which goes to the turbo inlet tube, is under vacuum while the turbo sucks in air.

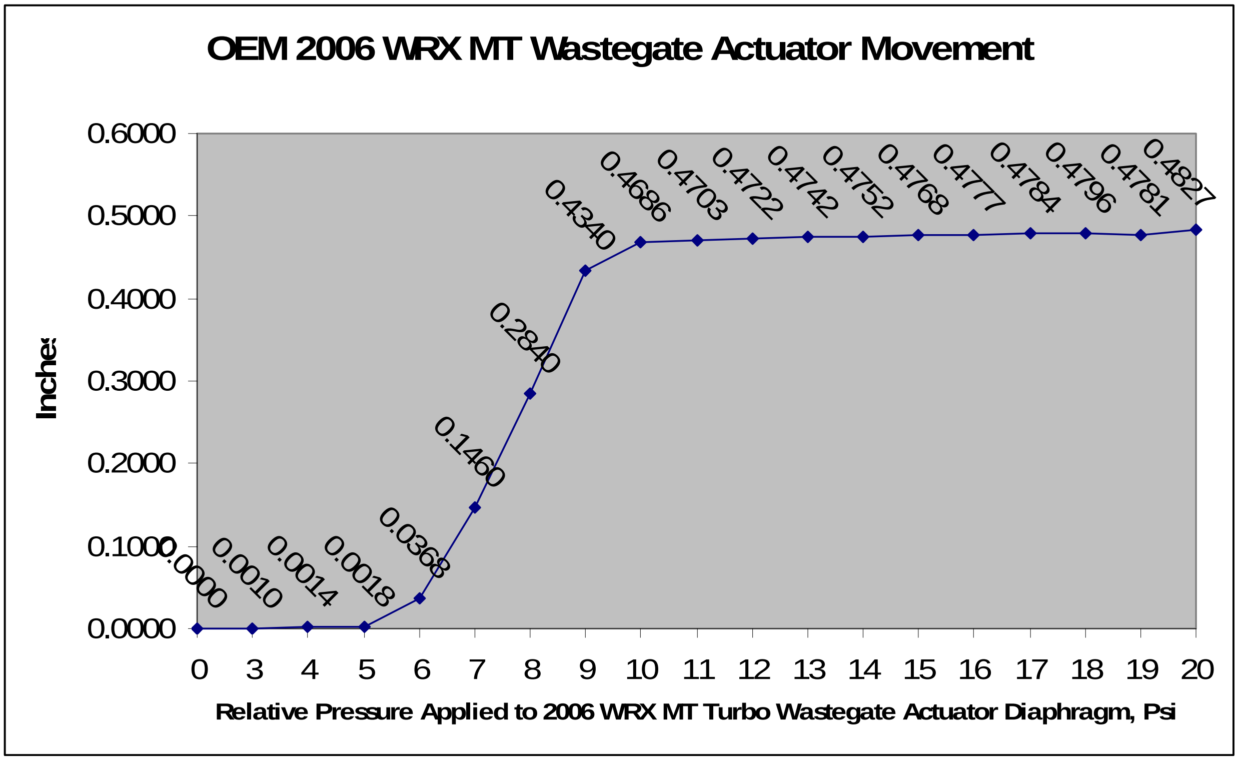
Line 1 plumbs the compressor housing to one end of the T-fitting. This line contains the brass restrictor pill.
Line 2 plumbs the wastegate actuator to the opposite end of the T-fitting.
Line 3 plumbs the middle of the T-fitting to the wastegate solenoid valve.
Line 4 plumbs the other side of the wastegate solenoid valve to the turbo-inlet pipe.

NOTE: You will notice your factory boost control system has more than four vacuum lines, because the factory uses couplers to connect the different size nipples to one section of line. For all intensive purposes you still only have four sections of line.

Chapter 3 – Hardware Function

Turbo - The function of a turbo is to compress the intake charge, creating a greater volumetric efficiency for the internal combustion motor.

Wastegate Actuator & Wastegate Valve - A wastegate actuator's function is to control the wastegate valve. The wastegate valve manages the exhaust energy being directed into or by-passing the turbine housing. If the wastegate valve is fully closed, more exhaust energy is directed into the turbine housing causing the shaft speed of the turbo charger to increase and the relative pressure (boost) to increase, all within the efficiency range of the turbo. If the wastegate valve is opened the exhaust energy by-passes the turbine wheel and goes into the downpipe so that the turbo shaft speed decreases or remains constant. Opening the wastegate valve will generally lower relative pressure (boost) produced by the turbo. Below is a line graph demonstrating the rod movement of the wastegate actuator arm as pressure is applied to the canister nipple.



NOTE: The MORE boost you run, the LESS wastegate you need/use. So unless you want to run less pressure than stock and/or have un-tunable boost problems, we suggest that you do not port your wastegate by hand. We suggest you leave your wastegate, the area around it, the turbine housing, etc. alone and tune your boost curve through the proper means.

Wastegate Solenoid Valve - The function of this device is to control the amount of air pressure being bleed away from the wastegate actuator.

Restrictor Pill - This component limits the amount of pressurized air flowing from the turbo compressor housing. The restrictor pill restricts the air flow so the wastegate solenoid valve and wastegate actuator are not overdriven, which would force the wastegate valve to open prematurely.

Vacuum Lines - Vacuum lines plumb pressurized air to the proper components so the Subaru boost control system works properly.

ECU - This is the master device which controls the wastegate solenoid valve, the slave device, so that the targeted relative boost pressure is obtained.

The factory boost control system bleeds pressure away from the wastegate actuator to the intake or turbo inlet pipe. With this device set at 0% wastegate duty cycle through the ECM calibration, all of the air pressure generated at the compressor housing will be applied to the wastegate actuator forcing the wastegate valve to fully open. When the wastegate actuator is fully open, the vehicle will run mechanical boost pressure which can be anything from 7-11psi on original equipment manufacturer (OEM) turbochargers. When this device is programmed to 100% wastegate duty cycle through the ECM calibration, all of the air pressure generated at the compressor housing will be allowed to by-pass to the wastegate actuator allowing the wastegate valve to close. The flow is limited by the size of the hole in the restrictor pill located in the first vacuum line attached to the turbo compressor housing. The wastegate valve will only close as much as it can (taking into consideration that the exhaust gas pressure between the exhaust port and the turbocharger is generally greater than the manifold pressure the turbo is generating) with the exhaust gas pressure pushing on the wastegate valve.

NOTE: If you run a turbocharger beyond it's compressor efficiency range, it will turn into a flame thrower.

Chapter 4 – Mechanical Calibration; Mechanical Tuning and Boost Control System Calibration Using the AccessECU StreetTUNER Software

Mechanical Tuning

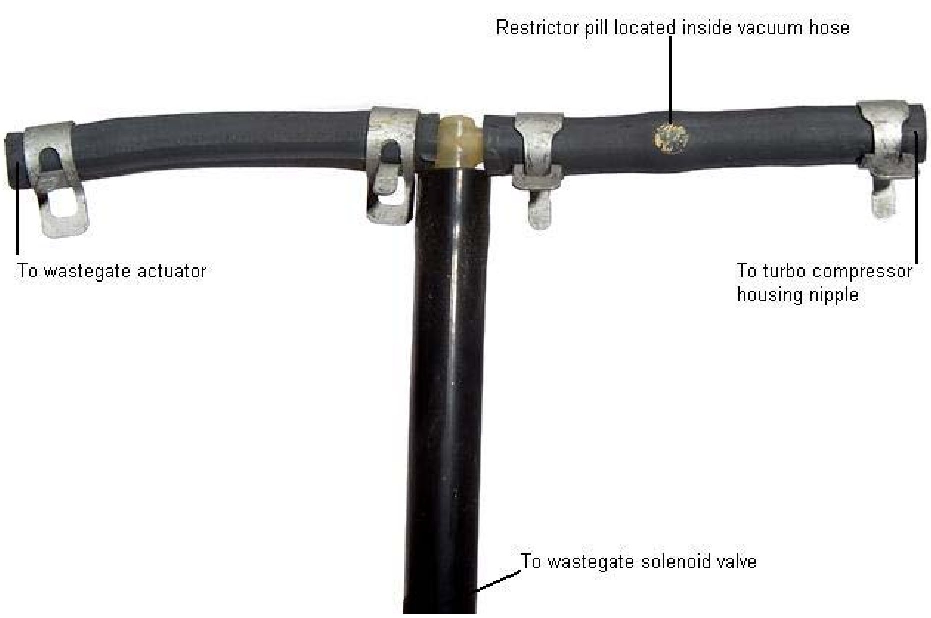
Changing the size of the center hole in the restrictor pill; the vacuum lines for the factory boost control system contain a small brass restrictor pill located in the short vacuum line coming off the turbo compressor housing. The middle of this restrictor pill has a lengthwise hole precisely machined to a certain specification so that it works with the factory wastegate actuator and the wastegate duty cycle settings in the stock ECU. The size of this center hole can be changed in order to mechanically assist boost control.

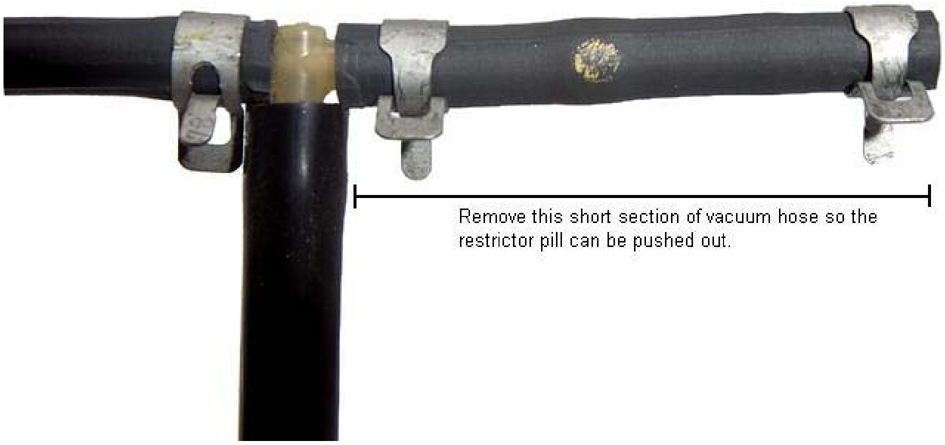
A smaller diameter hole in the center of the brass restrictor pill will have a higher tendency to create boost spike in the system and require less wastegate duty cycle to run higher boost. The larger the diameter hole in the center of the restrictor pill, the less chance the boost control system will boost spike and greater wastegate duty cycle will need to run in order to produce higher boost. If you have a stock turbo and are running an AccessPORT map, you have no reason to modify your restrictor pill. If you have installed a new turbocharger and you are using the stock boost control system to tune boost, please verify that the vacuum line coming off the turbo compressor housing (prior to the T-fitting) contains a restrictor pill with a hole machined in the center of the pill.

The stock boost control system most commonly uses a restrictor pill with a center hole size of 0.040"-0.048" +/- 0.001"

For larger-than-stock turbochargers or turbochargers with a stronger mechanical spring in the wastegate actuator you will need to use a restrictor with a larger center hole, something along 0.050"-0.055" +/- 0.001"

For similar-to-stock-sized turbochargers with a weaker mechanical spring in the wastegate actuator you will need to use a restrictor with a smaller center hole, something along 0.030"-0.040" +/- 0.001". Be very careful when using a restrictor with a center hole of this size, there is a higher tendency for the system to boost spike and you will need less wastegate duty cycle to run higher boost.





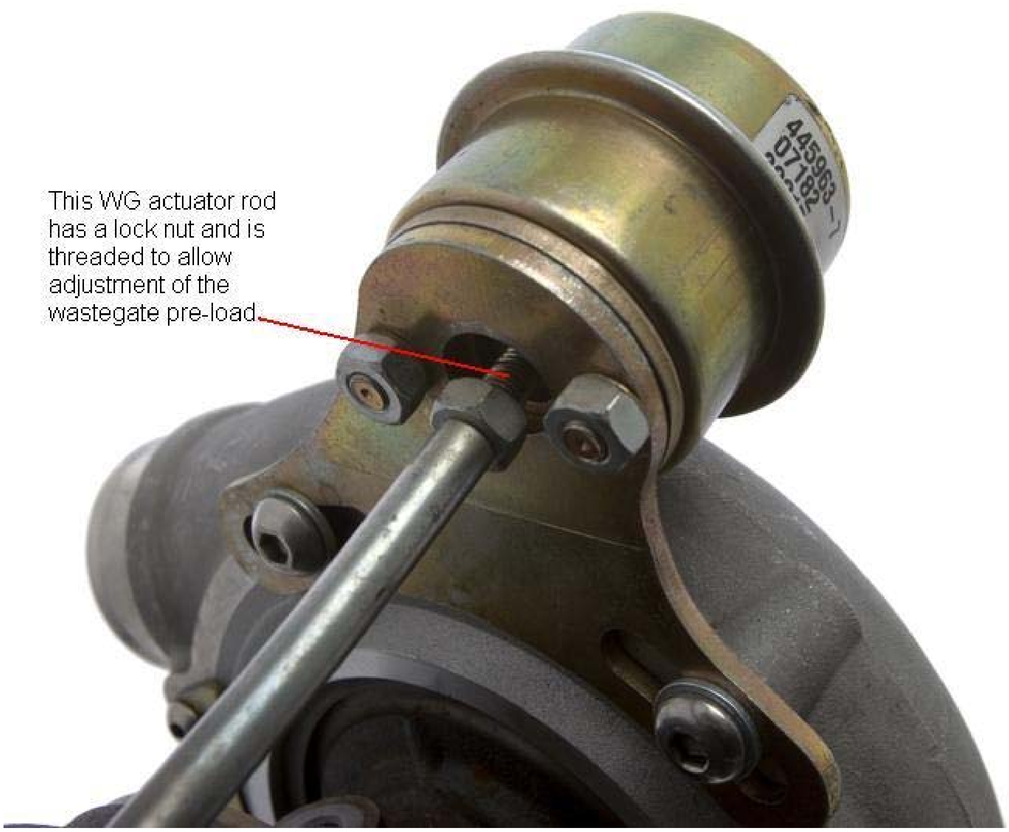
Carefully insert straight pick into the center of the restrictor pill and gently push out the brass restrictor pill. Be sure not to poke or rip the vacuum hose.

After the restrictor pill has been properly modified, be sure to insert the pill so that it does not block the air path. If this vacuum line is blocked the turbo will very quickly overboost and potentially cause severe engine damage.

The restrictor pill should fit tightly inside the vacuum line
and should have the hole machined in the center of the pill.

NOTE: The hole in the restrictor pill can always be machined to a larger diameter. Be sure to make very small increases in the diameter of the hole. If the center hole is machined too large you will not be able to hit your boost targets…even with 100% wastegate duty cycle.

The location of the threads can be located at either end of the wastegate actuator rod, see the below picture where it demonstrates the threaded section is closest to the WG actuator diaphragm.



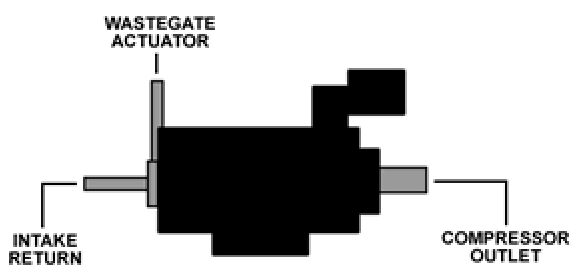
Pre-loading the wastegate actuator arm; adjustment of the wastegate actuator rod (if the rod length is not fixed and adjustments can be made) will allow proper calibration and some additional tuning as well. All IHI turbochargers have a fixed wastegate actuator rod that cannot be adjusted, while all MHI turbochargers have an adjustable wastegate actuator rod. If the rod coming out of the wastegate actuator is shortened, it will pre-load the spring inside the wastegate actuator increasing the pressure level at which the actuator will allow the wastegate valve to open and the total boost pressure that the turbo can generate will increase (as long as the turbo is still within its efficiency range). This pre-load will also limit how far the wastegate valve can open. Pre-loading (shortening) the wastegate actuator rod too much CAN POTENTIALLY CREATE A MECHANICAL BOOST CREEP ISSUE THAT CANNOT BE TUNED OUT! If the wastegate actuator rod is lengthened, the actuator will decrease the load on the spring and decrease the pressure level at which the actuator will open and the total boost pressure the turbo can generate will decrease. If the wastegate actuator rod does not put enough pre-load on the wastegate valve, then you could see boost fluctuations of + or – 2psi even when the wastegate solenoid duty cycles are constant. If you have a stock turbocharger then you should not have to adjust the wastegate rod length.

NOTE: The larger diameter wastegate valve a turbo has, the more difficult it is to stabilize boost pressure as the valve initially opens. This is also true for greater exhaust gas back pressures created by a smaller A/R on the turbine housing.

Electronic Tuning Through ECU Calibration

The stock boost control system can be used to control boost on properly designed internal and external wastegated systems. If you have a turbocharger with a properly designed internal wastegate valve/actuator that has been properly calibrated using the correct size restrictor pill and wastegate pre-load you will be able to use the factory boost control solenoid.

NOTE: If you are tuning with an external wastegate, we have found that the Pro Drive electronic boost control solenoid (EBCS) works perfectly with the stock compensatory wastegate calibrations (coolant, intake air temperature, etc.). This solenoid is a replacement for the stock EBCS and plugs in to the factory wiring harness. Tuning external wastegates with the factory boost control system (ECU) has worked very well as long as you use the Pro Drive EBCS. Please refer to the below picture so you know how the plumbing of the Pro Drive EBCS should be set-up. With the Pro Drive EBCS you WILL NOT NEED TO USE ANY RESTRICTOR PILL!



You must be made aware that tuning the boost control system is the most difficult tuning you will perform on your Subaru. TUNING THE BOOST CONTROL SYSTEM IS ALSO GOING TO TAKE THE LONGEST TIME TO COMPLETE. Although, once you are finished tuning your boost control system you will be very appreciative of the complexity and capability of the OEM boost control system. The OEM boost control system is much faster than any human input so we highly suggest you start with lower wastegate duty cycles than you may need and work your way up from there. The boost curve and the stability of the boost curve must be established in order to allow you to properly tune all tables from this point on. The mass air flow (MAF) signal has a major influence on the ignition advance and fuel curve since this signal is the major component used by the ECU to calculate engine load.

Subaru boost control systems employ a closed-loop, targeting system for tuning boost. You must first establish your boost targets in the **Boost Targets** table. Running these boost targets is going to be the primary goal for the ECU. The ECU will start by using the wastegate duty cycles established in the **Wastegate Duty Cycles (Low & High)** table(s). Some Subaru ECUs use a single Wastegate Duty Cycles table and some use two, Wastegate

Duty Cycles Low and Wastegate Duty Cycles High. *If your ECU uses the Low and High Wastegate Duty Cycles tables, we suggest you set your Wastegate Duty Cycles Low table ~8% lower than the Wastegate Duty Cycles High table for the corresponding Throttle Position and revolutions per minute (RPM). We have composed a worksheet called the "AccessECU Calibration & Tuning Guide Worksheet for Subarus" which has various tabs set up to assist you with the Low and High WGDC calculations.* The ECU will then use the **Turbo Dynamics** tables to adjust the wastegate duty cycle in order to achieve the dictated boost targets. Other compensatory boost and wastegate tables are also used by the ECU to fine tune boost for environmental changes, temperature, barometric pressure, etc. If the wastegate duty cycle values are too low, you will not achieve your target boost pressure. If the wastegate duty cycle values are too high, you will overshoot your boost targets and potentially damage the engine. We do not suggest you run a wastegate duty cycle of more than 90% to prevent overheating or lock-up of the wastegate solenoid, and to promote the longevity of the wastegate solenoid.

While tuning the boost control system you will want to datalog and/or view your RPM, Throttle Position, Wastegate Duty Cycle, Relative Pressure, and Turbo Dynamics % values so you can see what your ECU is actually doing to achieve its boost targets. The further your turbo dynamics % is from zero, the further off your wastegate duty cycles are from ideal. When your boost targets are too high or too low for that particular RPM and throttle position sensor (TPS) point to achieve your boost target, your wastegate duty cycles are not close enough to where they need to be. We suggest you tune so that your turbo dynamics % is a small (10% or less) positive number across the RPM range.

If your datalogged turbo dynamics value is a negative value, then your ECU is removing wastegate duty cycle to hit your boost targets. This is due to the engine over-boosting; the pressure measured at your intake manifold is higher than what is dictated in the Boost Targets table for the given RPM and TPS values. If your boost is surging up and down, then your boost control is searching because it is grossly overshooting its target. If your datalog shows a negative value for turbo dynamics, the ECU will use the additional authority in the negative portion of the **Turbo Dynamics** tables to lower WGDC until the target boost is achieved.

If your datalogged turbo dynamics value is a positive value, your ECU is adding wastegate duty cycles to hit your boost targets because the engine is under-boosting. If your datalog shows a positive value for turbo dynamics then the ECU will use the additional authority in the positive portion of the **Turbo Dynamics** tables to increase WGDC until the target boost is achieved.

If you are increasing or holding wastegate duty cycles steady and boost is dropping, then you have most likely reached the threshold of the mechanical efficiency of the turbo or your exhaust gas back pressure prior to the turbo is too high and is forcing the wastegate valve to open.

If you are having a small boost spike, you may need to decrease the WGDC percentage a few hundred RPM prior to the overboosting event to allow the exhaust energy to be released past the turbine wheel.

NOTE: With porting a wastegate, you are trying to make the wastegate valve function potentially work better. This means that your turbo is going to lower boost super fast when the wastegate door/valve opens or not run as much boost as it was engineered to. If you make your wastegate react quicker, boost will be very difficult to stabilize and reach peak #s at an earlier RPM. If you make the wastegate flow better, then the exhaust energy your turbo needs to make and maintain boost will have less opportunity to flow across the turbine wheel. Generally speaking, air/pressure/exhaust gases will always flow along the path of least resistance. Not bashing, just trying to give you a different perspective.

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