

GPRP PRO

SETUP & TUNING GUIDE

Note: *This guide applies to GPRP Pro firmware version 1.06.1177 and later.*

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OVERVIEW

MoTeC's GPRP Pro Packages are based around a torque model that allows users to implement torque aim, management and reduction strategies through throttle, ignition or fuel control. This firmware is sophisticated in operation and targeted for use in professional motorsport. Users will need to have a strong understanding of engine operation principles to use it effectively.

Those familiar with MoTeC's targeted Packages for the Nissan R35 and Lamborghini Huracan will note similarities in operation and control strategies. These advanced features have been implemented in this General Purpose, paddle shift-capable Pro platform.

This document describes the principles of operation of GPRP Pro and GPRP-DI Pro. It will help with configuring and tuning these Packages, and briefly covers the torque model and the control strategies that use it. It is not a migration guide for moving a tuned GPRP Package to GPRP Pro. The control strategies can be very different, so while a tuned GPRP calibration cannot simply be transferred, some parts like the main setup, efficiency and ignition tuning can be migrated to form a starting point.

Pro firmware is not compatible with all applications. The GPRP Pro and GPRP-DI Pro datasheets should be checked for compatibility - find them at our website.

Some features of GPRP Pro are not yet detailed in this guide. Revised versions may be uploaded from time to time so be sure to check our website regularly.

USING THIS DOCUMENT

Parameters and tables are listed as the actual name in the GPRP Pro Package and are represented in blue in this guide.

Green text in this document can refer either to a specific Worksheet in M1 Tune, or in the case where a dedicated Worksheet may not yet exist, this refers to the name of the subsystem. Setup information must be entered into the parameters and tables. A specific parameter or table can be found using the search box at the top of each Calibrate box on a Worksheet.

A live channel is the direct feedback from a sensor or function calculation. This can be a sensor reading like air pressure, or an enumerated result of a state group or diagnostic group, and will be listed in orange.

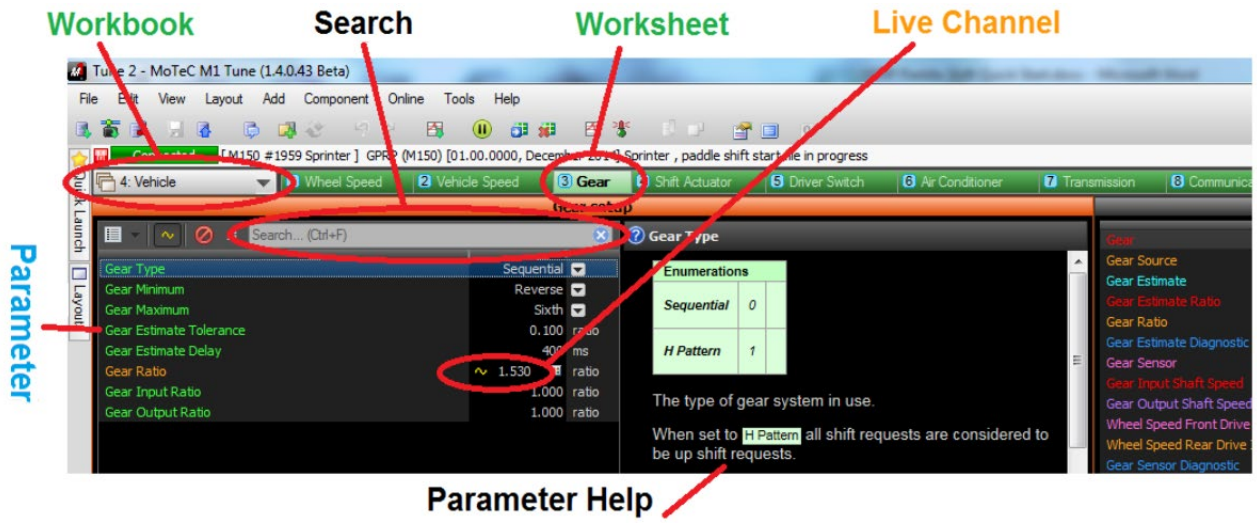


Figure 1.

Help for a specific parameter or table will appear whenever that parameter or table is highlighted by clicking on it. The Help can also be accessed by pressing **F1** or by going to **Help > Firmware Help**. Any parameter or table with a green **Q** next to it has a hotkey adjust function assigned to it, which can range from a read value to a function toggle or a calibrate operation. The particular function will be described in the Help.

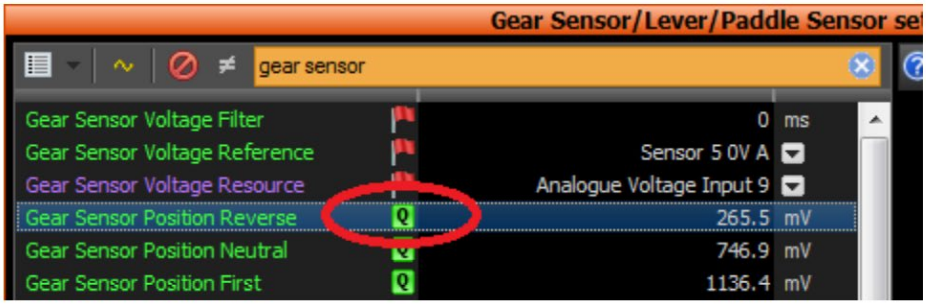


Figure 2.

Note: Due to updates in ECU Packages, some items in this document may move to a different Worksheet. If you are unable to locate parameters/tables, use the Search function in an All Worksheet; these will be in most Workbooks.

TORQUE MODEL

One of the key characteristics that sets GPRP Pro apart from other firmware in the GP suite is the use of a Torque Model, which is central to the way many of the control strategies operate.

Using a torque strategy is beneficial because it is relatable to other tuning aspects, such as acceleration. Engine cylinder cut events or ignition timing changes are also relatable to a reduction in torque, so implementing such a model allows multiple methods of controlling torque to be integrated together with predictability.

The torque modelling in our Pro Packages is simplified as much as possible for ease of tuning, and while there are many factors that affect torque in a small way that are not compensated for in the implemented model, this is of no concern for fuel and ignition control and it is well suited for the intended purpose.

As torque is related to airflow, the throttle position is derived from the Torque Aim system. For example, in most systems the Throttle Pedal sets a Throttle Servo Position Aim, but in GPRP Pro it sets a Torque Aim (Throttle Pedal Torque Aim). This gives a more linear and consistent throttle response. Likewise, systems that command a Throttle Aim in other GP Packages, such as Anti Lag, command a Torque Aim in GPRP Pro.

Torque Generated

The amount of torque the engine produces is closely linear to the mass of air inducted into the engine for each firing. The model is based on Engine Load (mass of air per induction), which is calculated by the Engine Efficiency model for fuelling. Engine Load is converted to torque using the Torque Ideal Generated Scale parameter. Adjust this parameter so that the modelled torque matches the measured engine torque output.

Torque Ideal Generated Scale defines how many milligrams of Engine Load are needed to generate one newton metre (Nm) of torque in one cylinder (mg/Nm/cylinder). The result is multiplied by the number of cylinders to give Torque Ideal Generated. A typical value is 12 mg. For example, with a scale of 12 mg and an Engine Load of 600 mg, each cylinder generates 50 Nm, so a 6 cylinder engine generates 300 Nm.

Torque Ideal Generated includes all torque generated by combustion. It does not include internal friction or the torque used to drive ancillaries such as the alternator, water pump, power steering pump, A/C compressor and oil pump. These are handled by the corrections below.

Torque Loss via Friction

The Torque Ideal Correction Internal Loss table corrects for the engine's internal friction and internal drives such as the camshafts, oil pump and water pump. It is referenced to Engine Speed and Coolant Temperature. It is the torque needed to turn the engine over when it is producing no flywheel torque, so values are negative.

External and switched loads are calculated separately in the Torque Ideal Correction External Loss channel. This combines the alternator, the A/C compressor, the cooling fan and power steering .

Additional losses occur at high cylinder pressure, from piston to bore friction and from piston ring friction. The optional Torque Ideal Correction Engine Load table, referenced to Engine Load, compensates for these. Calibrate it to 0 Nm in overrun and at light load, because those losses are already covered by the Internal Loss table.

The sum of these values is reported in Torque Ideal Correction.

Tuning the Internal Loss table. Idle control aims for 0 Nm of flywheel torque, so this table is effectively the feed forward for idle control. If the throttle is too closed to idle properly, make the value more negative so more throttle opening is needed. A quick adjust (Q) function is provided on this table. It sets the value that makes Torque Modelled Corrected equal 0 Nm at idle, and allows for any ignition retard applied by idle control.

Torque Ideal and Timing Gain

The resulting value is Torque Ideal: the flywheel torque produced by the inducted air, assuming optimal ignition timing, correct fuelling and no cuts. The final Torque value applies corrections for ignition timing retard (Torque Ideal Ignition Timing Correction), fuel and ignition cut (Torque Ideal Cut Correction) and Nitrous Torque.

Modelled torque. A second set of values is calculated from the modelled manifold pressure (Inlet Manifold Pressure Modelled). Torque Modelled is the modelled equivalent of Torque Ideal, and Torque Modelled Corrected is the modelled equivalent of Torque. The throttle based torque control works on the modelled values only, so the Torque Aim directly controls Torque Modelled. Any difference between Torque Modelled and Torque Ideal comes from model tuning, mainly the Throttle Area table and the Engine Efficiency Main table.

The torque reduction due to ignition timing retard is assumed to be linear to simplify calibration. Torque Ideal Ignition Timing Gain sets the percentage of torque reduction per degree of retard from Ignition Timing Optimal. Ignition Timing Optimal is the Ignition Timing Main value (including any alternative fuel timing) before the trims and compensations that reduce torque. Advancing the timing past optimal does not increase the modelled torque. A typical gain is 1.3%/°. The same gain is also used in reverse by Torque Reduction to calculate how much retard is needed to achieve a requested torque reduction.

In a simplified example (excluding internal loss), where the Torque Ideal Ignition Timing Gain value is 1.3%/° :
20° RTD would reduce torque by 26%, so if Torque Ideal was 400 Nm, the Torque would be 296 Nm, 26% less.

The model also presumes optimum Ignition Timing is tuned in the Ignition Timing Main table. If ignition timing is reduced to prevent knock, the calculated torque will be noticeably greater than actual torque. This higher calculated torque during knock is not normally a concern and has minimal impact on the control systems in almost all operating conditions.

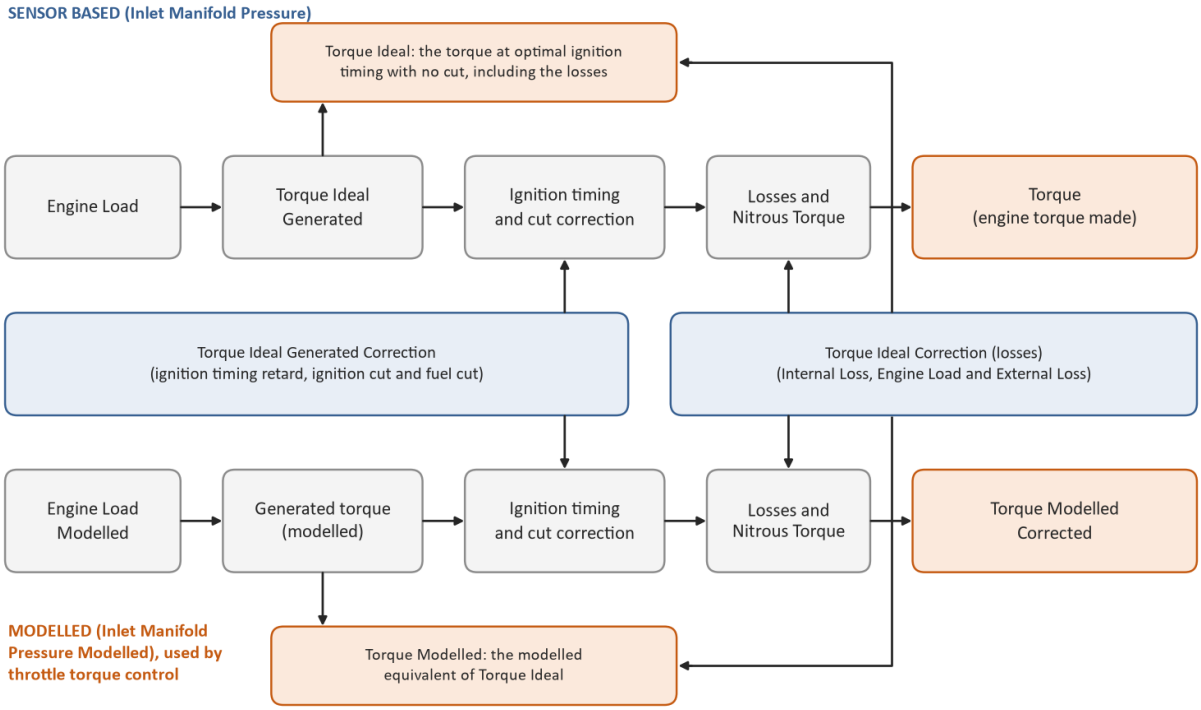


Figure 3. The torque model. Engine Load is converted to Torque Ideal Generated, corrected for ignition timing and cut, then the losses (Torque Ideal Correction) are added. The same calculation runs on Engine Load Modelled to give Torque Modelled and Torque Modelled Corrected.

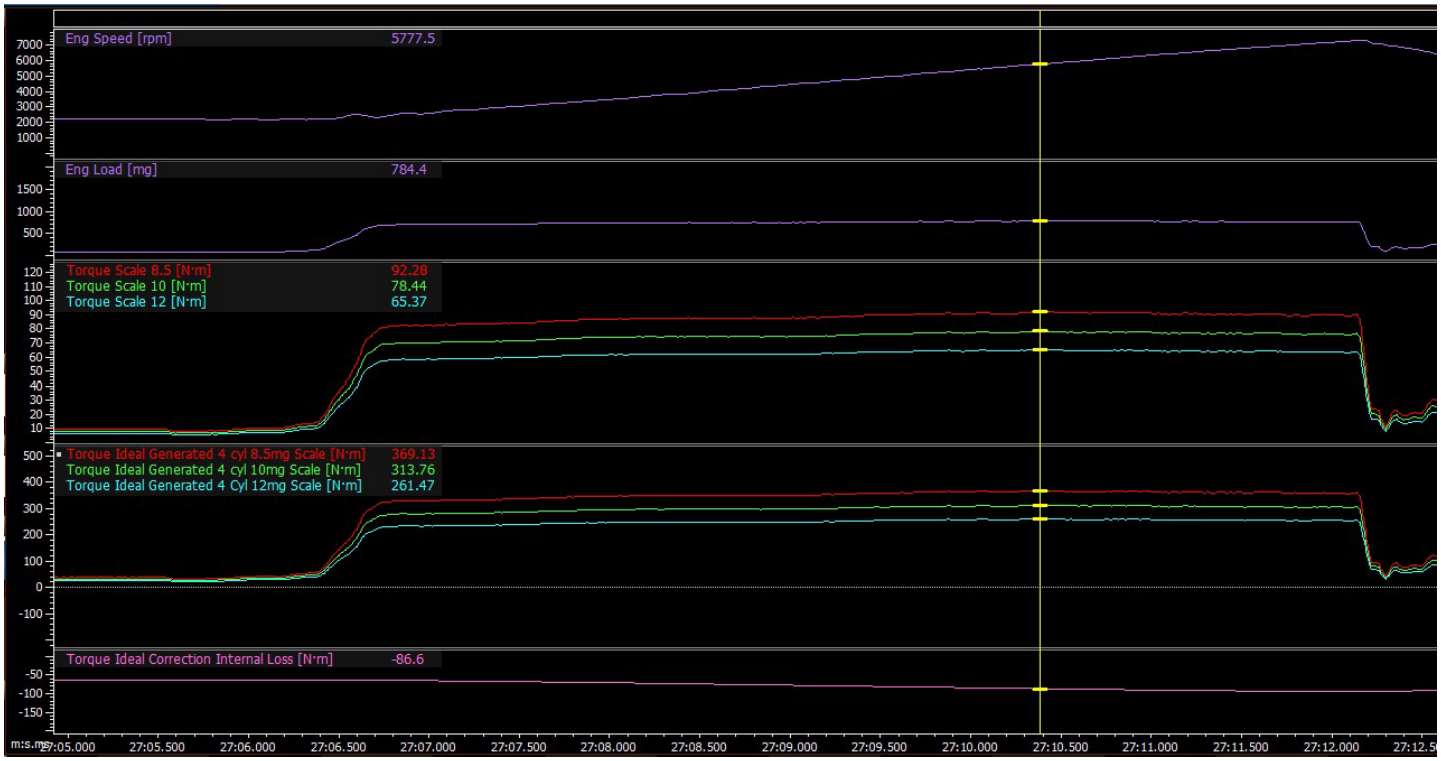


Figure 4. Example of the influence Torque Ideal Generated scale can have on Torque Output. Use case is a 4 cyl engine.

THROTTLE MASS FLOW AND MANIFOLD PRESSURE MODELLING

The Throttle Mass Flow and Inlet Manifold Pressure model is a complex array of mathematics to determine a very accurate Inlet Manifold Pressure without physically measuring it. The advantage of modelling over measuring is primarily the clean and very responsive result achieved. The modelled values are used for all Torque Limiting and Torque Aims for this reason.

An example of the difference between the modelled and measured manifold pressures is shown here:

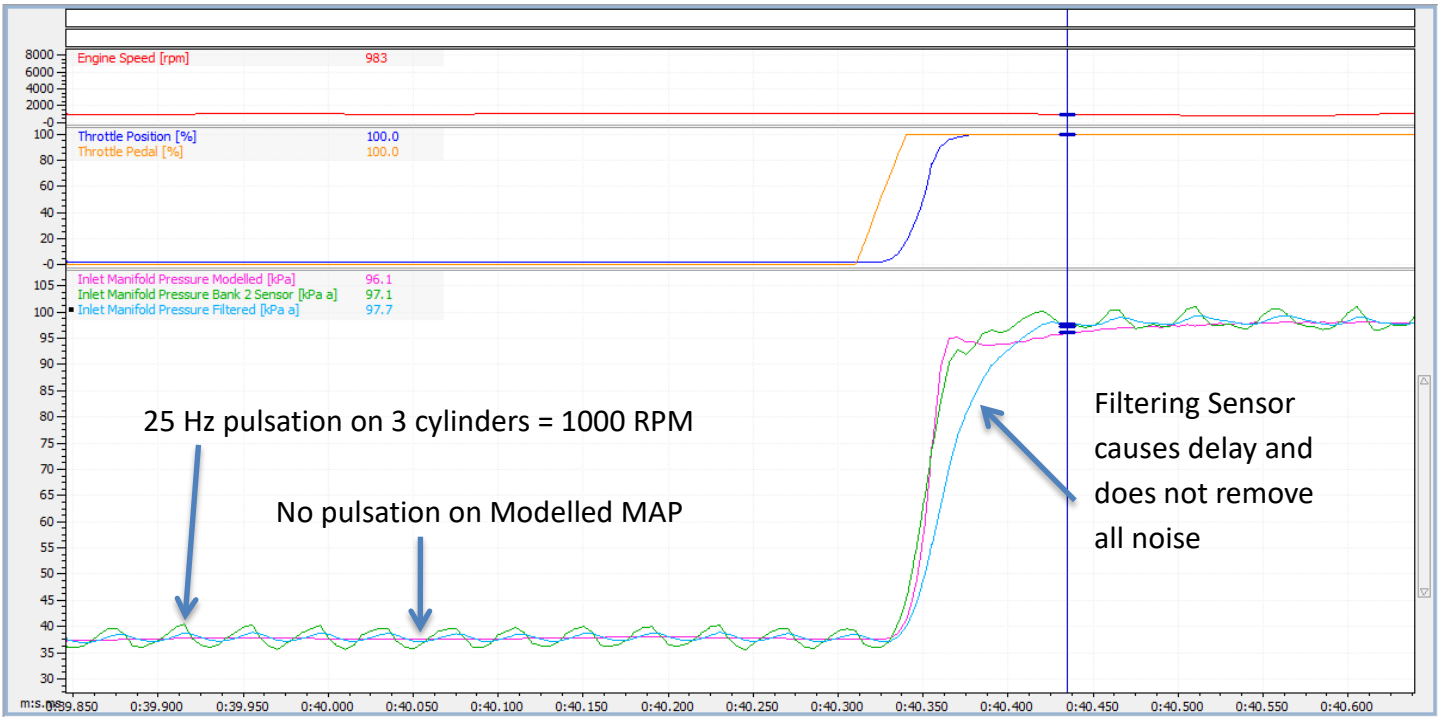


Figure 5. Example of a 6 cylinder dual plenum engine. One bank of 3 cylinders.

Basic Principle

Inlet Manifold Pressure Modelled is calculated from the mass of air flowing into the manifold through the throttle (Throttle Mass Flow) and the mass of air flowing out of the manifold into the cylinders (Inlet Mass Flow Modelled).

If there is a greater mass of air flowing into the manifold than flowing out then the manifold pressure must be rising. If the mass of air flowing into the manifold is less than the mass flowing out then the manifold pressure must be falling. If the mass in and out is equal then manifold pressure remains constant.

This calculation is very stable due to its self balancing nature. If Throttle Mass Flow is increased by opening the throttle, Inlet Manifold Pressure rises and in turn raises the Inlet Mass Flow to the point where the flow in and out is equal and the pressure stabilises. Likewise, if Throttle Mass Flow decreases with the throttle closing, Inlet Manifold Pressure falls and the Inlet Mass Flow also falls until pressure and flow stabilises.

Throttle Mass Flow

The Throttle Mass Flow is a separate model used in conjunction with the Inlet Manifold Pressure model.

To calculate the Throttle Mass Flow, the pressure ratio across the throttle is used. This uses a combination of the Boost Pressure, Inlet Manifold Pressure Modelled, Throttle Position and Throttle Area table to calculate the flow.

The resulting value can be proportionally substituted by the Airbox Mass Flow sensors by setting the Throttle Mass Flow Kalman Gain table appropriately.

Inlet Mass Flow

The mass of air flowing out of the manifold, past the valves and into the cylinders, is the Inlet Mass Flow. The model uses Inlet Mass Flow Modelled, which is calculated from Engine Load Modelled, Engine Speed and the number of cylinders. Engine Load Modelled uses the Engine Efficiency calibration, so the Engine Efficiency Main table must closely match the real engine. When fuelling is tuned correctly with the Engine Efficiency table (and sensor, injector and engine details are correct), the Inlet Mass Flow is also correct.

Calculated Inlet Manifold Pressure

Inlet Mass Flow and Throttle Mass Flow both require Inlet Manifold Pressure to calculate their values, but calculating the Inlet Manifold Pressure requires both of these values.The system works using the value of Inlet Manifold Pressure from the previous calculation cycle. Some error is introduced because of this, but the error is small as the calculation is performed thousands of times per second. Each calculation corrects the error and Inlet Manifold Pressure can change with little lag, ahead of the sensor reading in most cases.

How quickly the modelled pressure responds depends on Inlet Manifold Volume. Enter the volume from the throttle butterfly to the inlet valves. For a dual plenum engine, enter the volume of one plenum. If two throttle servos feed one plenum, enter half the plenum volume.

The model is calculated twice, as shown in Figure 6. Both runs use the same throttle inputs and Inlet Manifold Volume. The first run uses only modelled values: the cylinder flow is Inlet Mass Flow Modelled, and no sensors are used. Its result, Inlet Manifold Pressure Modelled, is used for Engine Load Modelled and Torque Modelled, so torque control is never affected by sensor noise, the Airbox Mass Flow sensors or the Kalman gains. The second run uses Inlet Mass Flow, which comes from the sensor based Engine Load. In this run the throttle flow can be blended with the Airbox Mass Flow sensors (Throttle Mass Flow Kalman Gain), and the result can be blended with the Inlet Manifold Pressure sensors (Inlet Manifold Pressure Kalman Gain) to give Inlet Manifold Pressure Bank N, which sets Engine Load for fuel and ignition.

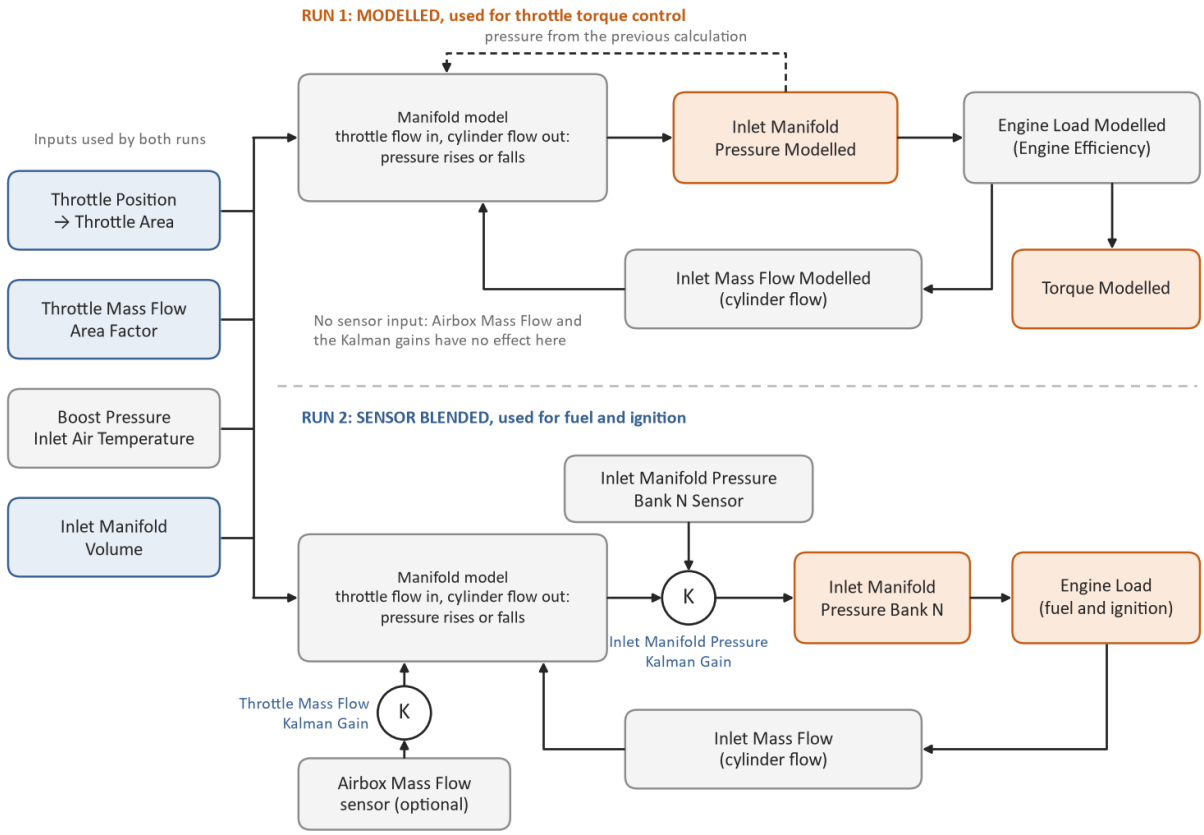


Figure 6. The inlet manifold pressure model is calculated twice. Run 1 uses only modelled values and sets Inlet Manifold Pressure Modelled for torque control. Run 2 includes the Airbox Mass Flow sensor and the Inlet Manifold Pressure sensor through the Kalman gains and sets Inlet Manifold Pressure Bank N for Engine Load.

Throttle Area

The Throttle Area table provides two functions:

1. To linearise the Throttle Position value. Throttle Servo Position is the % angle of the butterfly. The Throttle Position value is translated from Throttle Servo Position through the Throttle Area table.
2. To define the area of the throttle at all throttle positions. This is used in conjunction with the Throttle Mass Flow Area Factor and defines the size of the throttle required for the calculation used in the Throttle Mass Flow model.

The Throttle Area sets the relationship between the Throttle Servo Position and the throttle opening area. This is tuned by matching the Inlet Manifold Pressure Sensor value to the Inlet Manifold Pressure Modelled.

The values in the Throttle Area table must always increase with Throttle Servo Position. If any part of the table is flat or falling, Throttle Aim State reports Throttle Area Invalid and the throttle aim is compromised (typically the throttle will not fully open).

For low throttle opening, and especially near idle, the accuracy of this table is important but also easy to tune. At higher throttle openings tuning becomes more difficult, but also accuracy is less important. Provided the shape of the table is representative of the physical throttle area, accurate torque control can be obtained for all throttle openings in a short time.

A quick adjust **Q** function is included to assist with tuning this table. This adjusts the Inlet Manifold Pressure Modelled value to equal the Inlet Manifold Pressure when derived from a sensor (Inlet Manifold Pressure Kalman Gain MUST be set to 1000 mgain) while tuning.

Also, when the Throttle Test is set to Static Test while the engine is running, the Throttle Test Aim limits the Throttle Servo Position opening. This means the throttle pedal can be pressed and the throttle will only open to test aim position, usually set to an exact Throttle Area table site so it is held stable to assist with tuning this table.

If using this feature and the **Q** tune is successful, the Throttle Test Aim is automatically set to the next site above the currently tuned site, so the next site can be tuned quickly.

Additionally, **L** can be pressed to reset the Throttle Test Aim to the Throttle Area table cursor position while the test is active.

Throttle Mass Flow Area Factor

This is a size factor used for modelling air flow through the throttle. This value can be adjusted to increase the overall throttle flow used for calculating the Inlet Manifold Pressure Modelled, and in throttle based torque control.

When changing to a different sized throttle body in a tuned application, scale Throttle Mass Flow Area Factor by the change in throttle area. For example, changing from a 60 mm to a 70 mm throttle changes the value from 1.000 to 1.361. The Throttle Area table will likely need adjusting at low throttle openings, but this value corrects most of the high throttle opening flow. A typical value is 1.000 for a 60 mm throttle. For dual throttle engines, the value is for each throttle and assumes both are the same size.

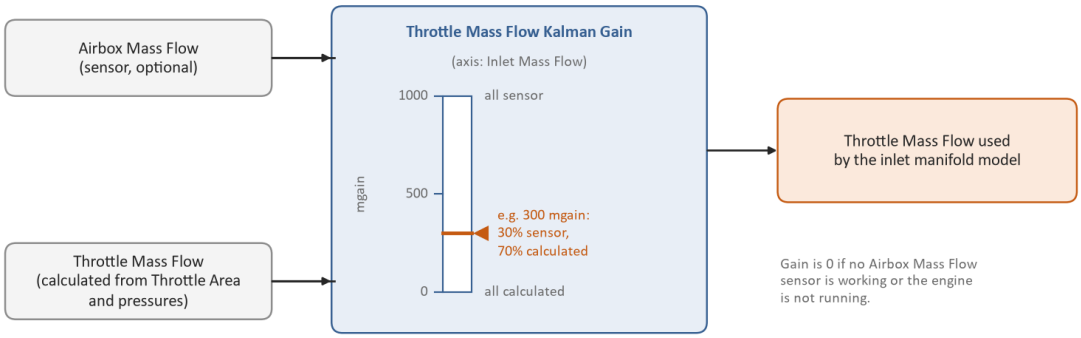
The accuracy of this value is not critical. If it is set too low, Inlet Manifold Pressure Modelled may be a few kPa below Boost Pressure (absolute) at 100% throttle; 0.5 to 1 kPa difference is normal. If it is set too high, the torque calculations may become unstable.

Kalman Gains

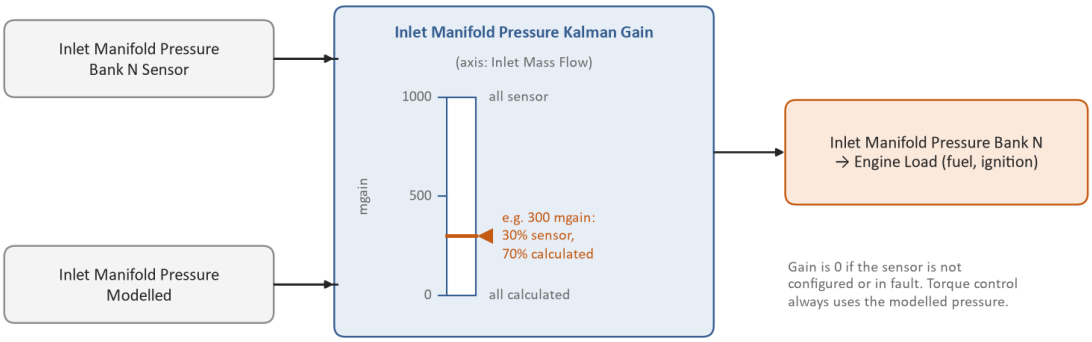
A Kalman filter is a method for using a weighted portion of two values based on the Kalman Gain factor. A gain of 0 means all of one value is used and a gain of 1 means all of the other value is used. Values between 0 and 1 use a portion of both values as illustrated below. The Gains are set in units of 'milligain' (mgain) where 1000 mgain = 1.

Use of Kalman Filters in GPRP Pro:

- Throttle Mass Flow Kalman Gain. Introduces a portion of the Airbox Mass Flow sensor reading over the calculated Throttle Mass Flow to find the final Throttle Mass Flow value.



- Inlet Manifold Pressure Kalman Gain. Introduces a portion of Inlet Manifold Pressure sensor reading over the calculated Inlet Manifold Pressure to find the final Inlet Manifold Pressure value.



Effects of Kalman Gains

Both Kalman Gain tables are referenced to Inlet Mass Flow, so the balance of response and stability can be set for different engine loads. The Inlet Manifold Pressure Kalman Gain sets how much of the modelled pressure is used in Inlet Manifold Pressure, which is the primary load input for fuel and ignition (Engine Load). It does not affect torque control, which always uses Inlet Manifold Pressure Modelled.

The recommended setting for Inlet Manifold Pressure Kalman Gain is 1000 mgain, so the Inlet Manifold Pressure sensor values are used for engine load. Using modelled values for engine load can reduce signal noise or improve response, but should only be done with a full understanding of the side effects. If both Inlet Manifold Pressure sensors fail or are not configured, the modelled values are used automatically (the same as 0 mgain) for redundancy.

The Throttle Mass Flow Kalman Gain table is only used when an Airbox Mass Flow sensor is configured and working, and the engine is running. Otherwise the firmware uses 0 mgain, so Throttle Mass Flow is the modelled throttle flow only.

If Throttle Mass Flow Kalman Gain is 1000 mgain:

- Inlet Mass Flow always balances to the Throttle Mass Flow, which is locked to the Airbox Mass Flow sensor values. Provided Inlet Manifold Pressure Kalman Gain is also 0 mgain, Engine Load is then defined by the mass air flow sensors and the Engine Efficiency table has no effect on it. Changing efficiency only alters the modelled Inlet Manifold Pressure.
- Problem: Airbox Mass Flow sensors are generally slow in response.

If the Inlet Manifold Pressure Kalman Gain is 1000 mgain

- Ignores modelled values and uses Inlet Manifold Pressure sensor for the primary load source. This is like a traditional speed / density table method.
- Problem: Minor problem with signal noise.
- This has priority over the Throttle Mass Flow Kalman Gain.

Inlet Manifold Pressure Post Throttle

For engines with a supercharger or intercooler between the throttle and the inlet ports, the air pressure after the throttle can differ to the pressure at the ports. Inlet Manifold Pressure is the pressure at the ports, but so throttle mass flow can be modelled correctly an additional pressure reading is needed directly after the throttle to calculate the throttle's pressure ratio.

This is set up with Inlet Manifold Pressure Post Throttle Mode:

- **Ratio Table:** for a flow restriction such as a small water to air intercooler or a restrictor plate. The pressure drop is consistent with air speed, so it can be modelled in the Inlet Manifold Pressure Post Throttle Ratio table. An Inlet Manifold Pressure Post Throttle sensor is needed to tune this table, and it can then be removed or kept for reference.
- **Sensor:** required for a supercharger after the throttle, because the pressure rise varies with the bypass valve and cannot be modelled. A permanent Inlet Manifold Pressure Post Throttle sensor must be fitted, the Inlet Manifold Pressure Kalman Gain axis must be turned off with the value set to 1000 mgain, Inlet Manifold Crossover Area Factor must be 1.0 (single plenum only) and both Boost Pressure sensor resources must be Not in Use. If these conditions are not met, Engine Bank Configuration Check reports invalid and no fuel is injected. In this mode Torque Maximum is based on Boost Aim Main, so tune that table to the maximum boost the supercharger produces.

Individual Throttle Body engines

For engines with a throttle per cylinder and no plenum chamber (ITB), Inlet Manifold Pressure does not exist in the same way as on an engine with a plenum. For this configuration, the manifold pressure and throttle flow models are replaced by an engine efficiency model that combines fuel tuning and torque control. This requires a separate firmware version, GPRP Pro ITB (M150).

The new model replaces Inlet Manifold Pressure with Throttle Position on the Engine Efficiency Main table and uses Boost Pressure (turbo) or Airbox Pressure (NA) as the efficiency model's reference pressure. The tuned engine efficiency is of the throttle and cylinder combined, rather than the cylinder alone. An additional Engine Efficiency Boost Compensation table is provided to compensate for efficiency changes due to varying boost pressures. An Inlet Manifold Pressure value is calculated, but only for use by other subsystems that use Inlet Manifold Pressure for an engine load value Engine Load Normalised.

Engine Load Normalised is calculated in the same way for GPRP Pro as it is in any other GP firmware. For the calculation of Engine Load Normalised, this is simply a value that represents the load on the engine as a percentage value that is normalised to the specification of the engine. This is so similar values are seen across a wide variety of engines and 100% roughly represents ambient pressure entering in the cylinder.

This is mainly used as the load axis on the Ignition Timing tables, rather than using Engine Load as mass; on a small engine you may see 100 mg at full load, but on a large engine you may see 1000 mg. In both cases the Engine Load Normalised may report 100% and similar amounts of ignition timing may be needed.

There are three options for the calculation set in Engine Load Normalised Mode:

- **Normal** compares Engine Load with the engine's standard Engine Load: the air mass for one cylinder's displacement at 101.325 kPa and 20 °C, 100% pumping efficiency, with no fuel vapour correction and no charge cooling. Engine Load Normalised = the greater of Engine Load Bank 1 and Engine Load Bank 2 divided by the standard Engine Load. Because Engine Load uses Engine Efficiency, any change to the efficiency table also changes Engine Load Normalised at that point.
- **Inlet Manifold Pressure** uses Engine Load Normalised = the greater of Inlet Manifold Pressure Bank 1 and Inlet Manifold Pressure Bank 2 (kPa) / 101.325. Using the higher bank means the timing is safe for the bank with the higher pressure.
- The mode selection Throttle Position uses Engine Load Normalised = Throttle Position. This is not very useful for a boosted engine.

Typically most applications are best suited to Inlet Manifold Pressure for the Engine Load Normalised mode, but there is some advantage to using Normal since it effectively links ignition timing to the mass of air in the cylinder.

Important: do not change Engine Load Normalised Mode after Ignition Timing Main and the other tables that use Engine Load Normalised have been calibrated. Changing it changes the load axis of all those tables.

THROTTLE PEDAL

As GPRP Pro is torque model based firmware, the pedal position has quite a different relationship with throttle position where the pedal is now requesting a torque value. This relationship has a significant impact on vehicle drivability and torque delivery, and as such, in many instances will need to have a dynamic relationship to engine speed. This balance is achieved through the use of the Throttle Pedal Translation table.

Throttle Pedal Translation

Because the pedal is used to request a percentage of the available engine torque, it must be representative of what is required in different operating conditions, i.e. low engine speed vehicle take off, or linear behaviour at high engine speed.

To give a feel more like a 1:1 pedal to throttle position relationship, the table must be quite steep at low engine speed and become more linear at high engine speed.

The Throttle Pedal Translation table must be 0% at 0% Throttle Pedal, and values must always rise as Throttle Pedal rises. As well as Throttle Pedal and Engine Speed, the table has a Driver Throttle Pedal Translation Switch axis, so different pedal maps can be selected by the driver.

A typical pedal translation table for a Nissan R35 GT-R is shown here:

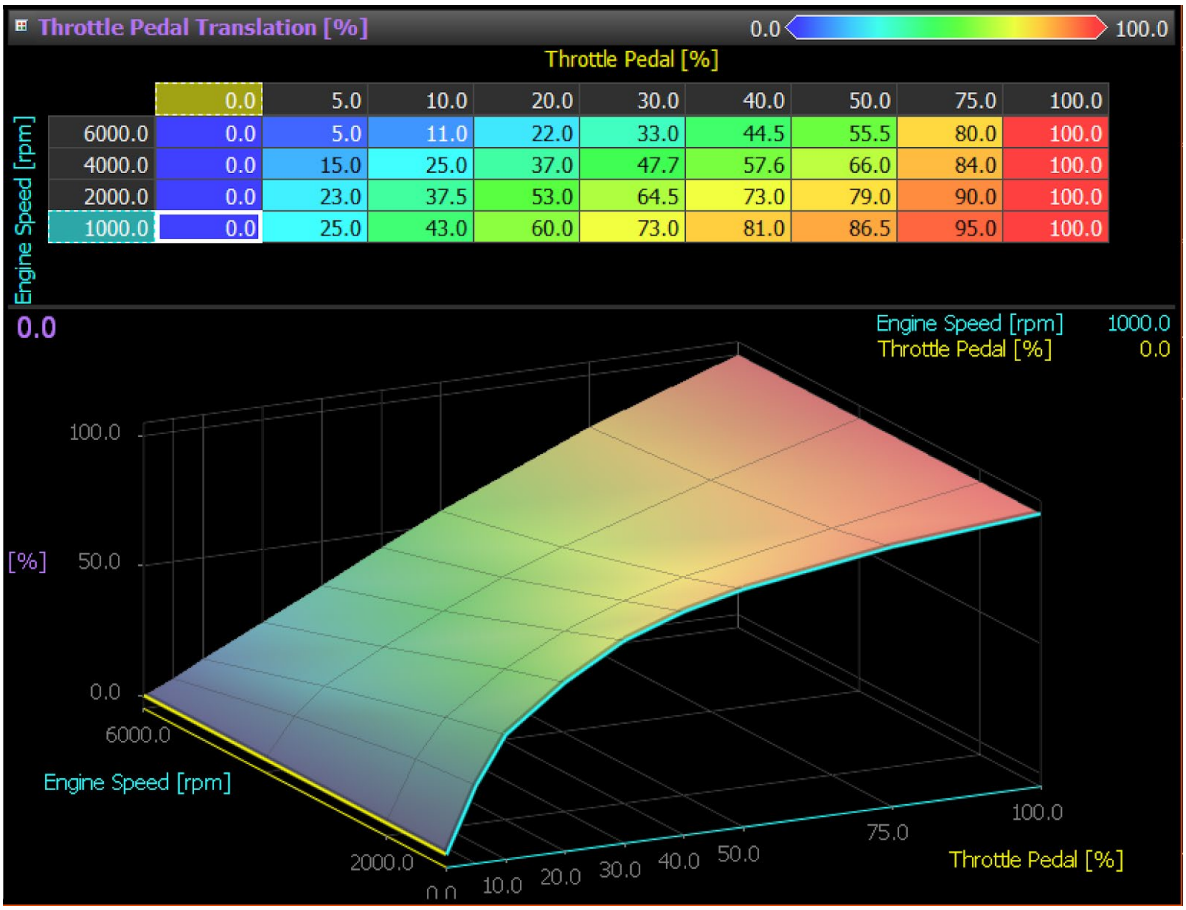


Figure 7. A Throttle Pedal Translation table from a Nissan GT-R with Throttle Pedal and Engine Speed axes.

In this table, the first 5% of pedal travel is requesting 25% of the available engine torque at 1000 rpm. This may seem like a lot, but the maximum engine torque at 1000 rpm is very low, so this gives a good pedal feel for driving on the road.

At higher engine speeds, where the engine can make a lot of torque, the more linear pedal translation provides greater progressive control over engine torque. A more linear translation at higher engine speeds does not represent the typical behaviour when the pedal translation is directly connected to the Throttle Servo Position, however it enables the driver to more finely control the torque delivery of the engine.

As stated above, the Throttle Pedal requests a torque rather than a throttle servo opening. This is reported as Throttle Pedal Torque Aim. In its simplest form, Throttle Pedal Torque Aim = Torque Maximum × Throttle Pedal Translation. The range is scaled in generated torque, so 0% translation equals Torque Ideal Correction at higher engine speeds, transitions to idle torque at idle engine speeds. The firmware adds the idle torque (Idle Torque Aim, allowing for idle ignition retard) as an offset, so the throttle holds at the idle opening when the pedal is first pressed.

Torque Maximum is what the engine torque would be if the throttles were open to 100% at the current engine speed and boost pressure. This means that 100% on the pedal translation will always command 100% throttle opening, and reducing the pedal to 95% will close the throttle some amount. This is similar in behaviour to when the pedal position commanded a throttle position directly.

Throttle Pedal Mode selects the torque that 100% translation represents. Torque Maximum (default) uses the calculation above. Torque Limit Maximum uses Throttle Pedal Torque Aim = Torque Limit Maximum × Throttle Pedal Translation.

Torque Limit Maximum is another table that can be filled out for more control over the pedal to torque aim relationship. The torque value entered in this table sets the upper limit for the throttle pedal. This means the torque aim can be a fixed, consistent amount for a given Throttle Pedal Position. However, it also means it can request more torque than the engine can produce so it might request 100% throttle position at a pedal position much below 100%. The top of the pedal travel would not change the torque in this case, but this may be desirable.

Throttle Pedal Damper

The Throttle Pedal Damper filters the Throttle Pedal Torque Aim when it is below a threshold. This softens the transition from hard acceleration into overrun. Torque requests above the threshold are used directly, so throttle response is not affected. The threshold is set by Throttle Pedal Damper Threshold Scale, Throttle Pedal Damper Threshold Minimum and Throttle Pedal Damper Threshold Maximum, and the amount of filtering by Throttle Pedal Damper Filter. The filter is reset when the clutch is disengaged, so engine speed does not flare during gear shifts.

Throttle Pedal Take Off

The Throttle Pedal Take Off is an assistant system, designed to help provide consistent behaviour in the form of a 'soft launch' control strategy, which can be particularly useful in vehicles with low inertia drivetrains and/or aggressive clutches.

Consider this an 'always on' launch control for normal driving where the aggressiveness of the control is dependant on how far the driver presses the throttle pedal, for example moving out of a garage, or for pit stop take off. The Throttle Pedal Take Off Engine Speed table sets an engine speed limit against Throttle Pedal, and the engine speed is controlled by closed loop ignition timing. The Ignition Timing Control system must also be tuned for the Throttle Pedal Take Off state. Typically engine speed rises with pedal position, for example 10% = 2000 rpm, 20% = 2500 rpm.

The system does not change the requested torque; that is still set by the pedal. When the pedal is pressed to a position, the engine can only rev to the engine speed set for that position, and the ignition timing is retarded to hold it there. Some boost can still build, and more if the pedal is pressed further. When the clutch is released and the engine slows under load, the timing is advanced, delivering more torque to get the car moving and reducing the chance of stalling.

Enable conditions:

- Throttle Pedal Take Off Mode is Enabled, or Brake State to also require the brake as an enable condition. Set it to Not in Use to disable the system.
- The Gear is Neutral, First, Reverse or Default (the system is disabled in 2nd gear and above, so the engine can be blipped freely on downshifts), and a valid Gear Output Shaft Speed is reported.
- Engine Speed is within 500 rpm of the table value. Table values within the idle control range are ignored.
- Throttle Pedal Take Off Margin (typically 500 rpm) is added to the engine speed calculated from vehicle speed and gear ratios, so the limit is raised as vehicle speed rises.

Launch control overrides this system.

ACTUATOR DUTY CYCLE

One feature of the GPRP Pro firmware that is a significant departure from the standard GP Packages is the ability to define the correlation between the requested control and the commanded duty cycle of an output pin. Often on an engine there are situations where the output duty cycle will not have a linear relationship to the behaviour of the actuator. One such example is the flow through a 3 port boost control solenoid. The ability to define this relationship against the commanded control to linearise behaviour gives users finer and more consistent PID behaviour, as well as removing the need for additional parameters, such as minimum and maximum duty cycles or polarity.

A different example of non-linear behaviour is camshaft control. In this instance, we want an immediate reaction from the actuator, but will typically operate in a narrow duty cycle range.

A practical example of this is shown below for the boost actuator Duty Cycle vs Control. It takes 15% duty to begin to flow air through the solenoid, so this is our 1% - start of control range. As the valve is effectively fully open with 90% Duty, this is our 100% Control value.

Set the output duty cycle tables before tuning the control system that uses them, and do not change them afterwards. Changing them alters the values needed in the control system (for example the Boost Control gains), which may then need retuning.

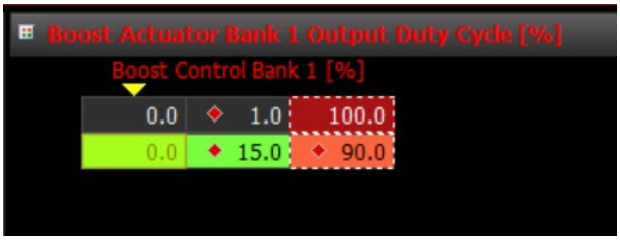


Figure 8.

In many cases, the Control value will be 0% when the control system is turned off and use a range of 1% to 100% when operating. This allows a default duty cycle to be set, typically 0% to reduce power usage when the engine is stopped, for example. Check the Help on the Control channel for each system.

This method of calibrating actuator behaviour also allows the linearisation, polarity, minimum and maximum duty cycles and drive type to be defined in a single table.

In these duty cycle tables, the duty cycle is defined with the following logic:

- 0% Duty Cycle: the output pin is floating.
- 100% Duty Cycle: the output pin is connected to ECU Ground.
- 50% Duty Cycle: the output pin is connected to ECU Ground half of the time.
- -100% Duty Cycle: the output pin is connected to ECU Battery Positive (only if a Half Bridge resource is selected).
- -50% Duty Cycle: the output pin is connected to ECU Battery Positive half of the time (only if a Half Bridge resource is selected).

EXHAUST LAMBDA RESPONSE

The position of the lambda sensor in the exhaust affects how the measured lambda can be used by control strategies. There is a transport delay between the combustion chamber and the sensor, and the sensor itself takes time to respond. This delay is not fixed: it is shorter at high engine speed and high load, when exhaust flow is higher.

GPRP Pro models this delay with the Exhaust Lambda Bank N Response system, one for each bank. The response time is set in the Exhaust Lambda Bank 1 Response Period table (and Exhaust Lambda Bank 2 Response Period), which uses Engine Speed and Inlet Manifold Pressure Bank N as axes. Exhaust Lambda Bank N Response Mode selects how the Period is found:

- **Not in Use**: no response is calculated. Exhaust Lambda Bank N Response, Exhaust Lambda Bank N Response Delay and Exhaust Lambda Bank N Response Lag are invalid, and Engine Efficiency Adaption Enable cannot become Enabled while that bank's lambda sensor is in use.
- **Calculated**: the Period is calculated from engine cycle time (720° divided by Engine Speed) and the inverse of Inlet Manifold Pressure Bank N. This models the transport delay across the full operating range from only four measured points. The Exhaust Lambda Bank N Response Period table must have exactly two sites on each axis, all axis values must be above zero, and the Period must get shorter as Engine Speed and Inlet Manifold Pressure increase. If these conditions are not met, the Period is read directly from the table.
- Manual: the Period is read directly from the Exhaust Lambda Bank N Response Period table by interpolation.

In Calculated mode, the four corner values of the Exhaust Lambda Bank N Response Period table are read once, the first time the calculation runs after the ECU starts. Changes to the table have no effect until the ECU is restarted, so **restart the ECU after changing the Period table**. If the table does not meet the conditions above at that time, the Period is read directly from the table (the same as Manual) until the ECU is restarted with a valid table.

Exhaust Lambda Response Period and Delay

GPRP Pro uses both a Dead Time and Period parameter to help define exhaust lambda response and behaviour. The Period represents the response time used to achieve 95% reaction to a change in lambda aim from injection pulse to measured change by the lambda sensor. The delay is a percentage of this period taken to show a reaction in the lambda to a change in aim (a change around 5% is a valid representation for the delay).

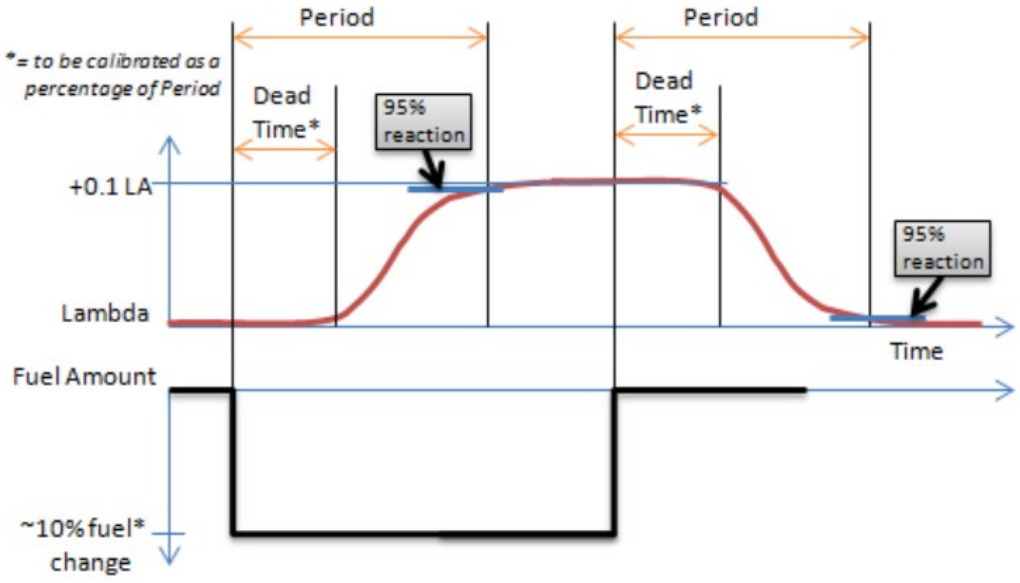


Figure 9. Graphical depiction of the Dead Time and Period areas in the change in Lambda.

To determine Period, apply fuel trim steps - for example, by using a Fuel Volume Trim or by changing Fuel Mixture Aim - in both directions (increase and decrease) and use the medium time value. If the sensor signal does not react with exactly the same magnitude as the fuel amount changed, use the 95% time that the signal takes to reach its new stable value.

Dead Time is the time at which the lambda signal first shows a reaction, for example about 5% of the expected lambda change. Exhaust Lambda Bank N Response Dead Time is set as a percentage of the Period. If a fuel volume trim is used to make a 0.1 LA change, note that the relationship between fuel and lambda is not linear.

For example:

- If Lambda is 1.0, for a step to Lambda 1.1 = a fuel trim of -9.1% must be applied
- If Lambda is 0.9, for a step to Lambda 1.0 = a fuel trim of -10% must be applied
- If Lambda is 1.0, for a step to Lambda 0.9 = a fuel trim of +11.1% must be applied
- If Lambda is 0.8, for a step to Lambda 0.7 = a fuel trim of +14.3% must be applied

These are used in conjunction with a first order filter to calculate system response behaviour. The Period, in conjunction with the Dead Time, define the dead time Delay and the filter time constant Lag. As the Period is defined as the 95% response, Lag is calculated as 1/3*(Period-Delay) as per definition of a time constant from a first order filter.

Exhaust Lambda Bank N Response Delay and Exhaust Lambda Bank N Response Lag are used by:

- Fuel Mixture Aim Bank N Sensor: the Fuel Mixture Aim delayed and filtered to match what the lambda sensor should currently be measuring.
- Engine Efficiency Adaption: to find the Engine Efficiency Adaption Effective values (Engine Speed, Inlet Manifold Pressure, Ambient Pressure, Engine Efficiency and closed loop trim at the time the measured fuel was injected).

Exhaust Lambda Bank 1 Response also sets the minimum Engine Efficiency Adaption Advanced Repeat Delay and scales Engine Efficiency Adaption Advanced Tolerance Delay.

Calibrate the lambda response before using Engine Efficiency Adaption.

EFFICIENCY ADAPTION

GPRP Pro offers an Efficiency Adaption (auto tune) function. This can be used for a variety of functions, such as a method to tune the efficiency table or to act as a long term fuel trim for further refining a tune. The Engine Efficiency Adaption function works by comparing the Fuel Mixture Aim with the combusted mixture, measured at the exhaust lambda sensor, and determining the required corrections. This correction is based on a number of factors including the Engine Efficiency Adaption Enable conditions, Exhaust Lambda Bank N Response, previous adjustments, current and surrounding Engine Efficiency Main values.

This correction is stored separately from Engine Efficiency Main, so it can be enabled, disabled or applied to the Engine Efficiency Main table. The system can be used to quickly populate an efficiency table on the first tune of an engine, to fix a poorly tuned efficiency table, or as a long term fuel trim. The accuracy depends on the setup of the lambda response Period and Dead Time, and the behaviour depends on the selected Engine Efficiency Adaption Sensitivity Mode.

It should be noted that this table is being constantly updated by the M1 firmware, not by the user; the table values can only be viewed while connected to the ECU through M1 Tune as they are saved on the device and not within the Package. This means these values will be cleared if a new firmware version is sent to the M1. The steps required to apply these settings will be covered in this Tuning Guide, as well as in the firmware Help.

Initial Setup

Before Engine Efficiency Adaption can be used, the engine must run and must be set up with the correct inputs. This includes correct settings and calibrations for:

- Engine Displacement
- Engine Cylinders
- Fuel Properties
- Coolant Temperature
- Inlet Air Temperature
- Ambient Pressure
- Inlet Manifold Pressure
- Fuel Pressure
- Fuel Temperature
- Fuel Injector
- Engine Charge Temperature
- Engine Charge Cooling
- Fuel Mixture Aim
- Exhaust Lambda
- Inlet Camshaft
- Exhaust Camshaft

Changing any of these settings may require the Engine Efficiency Adaption to be reset and run again.

Lambda response: Exhaust Lambda Bank N Response must be calibrated first (see the Exhaust Lambda Response section). It is used to find the engine operating conditions at the time the fuel now being measured at the lambda sensor was injected. If the response for a bank with an active lambda sensor is not set up, Engine Efficiency Adaption Enable Diagnostic reports Exhaust Lambda Response Fault and adaption will not run.

Setup

The following parameters and tables must be configured in order for Engine Efficiency Adaption to function:

- Engine Efficiency Adaption Mode: Set to Enabled.
- Engine Efficiency Adaption Lambda Sensor: select Bank 1 for a single bank engine. For a dual bank engine with a lambda sensor on each bank, Bank 2, Average, Leanest Bank or Richest Bank can be used. Exhaust Lambda Bank 2 Response must then also be set up.
- Engine Efficiency Adaption Sensitivity:
  - Coarse: Use this setting on the first run of an engine with an unknown Engine Efficiency Main table.
  - Medium: Use this setting when the Engine Efficiency Main table is within 10% of the actual Engine's Efficiency.
  - Fine: Use this setting as a "Long-Term" trim to fine tune the Engine Efficiency Main table over time.
- Each sensitivity setting becomes more refined with use. For example, the Coarse setting becomes finer as more samples are collected at a site. Engine Efficiency Adaption Advanced Mode is normally left Not in Use. When it is Enabled, the tables in Engine Efficiency Adaption Advanced (Factor, Range, Tolerance, Repeat Delay and Correction Minimum) can be adjusted against Engine Efficiency Adaption Sensitivity Mode and Engine Efficiency Adaption Samples.
- Engine Efficiency Adaption Enable: adaption only runs when this is Enabled. The enable limits are set by Engine Speed, Inlet Manifold Pressure, Ambient Pressure, Inlet Air Temperature, Coolant Temperature and Lap Distance minimum and maximum tables, plus Engine Efficiency Adaption Enable Run Time Total Maximum. All conditions must be met for Engine Efficiency Adaption Enable Delay (typically 1 s). The limit tables use Driver Engine Efficiency Adaption Setting Switch as an axis, so the enable conditions can be changed quickly with a driver switch. Adaption is also disabled during engine overrun, launch, anti-lag, nitrous, and fuel or ignition cuts. Engine Efficiency Adaption Enable Diagnostic shows why adaption is disabled.
- Table axes: Engine Efficiency Main, Engine Efficiency Adaption, Engine Efficiency Adaption Trim and Engine Efficiency Adaption Samples must all have identical axes and axis site values. The axes are copied from Engine Efficiency Main automatically when the Engine Efficiency Adaption is reset. If the axes of Engine Efficiency Main are changed, reset the adaption.
- Engine Efficiency Adaption Aim Tolerance: limits Engine Efficiency Adaption Aim to within this percentage of the original efficiency value at that site. A larger error is clamped to this limit, not rejected. Suggested start values are 300% for Coarse, 30% for Medium and 15% for Fine. An untuned engine using Coarse needs a large tolerance.

Correcting Efficiency

While the engine is running and Engine Efficiency Adaption Enable is Enabled, the Engine Efficiency Adaption calculates how much the engine efficiency must change so that Exhaust Lambda Bank N equals Fuel Mixture Aim Bank N Sensor (the aim delayed to match the sensor). The closed loop trim that was active when the fuel was injected is included. The result is shown in Engine Efficiency Adaption Aim.

Provided that the values of Engine Speed (Engine Efficiency Adaption Effective Engine Speed), Inlet Manifold Pressure (Engine Efficiency Adaption Effective Inlet Manifold Pressure) and Ambient Pressure (Engine Efficiency Adaption Effective Ambient Pressure), when the fuel was injected that is currently being measured at the lambda sensor, are within tolerance of a table site for a given time, the Engine Efficiency Adaption Trim is adjusted.

The amount that the current and neighbouring sites are adjusted is dependent on the Engine Efficiency Adaption Sensitivity. Coarser sensitivity settings adjust the Engine Efficiency Adaption table with more influence over a larger range than the finer settings. The influence amount and spread of the adjustment can be customised by setting Engine Efficiency Adaption Advanced to Enabled and modifying Engine Efficiency Adaption Advanced Factor and Engine Efficiency Adaption Advanced Range.

After adjusting one site, another correction on that site will only be processed after a delay. This delay can be customised when in the Advanced Mode by modifying Engine Efficiency Adaption Advanced Repeat Delay. The process above is repeated immediately when the engine operation moves to a different site.

The Efficiency Adaption system has many checks to make sure changes are only made with accurate data. Engine Efficiency Adaption State shows what the system is doing:

- Disabled: adaption is not enabled. See Engine Efficiency Adaption Enable Diagnostic.
- Outside Engine Speed Tolerance, Outside Inlet Manifold Pressure Tolerance, Outside Ambient Pressure Tolerance: the effective operating point is not close enough to a table site.
- Wait Unstable: within tolerance, waiting for Engine Efficiency Adaption Advanced Tolerance Delay.
- Sample or Sample Limited: a correction is being made. Sample Limited means the aim was clamped by Engine Efficiency Adaption Aim Tolerance.
- Wait Repeat: waiting for Engine Efficiency Adaption Advanced Repeat Delay before correcting the same site again.
- Save, Reset, Apply: the tables are being saved, reset or applied.

Engine Efficiency Adaption and Samples Tables

The Engine Efficiency Adaption and Engine Efficiency Adaption Samples tables can only be viewed in M1 Tune while connected to the ECU. When the Engine Efficiency Adaption is reset, the axes are set up and Engine Efficiency Adaption is filled with the values from Engine Efficiency Main. Corrections are then made to Engine Efficiency Adaption.

When Engine Efficiency Adaption Mode is Enabled and Driver Engine Efficiency Adaption Switch is On (or not in use), Engine Efficiency Adaption is used to calculate fuel volume instead of Engine Efficiency Main.

Engine Efficiency Adaption Samples shows how many full corrections have been made at each site. More than 10 at a site is considered finely tuned. Each correction adds Engine Efficiency Adaption Advanced Factor to the count, so with a Factor of 50% the count rises in steps of 0.5. Only the site closest to the operating point is counted.

Neighbouring sites adjusted through Engine Efficiency Adaption Advanced Range are not counted. Because the Factor and Range tables use Samples as an axis, corrections get smaller and more local as a site collects more samples.



Figure 10. An example of the Engine Efficiency Adaption Samples table updating on the number of samples taken.

Applying Corrections and Resetting

The corrected values in Engine Efficiency Adaption are saved on the M1 ECU but not in the Package, and are cleared when new firmware is sent to the M1. To permanently apply them to Engine Efficiency Main, connect with M1 Tune, open the Tuning - Efficiency Adaption worksheet, select Engine Efficiency Adaption Apply and press the **Q** key (or right-click and select Functions, then Apply Adaption).

The Engine Efficiency Main table will be updated and the Engine Efficiency Adaption, Engine Efficiency Adaption Trim and Engine Efficiency Adaption Samples tables will be reset automatically.

The Engine Efficiency Main table can be selectively updated by copying the desired cells from Engine Efficiency Adaption table and pasting them into the Engine Efficiency Main table. On completion, the Engine Efficiency Adaption will need to be reset manually (See Manual Reset section).

Applying offline: while online, select the Engine Efficiency Adaption Trim table body and press **Q** to copy the current adaption trim into it. This table is saved in the Package. Later, when offline, select Engine Efficiency Adaption Apply and press the **L** key to apply the saved trim to Engine Efficiency Main.

After the corrections are applied, the Engine Efficiency Adaption Sensitivity should be adjusted to reflect the new updated Engine Efficiency (See Setup section).

Manual Reset

To manually reset the Engine Efficiency Adaption, connect with M1 Tune, open the Tuning - Efficiency Adaption worksheet, select Engine Efficiency Adaption Reset and press the **Q** key (or right-click and select Functions, then Reset Adaption). Engine Efficiency Main is copied into Engine Efficiency Adaption, the axes are copied, and Engine Efficiency Adaption Trim and Engine Efficiency Adaption Samples are cleared.

FUEL INJECTOR DUTY CYCLE MAXIMUM

On engines with Primary and Secondary injectors, Fuel Injector Duty Cycle Maximum sets the nominal maximum duty cycle for both sets of injectors. It is only used when both sets are available.

- If one set would need to exceed this maximum to deliver the requested fuel volume, Fuel Injector Secondary Contribution is shifted so that set stays at the maximum and the other set delivers the rest.
- If both sets would exceed the maximum, the contribution is set so both sets have very similar duty cycles and reach 100% together, delivering the most fuel the injectors can provide. Because of the non-linear region of the injector, the duty cycles may differ slightly when the maximum is below 100%.

The duty cycle used is from the injector delivering the most fuel, which may be set by an individual cylinder trim or a closed loop bank trim. Fuel Injector Contribution Diagnostic reports what is setting the contribution:

Diagnostic	Meaning
Secondary Contribution Main	The Secondary Contribution Main table is in control.
Duty Cycle Maximum Primary	The primary injectors are at the maximum, so fuel is shifted to the secondaries.
Duty Cycle Maximum Secondary	The secondary injectors are at the maximum, so fuel is shifted to the primaries.
Duty Cycle Maximum Both	Both sets are at the maximum, so the duty cycles are evenly split.
Duty Cycle Maximum Disabled	Shifting is not possible at this operating point (see below).

Fuel Injector Contribution Diagnostic can also report Primary or Secondary when only one set of injectors is available, and Fuel Cut Active when fuel cut is active and all fuel has been moved to one set of injectors.

Injector Linearisation table limit. To shift fuel, the ECU calculates how much fuel each set of injectors delivers at a given pulse width. This only works in the linear part of the injector flow, above the longest pulse width in the injector linearisation table. Two checks follow from this, at the current operating point:

- **100% duty cycle inside the linearisation table: shifting is disabled.** At 6000 rpm an engine cycle takes 20 ms, so 100% duty cycle is a 20 ms pulse. If the linearisation table has pulse widths above 20 ms, the ECU cannot calculate the fuel delivered. Fuel Injector Contribution Diagnostic reports Duty Cycle Maximum Disabled, and Secondary Contribution Main is followed even if the duty cycle is above the maximum.
- **Duty Cycle Maximum PW is inside the linearisation table, but 100% duty is outside: the even split is always used.** At 6000 rpm a Duty Cycle Maximum of 50% is a 10 ms pulse. If the linearisation table goes up to, say, 12 ms, the 10 ms limit is inside the non-linear region and the ECU cannot tell how much fuel 50% delivers. It then uses the Duty Cycle Maximum Both split all the time at that operating point, even when the injectors are well below the maximum.

To avoid both issues, keep the linearisation table to the short pulse widths where the injector is actually non-linear (usually below a few ms), or raise the Duty Cycle Maximum if a low value is used.

BOOST CONTROL

The Boost Control function of GPRP Pro operates in the same manner as other GP firmware, however there are several small variances that increase the versatility of the M1 Boost Control system. One instance is the ability to define the duty cycle versus commanded control (as covered in the Actuator Duty Cycle section), allowing the user to adjust the duty transfer when using two outputs in "phase and anti phase" operation, or the ability to run a second actuator in parallel at different duty cycles.

The Boost Control system also allows two banks to be controlled independently by enabling Boost Control Bank 2 Mode. Once it is enabled, Bank 2 has its own feed forward table, feed forward offset and PID settings to drive its boost control outputs. Both banks normally follow the same boost aim, but Turbo Speed Control can lower the pressure ratio aim for each bank separately (see Turbo Speed Control). This allows independent closed loop control on engines with separate bank plenums and little or no balance pipe between them. Dual bank control also applies to wastegate pressure control and boost servo control.

Supported turbo configurations:

- Single turbo:
  - Single actuator (boost, wastegate pressure or servo)
- Twin turbo, common plenum or boost piping. Or dual plenum with cross bank airflow (R35):
  - Single boost valve plumbed to dual actuators
  - Dual boost actuator (same DC)
  - Single wastegate pressure control plumbed to dual actuators
  - Dual wastegate pressure control (common aim)
  - Dual servo control (common servo aim position)
- Dual turbo speed sensors with dual Boost Control (dual actuators, wastegate pressure control or servos), where Turbo Speed Control sets a separate pressure ratio aim for each bank
- Twin turbo, independent bank plenums:
  - Dual boost valves
  - Dual wastegate pressure control
  - Dual servo control

Boost Pressure Ratio

The closed loop Boost Control system works in terms of compressor pressure ratio rather than boost pressure alone. A turbocharger compressor multiplies its inlet pressure, so the outlet pressure is a ratio of the inlet pressure. Controlling the ratio means the system still reacts correctly when the compressor inlet pressure changes, for example with a category-mandated turbo inlet restrictor.

Pressure ratio is calculated for each bank as boost pressure (absolute) divided by Turbocharger Bank N Inlet Pressure:

- Boost Pressure Bank N Ratio is the pressure ratio for each bank.
- Boost Pressure Ratio is the average pressure ratio.

To keep tuning familiar, the system is still calibrated in pressure. Pressure ratio values are converted back to pressure by multiplying them by Ambient Pressure. These channels have Corrected in their name:

- Boost Pressure Corrected and Boost Pressure Bank N Corrected are the feedback used by the closed loop control.
- Boost Aim Pressure Ratio Bank N Corrected is the aim used by the closed loop control. It is the lowest of the active boost aims (converted to pressure ratio) and Boost Limit Pressure Ratio Bank N Corrected.

When the turbo inlet is not restricted, the inlet pressure is Airbox Pressure, or Ambient Pressure if no airbox sensor is fitted. The Corrected values are then numerically the same as absolute boost pressure, so the control behaves exactly like a pressure control system.

Note on migrating from earlier firmware versions: earlier versions controlled boost pressure directly. Because the Corrected values equal absolute boost pressure when the turbo inlet is not restricted, Boost Control tuning from those versions carries forward without change. If a turbo inlet pressure sensor or estimate is used, the Corrected values differ from boost pressure, so check the boost tuning.

The Corrected values only differ from boost pressure when the turbo inlet pressure differs from ambient. For example, with an Ambient Pressure of 100 kPa:

Condition	Turbo inlet pressure	Boost Pressure (gauge)	Pressure ratio	Corrected value
Low air mass flow	100 kPa	200 kPa	3.0	300 kPa
High air mass flow, restrictor choking	75 kPa	200 kPa	4.0	400 kPa

In both cases Boost Aim Main may be 200 kPa, but the pressure ratio aim rises from 3.0 to 4.0 as the inlet pressure falls. The 400 kPa Corrected value is not a pressure that exists in the engine. It describes the turbo working as hard as it would with a 100 kPa inlet pressure and 400 kPa absolute boost pressure.

This matters when the restrictor reaches choked flow. Closing the wastegate further no longer raises boost pressure, but it does keep increasing turbo speed and compressor work, which can overheat or overspeed the turbo. As turbo speed rises the inlet pressure falls and the pressure ratio rises, so control based on pressure ratio keeps regulating the turbo instead of chasing a boost pressure that has stopped responding.

Turbocharger Inlet Pressure

Turbocharger Bank N Inlet Pressure Source selects the inlet pressure used in the pressure ratio calculation:

- **Not in Use:** the turbo inlet is not restricted. Airbox Pressure is used, or Ambient Pressure if Airbox Pressure is not available. Boost Control effectively works on boost pressure only.
- Resource: Turbocharger Bank N Inlet Pressure Sensor measures the pressure between the restrictor and the compressor inlet. If the sensor is not available, the value falls back to the other bank's sensor, then the estimate, then Airbox Pressure.

- **Estimate:** the inlet pressure is estimated from the Turbocharger Bank N Speed Compressor table (see Turbo Speed Control). A fitted sensor is not used for control in this mode, but it can still be logged and used by the Q quick adjust on the Compressor table.

The estimate is boost pressure (absolute) divided by the pressure ratio from the Compressor table at the current turbo speed and mass flow, limited to a maximum of Airbox Pressure. For example, a boost pressure of 250 kPa absolute and a table value of 3.0 gives an estimated inlet pressure of 83.3 kPa.

Boost Limit Pressure Ratio

Boost Limit Pressure Ratio sets a maximum pressure ratio across the compressor. It is the lowest of the sources reported by Boost Limit Pressure Ratio State: Main, Turbo Speed Control Bank 1 or Turbo Speed Control Bank 2.

Boost Limit Pressure Ratio Main has axes of Inlet Mass Flow and Boost Aim Maximum. It can be filled in from the surge line of the compressor map, so that boost is limited to where the compressor does not surge. The Boost Aim Maximum axis lets the limit follow changes in the maximum allowed boost, for example at altitude or with a blocked air filter. The table also sets the maximum value for Turbo Speed Control, which prevents integral wind up.

This is separate from the Boost Limit system, which works as a percentage of the range between Boost Control Activate and Boost Aim Main.

Turbo Speed Control

Turbo Speed Control limits turbo speed to Turbocharger Speed Limit by requesting a maximum pressure ratio across the compressor. The result, Turbocharger Bank N Speed Control, is a source of Boost Limit Pressure Ratio, which in turn lowers Boost Aim Pressure Ratio Bank N Corrected. Boost Control then moves the wastegate to hold the turbo at the speed limit.

Supported configurations

Configuration	Setup
Single Boost Control, single turbo	Use the Turbocharger Bank 1 group only.
Single Boost Control, twin turbo	Use Turbocharger Bank 1 Speed Control. The Bank 2 speed sensor and inlet pressure can also be used. The faster turbo is used for control, and the inlet pressure used switches automatically to the bank with the faster turbo.
Dual Boost Control, twin turbo, common plenum	Use both Turbocharger Bank 1 and Bank 2 Speed Control. Each bank uses its own sensors and sets its own Boost Aim Pressure Ratio Bank N. This supports dual throttles (dual boost sensors) or a single throttle (single boost sensor). Both banks flow to a common point, so there may be some bank to bank interaction.
Dual Boost Control, twin turbo, dual plenum	Use both Turbocharger Bank 1 and Bank 2 Speed Control. Each bank is controlled independently from its own sensors. Use this when there is no large connection between the plenums.

A twin turbo engine is identified by Turbocharger Bank 2 Speed Sensor Resource being assigned.

Speed limit

Turbocharger Speed Limit is Turbocharger Speed Limit Main, which has axes of Engine Speed and Airbox Pressure, with Turbocharger Speed Limit Airbox Temperature Compensation applied.

Control operation

Enable the system for each bank with Turbocharger Bank N Speed Control Mode. Turbocharger Bank N Speed Control State reports what the system is doing:

State	Meaning
Fault	Turbocharger speed is not available.
Not in Use	The system is not in use.
Disabled	Boost Control is not active.
Standby	The system is monitoring turbo speed but not taking any action.
Active Bank 1	The system is limiting the pressure ratio using Bank 1 values.
Active Bank 2	The system is limiting the pressure ratio using Bank 2 values. On a single Boost Control twin turbo engine this is reported on Bank 1 when the Bank 2 turbo is the faster one.

Control starts when turbo speed rises above Turbocharger Speed Limit minus Turbocharger Bank N Speed Control Activate Margin. At that point the integral is reset to a value based on the current pressure ratio and the feed forward, so the pressure ratio limit starts close to a value that should meet the speed limit. Control continues until another system sets a lower Boost Aim and turbo speed is below the limit.

The control value is the sum of three terms:

- **Feed forward:** the pressure ratio from Turbocharger Bank N Speed Compressor at the speed limit and the current mass flow.
- **Proportional:** Turbocharger Bank N Speed Control Proportional Gain multiplied by Turbocharger Bank N Speed Control Error, where Error is the speed limit minus turbo speed. Start with 1 %/1000rpm, which adds 0.01 to the pressure ratio for every 1000 rpm of error.
- **Integral:** Turbocharger Bank N Speed Control Integral Gain. Start with 1 %/1000rpm*s, which adds 0.01 to the pressure ratio for each second with 1000 rpm of error. Set it to 0 to disable the integral. The integral pauses when it has no range to move in, which is when the control value is below 1.0 or above Boost Limit Pressure Ratio Main.

When control starts, the new pressure ratio aim is usually lower than the previous one, and Boost Control takes a moment to react. Starting control a little before the limit with the Activate Margin can prevent turbo speed overshooting. Starting too early can wind up the integral and also cause an overshoot.

Compressor table

Turbocharger Bank N Speed Compressor relates turbo speed and Turbocharger Bank N Speed Mass Flow to the compressor pressure ratio. It is the feed forward for Turbo Speed Control, and the source of the inlet pressure estimate when Inlet Pressure Source is set to Estimate.

Turbo Speed Control creates a Boost Aim that Boost Control then follows, so tune Boost Control Bank N first, then fill in this table as accurately as practical. For example, when at 100% throttle on the speed limit, if the throttle closes to 50% the boost pressure may rise sharply while the wastegate needs to stay close to its current position to hold turbo speed. With an accurate table, the table value rises with the reduced mass flow and matches the actual rise in pressure ratio.

Fill in the table using one of these methods:

- **Compressor map:** use the turbo manufacturer's compressor map, if it is available and the turbo inlet pressure is known. For twin turbos, Mass Flow is Inlet Mass Flow Bank 1 on a dual bank engine, or half of Inlet Mass Flow on a single bank engine.
- **On the engine:** set each site to Boost Pressure Bank N Ratio while turbo speed is stable. A Q quick adjust function is available on the table.
- **On the dyno:** set Turbocharger Speed Limit Main to a fixed value and use an engine speed high enough to flow enough air. Hold 100% throttle with turbo speed controlled at the limit, then progressively close the throttle to reduce mass flow while the control is working. Repeat at other speed limits to cover the table.

While the table is being tuned, the integral may be large (above 1.0) and control may take some time to reach the limit. Once the table is tuned, the integral should stay small (below about 0.2), and control is faster and more accurate.

Speed sensor fault

If Turbocharger Bank N Speed Diagnostic reports a sensor fault, the control falls back to open loop and the control value is set to the feed forward minus Turbocharger Bank N Speed Control Feed Forward Fault Offset. Set this offset so the turbo cannot overspeed in this condition.

Controlling turbo speed directly with a restricted inlet

Turbo speed can be held at Turbocharger Speed Limit by Boost Control itself, without an inlet pressure sensor. Set Turbocharger Bank N Inlet Pressure Source to Estimate, and set Turbocharger Bank N Speed Control Proportional Gain and Turbocharger Bank N Speed Control Integral Gain to 0. Figure 11 shows how the aim and the feedback are formed.

- **Aim:** with both gains at 0, the Turbo Speed Control value is only its feed forward. This is the Turbocharger Bank N Speed Compressor table value at the speed limit and the current mass flow. It becomes the pressure ratio aim for Boost Control, provided no other boost aim is lower.
- **Feedback:** the estimated inlet pressure is boost pressure divided by the Compressor table value at the actual turbo speed. Boost Control then calculates the pressure ratio as boost pressure divided by that inlet pressure, so the boost pressure cancels out. The feedback, Boost Pressure Bank N Ratio, is simply the Compressor table value at the actual turbo speed.

So Boost Control is comparing two values from the same row of the Compressor table: one read at the speed limit and the other at the actual turbo speed. They are only equal when the turbo is at the speed limit, so Boost Control moves the wastegate until it is. For example, if the table reads 3.0 at 140,000 rpm and 3.2 at a 150,000 rpm limit, the aim is 3.2 and the feedback is 3.0. Boost Control closes the wastegate, and turbo speed rises until the feedback reaches 3.2 at 150,000 rpm. This only works because, at a given mass flow, a compressor's pressure ratio always rises with turbo speed. Provided the Compressor table is reasonably accurate and Boost Control has already been tuned on boost pressure, turbo speed control should be responsive and accurate, with no separate PID tuning needed.

Points to note:

- **Low air flow:** the estimated inlet pressure cannot be higher than Airbox Pressure, so the feedback is the greater of the table value and boost pressure divided by Airbox Pressure. At low air flow, where the restrictor is not limiting, the boost sensor value is the greater, and Boost Control works on boost pressure as normal.
- **Other boost aims:** Boost Aim Pressure Ratio is the lowest of all the boost aims. If another source, such as Boost Aim Main or a boost limit, asks for a lower pressure ratio than the speed limit gives, that aim is used and the turbo stays below the speed limit. The feedback is formed in the same way, so here the table accuracy does affect the boost achieved.
- **Speed sensor fault:** without turbo speed the Compressor table cannot be read, so the inlet pressure falls back to a fitted inlet pressure sensor, or to Airbox Pressure, and Boost Control works on boost pressure. Turbo Speed Control sets its value to the feed forward minus Turbocharger Bank N Speed Control Feed Forward Fault Offset.

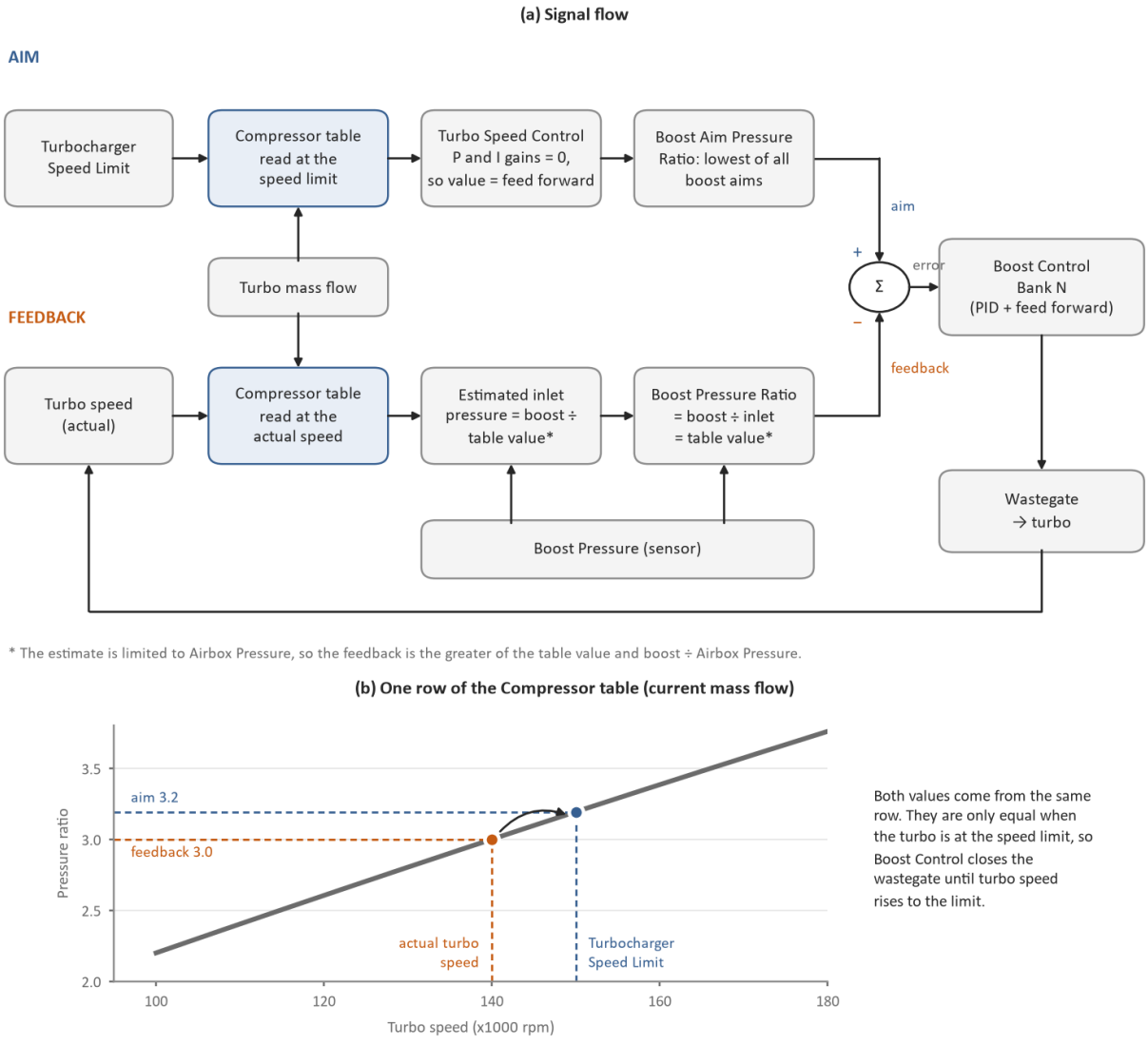


Figure 11. Direct turbo speed control. (a) The aim and the feedback are both read from the Compressor table, at the speed limit and at the actual turbo speed. (b) The pressure ratio error is zero only when turbo speed reaches the limit.

IDLE CONTROL

The system operates on the same principle as other MoTeC M1 ECU firmwares, using high response ignition timing control over lower response torque (throttle) control. Further idle control strategy improvements used in this firmware assist with drivability and seamless entry and exit from idle control. The air flow into the engine for idle control is defined as 'engine power' and uses a simple integral calculation.

This has the following advantages:

- Engine Power has a direct relationship to the torque control system.
- Torque compensation for air conditioner, alternator and gearbox loads at idle are directly integrated via Torque Ideal Correction External Loss.
- With the idle system controlling engine power, there is a natural proportional gain between engine speed and torque. For example, if the engine speed halves, the torque must double to maintain the same generated power.
- With a torque based pedal, the nominal torque (air flow) needed to idle is learned and stored in Idle Torque Aim Nominal. It is a filtered version of Idle Torque Aim (Idle Torque Aim Filter, typically 1000 ms) and only updates when idle is stable, within 50 rpm of Idle Aim for 1 second. The value is kept when the ECU is powered off. When the throttle pedal is pressed, Throttle Pedal Torque Aim is offset by this value, so any pedal movement above 0% increases engine speed and the exit from idle is seamless.

  When the engine is running at a constant speed with no load placed on the flywheel, flywheel torque is zero Nm. The mechanical energy produced by the engine is used completely to overcome internal friction and drive ancillary loads such as the oil pump and alternator.

  The Idle Control Power system always targets zero kW of flywheel power and does not need its own Feed Forward tables. This zero torque is based on best ignition timing. When entering idle control, ignition timing is reduced from best ignition timing which ensures negative torque to slow down the engine to enter idle control. The Idle Control Power must then add some air flow to compensate for the reduced ignition timing which results in a positive flywheel power value when idling stably.

  Both the torque calculation and idle control need corrections for non-flywheel loads put on the engine. To do this, the alternator, air conditioner and transmission systems have idle tuning parameters that are applied in the Torque Ideal Correction External Loss.

Idle Control Setup

To correctly set up the idle control system so that it can be accurately tuned, the following steps should be taken:

- Confirm Ignition Timing Main has been calibrated with the best torque ignition timing in the engine operating area where idle control operates.
- If not already configured in the Package, set all parameters and table values in Idle to the default values mentioned in their respective Help texts. The engine does not need to run for this. The fuelling should be reasonably well tuned, especially in the operating areas for idle control.
- The Throttle Area table should be reasonably well tuned at low throttle openings. See the Help for this table, or refer to the procedure as covered in the Throttle Mass Flow section of this Tuning Guide.

- Calibrate Torque Ideal Correction Internal Loss as described in the Help for that table.
- Optimise Idle Control Ignition Timing Proportional Gain so that Idle Control Ignition Timing is stable around Idle Control Ignition Timing Target.
- Check that Engine Speed tracks Idle Aim nicely after throttle tip-ins. Optimise Idle Aim Ramp Down to achieve this.
- Check that Engine Speed is stable at Idle Aim when the idle control is running. Optimise Idle Control Power Integral Gain and other integral settings to achieve this.

Idle Control Activation

Idle control activation happens in two phases:

1. When the idle activation conditions (described below) have been met, ignition timing is blended between Engine Overrun Ignition Timing and Idle Control Ignition Timing Target based on the Engine Speed. Note that Idle State is still Disabled in this condition.
2. Once Engine Speed falls below Idle Aim, Idle State becomes Enabled and the system begins closed loop control.

The idle activation conditions are:

- Engine State must be Run.
- Ignition Timing Mode must be Normal.
- Throttle Pedal must be less than or equal to Idle Activate Throttle Pedal Threshold.
- Engine Speed must be below Idle Aim + Idle Activate Engine Speed Margin. Idle Aim is the sum of Idle Aim Main, Idle Aim Compensation and Idle Aim Ramp Down.
- No gear shift throttle blip is being requested (Gear Shift Torque Aim is not active).

Idle control is deactivated when Throttle Pedal is greater than Idle Activate Throttle Pedal Threshold + Idle Activate Throttle Pedal Hysteresis or Engine Speed is greater than Idle Aim + Idle Activate Engine Speed Margin.

The target idle speed is set by the Idle Aim system. The primary influence on the target idle speed is the Idle Aim Main table. A number of compensations are provided to correct for external influences, such as the air conditioner compressor. Idle Aim Ramp Down assists in bringing engine speed under control by smoothly reducing the target idle speed upon entering closed loop control. When closed loop control is active, engine speed is controlled by two closely coupled control systems: Idle Control Ignition Timing and Idle Control Power.

Idle Control Timing

The Idle Control Ignition Timing system performs closed loop engine speed control by varying ignition timing. If Engine Speed falls below Idle Aim, ignition timing is advanced. If Engine Speed rises above Idle Aim, ignition timing is retarded.

Ignition timing is used because the response rate is faster than throttle control, so a more stable idle speed can be achieved than with throttle control alone.

In order for this control system to operate effectively, Ignition Timing Main must be calibrated such that it contains the minimum advance for best torque (MBT) ignition timing values in the region where idle control will be active. This gives the idle system a torque margin to correct for engine speed fluctuations. The ignition side only uses proportional control. The integral part of the control system is performed by the Idle Control Power (throttle based) side.

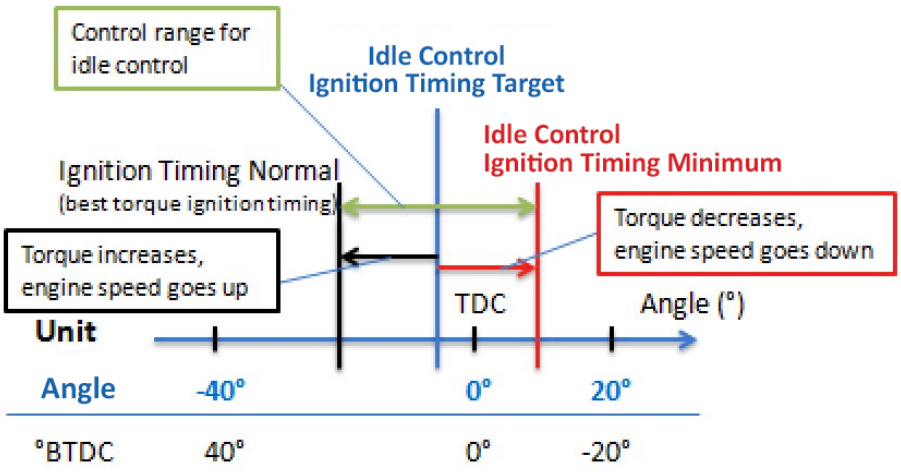


Figure 12. Interaction of Ignition Timing, Engine Speed and the resultant Torque.

The following items affect the operation of the control system:

- Idle Control Ignition Timing Target must be more retarded than the normal ignition timing.
- Idle Control Ignition Timing Proportional Gain sets the proportional gain of the control system.
- Idle Control Ignition Timing Minimum sets the retard limit for the control system.
- Idle Control Ignition Timing can never be more advanced than Ignition Timing Normal.

If the activation conditions for idle control (described above) are no longer met, ignition timing is advanced based on the Throttle Pedal Torque Aim and Engine Overrun system until normal ignition timing is reached.

Ignition Timing State will be Idle when the Idle Control Ignition Timing system is controlling ignition timing.

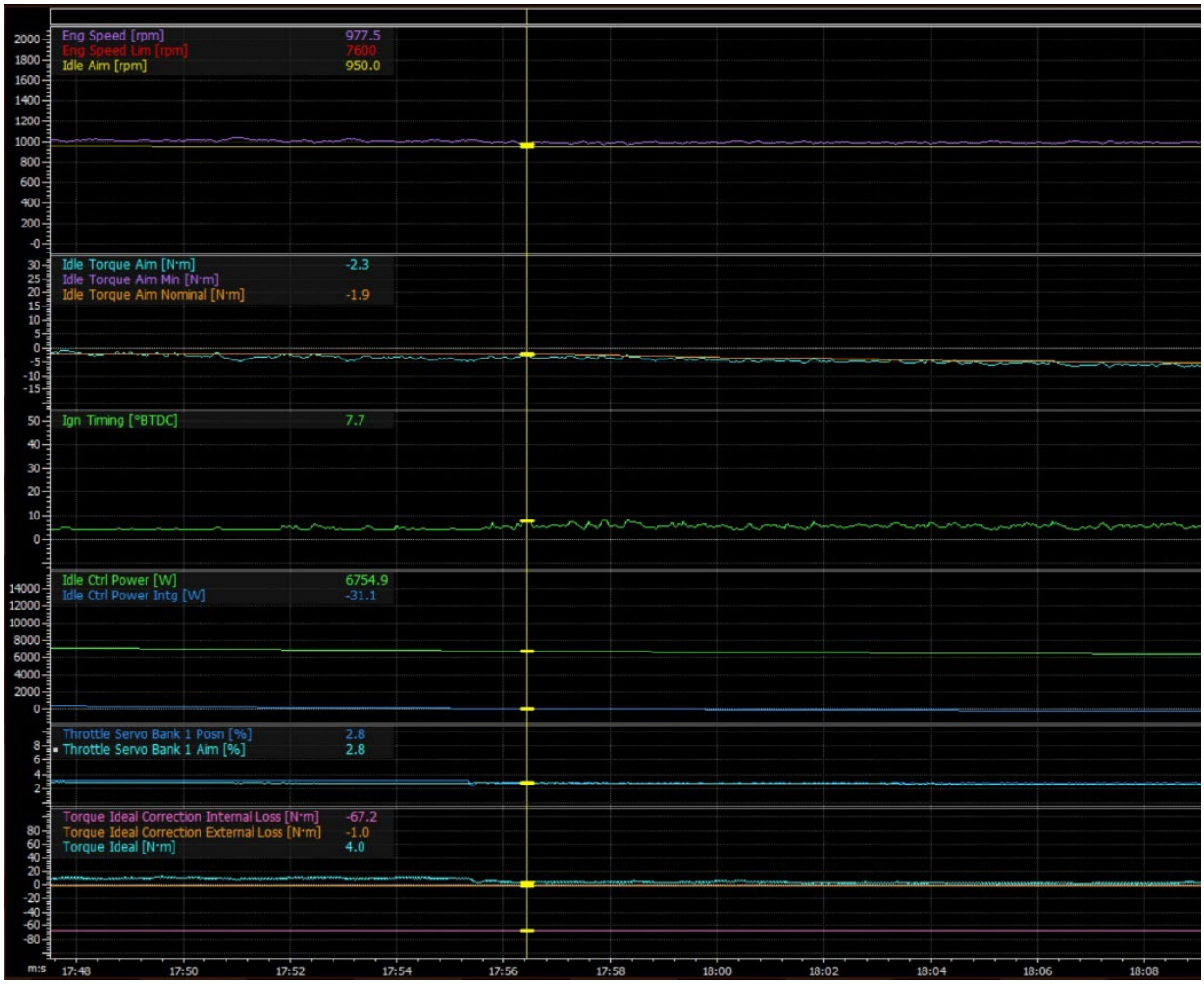


Figure 13. When Torque Ideal Correction Internal Loss and Throttle Area are accurately populated, Idle Torque Aim and Torque Ideal should be stable and near 0 Nm.

Idle Control Power

The Idle Control Power system controls the power produced by combustion by means of an Integral controller. The correct power has been reached when a stable Engine Speed is equal to Idle Aim.

The result of the Idle Control Power system is converted to Idle Torque Aim which is passed through the torque control system to the throttle/s.

The system works in terms of engine power so that if engine speed increases, the effective Torque Aim will decrease to maintain the same power. Engine power is closely related to air mass flow and so maintaining the engine power will maintain the air mass flow and the throttle position will stay stable even if engine speed changes.

With a well-tuned torque control system, if the ignition timing is at MBT and Torque at 0 Nm (at the flywheel) the engine should be running a constant engine speed. For this reason the Idle Control Power uses 0 kW of power at the Idle Aim engine speed as the 'feed forward' to the system. If the engine is idling at the aim speed, 0 kW of power is equal to 0 Nm of torque.

The effective feed forward to the idle control system is therefore tuned when the Torque Ideal Correction Internal Loss table is tuned. External losses for air conditioner etc. are also compensated in Torque Ideal Correction External Loss. No additional compensations are required.

The 0 kW of flywheel power is converted to generated power (total power generated by the pistons) from the Torque Ideal Correction values. This is added to Idle Control Power Integral to find the final Idle Control Power value which is the generated power needed to idle. This final power value is converted back to torque (Torque = Power / Engine Speed) and corrected back to flywheel torque for the Idle Torque Aim value.

As the Idle Control Ignition Timing Target is set less than MBT and feed forward using 0 kW, the engine speed should always fall to the Idle Aim and begin closed loop control where Idle Control Power Integral needs to increase and report a positive value when stable idle is achieved.

If this doesn't happen and engine speed does not fall, tune the following:

- If the Inlet Manifold Pressure Modelled and Inlet Manifold Pressure Bank N Sensor don't match, tune the Throttle Area.
- If the Torque Ideal is not 0 Nm with a stable engine speed and MBT, tune the Torque Ideal Correction.

The integral is shaped by these parameters:

- Idle Control Power Integral Start: the integral value when closed loop control starts. Set it positive to make up for the torque lost by running at Idle Control Ignition Timing Target instead of MBT. Tune for a smooth start to idle control.
- Idle Control Power Integral Minimum: stops the integral winding down too far, for example when rolling down a hill in gear. Too low can stall the engine when the clutch is pressed. Too high can stop Engine Speed reaching Idle Aim.
- Idle Control Power Integral Maximum: too low and Engine Speed may not reach or recover to Idle Aim. Too high and engine speed may flare, for example when load from the clutch is removed.
- Idle Control Power Integral Rate Positive and Idle Control Power Integral Rate Negative: limit how fast the integral can change when the speed error is large, so Idle Control Power Integral Gain can be tuned for steady idling.

ENGINE OVERRUN

The Engine Overrun system gives a smooth transition into and out of fuel cut (full engine braking) without a noticeable bump. It also lets the tuner choose how much engine braking is applied in overrun. Before overrun, the Throttle Pedal Damper softens the drop in torque by filtering Throttle Pedal Torque Aim when it is below Throttle Pedal Damper Threshold.

The system is fully tuneable to suit the driver's preference or vehicle application, but to make the appropriate adjustments it is important to understand how each tuning parameter affects the final engine torque.

Engine Overrun State shows what the system is doing:

- Pedal: the pedal torque request (Torque Pedal, or a higher blip, cruise or anti-lag request) has fallen below Engine Overrun Torque Aim Normal, and idle control is not active. The overrun system takes control of Torque Aim and ignition timing.
- Enabled: fuel cut is active. This needs all of: Engine Overrun Mode is Fuel Cut; the requested generated torque is within Engine Overrun Torque Threshold of Torque Ideal Correction; Engine Speed is above Idle Aim + Idle Activate Engine Speed Margin (plus 200 rpm once in Pedal state, for hysteresis); and Clutch State is not Disengaged or Gear Neutral.
- Disabled: the pedal torque request is above Engine Overrun Torque Aim Normal, or Idle State is Enabled.

The engine overrun system manages the reduction of engine torque to full engine braking in the following sequential steps:

- Reduce air flow. When Throttle Pedal Torque Aim falls below Engine Overrun Torque Aim Normal (typically -20 Nm), Torque Aim is held at this value so the throttle closes no further. Engine Overrun State becomes Pedal.
- Retard ignition. The overrun system retards ignition from Ignition Timing Optimal, using Torque Ideal Ignition Timing Gain, so the final torque still matches the pedal request. Timing cannot be retarded beyond Engine Overrun Ignition Timing Normal (typically -5°BTDC). Set Engine Overrun Torque Aim Normal and Engine Overrun Ignition Timing Normal together so the unloaded engine always decelerates.
- Activate fuel cut. When Engine Overrun Mode is Fuel Cut and the pedal request is within Engine Overrun Torque Threshold (typically 2 Nm) of Torque Ideal Correction, Engine Overrun State becomes Enabled. Engine Overrun Fuel Cut (typically 100%) and Engine Overrun Ignition Cut (typically 0%) are applied. Torque Aim is set to Engine Overrun Torque Aim Active (typically 20 to 50 Nm) and ignition timing to Engine Overrun Ignition Timing Active (typically -15°BTDC). A higher Active torque keeps some manifold pressure for engine braking feel and down shift blips. A smaller Torque Threshold delays fuel cut for longer after the pedal is lifted. If Engine Overrun Mode is Ignition Timing, no fuel (or Ignition) cut is applied.

IGNITION TIMING CONTROL

For closed loop engine speed limiting using ignition timing reduction, the Ignition Timing Control system is used. This system uses PID control to reduce ignition timing to help achieve an engine speed maximum, with a margin above in which ignition cut can be applied.

Due to the system needing to work with a variety of control subsystems and engine running conditions - such as an unloaded free rev during a down shift blip or heavily loaded operating conditions when managing traction control at high torque - there are independent settings for several states, with some subsystems using several states. These parameters need careful calibration to ensure effective control, without commanding excessive ignition retard.

The subsystems that use Ignition Timing Control are:

- Launch - while staging
- Launch - after launching
- Traction Control
- Clutch Slip Control
- Gear Shift for Power Off shifts

- Gear Shift for Power On shifts
- Throttle Pedal Take Off
- Anti Lag

Only one subsystem drives Ignition Timing Control at a time. When several subsystems request an aim, the lowest engine speed aim is used. A gear shift that uses ignition retard overrides all other subsystems until the shift reaches the rearm stage. Ignition Timing Control State reports which subsystem is in control, and Ignition Timing Control Aim reports its aim engine speed.

Each control table (Ignition Timing Control Limit, Ignition Timing Control Feed Forward Torque, the PID gains, Ignition Timing Control Integral Limit and Ignition Timing Control Cut Margin) has Ignition Timing Control State as its axis, so each subsystem can be tuned separately. The tables are only read when the state changes, so they cannot be live tuned. Make a change, then trigger the subsystem again to test it.

Activation: if Coolant Temperature is above Ignition Timing Control Activate Coolant Temperature, or the maximum exhaust temperature is above Ignition Timing Control Activate Exhaust Temperature, Ignition Timing Control Diagnostic reports a fault. The system then stops retarding the timing and passes the aim to the ignition cut based Engine Speed Limit system instead, to avoid the extra exhaust heat caused by retard. A configured sensor in fault also causes this fallback. Set either parameter to 0 °C to disable that check.

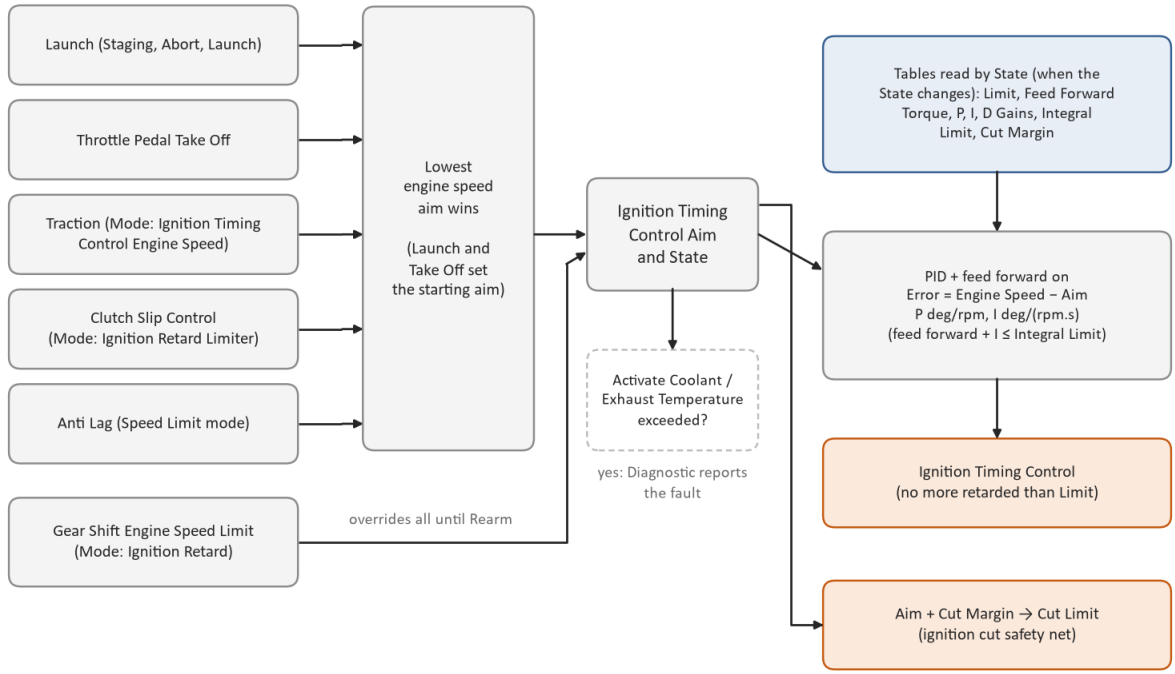


Figure 14. Ignition Timing Control. The lowest engine speed aim from the active systems is used, Gear Shift overrides the others until Rearm, and the tables for the active State set the control loop and cut limit.

Control Parameters

Ignition Timing Control Limit

Ignition timing will never be retarded past this value from this subsystem. This value may be set to allow a lot of retard, and Engine Speed can be controlled using retard alone. Alternatively, if some ignition cut and retard is desired, this can be set to limit the amount of retard, meaning the Engine Speed can exceed the Ignition Timing Control Aim target by more than the Ignition Timing Control Cut Margin, and a variable amount of ignition cut is applied to control the Engine Speed via the Engine Speed Limit system.

Ignition Timing Control Feed Forward Torque

This feed forward table sets the torque likely to be applied to the engine once Engine Speed reaches Ignition Timing Control Aim. The ECU converts this torque into a starting ignition timing (Ignition Timing Control Feed Forward) for the closed loop control. In free revving states, such as Launch Staging or a down shift blip, set 0 Nm. In loaded states, such as Traction Control and Launched, set a high value. A value higher than the engine can produce (for example 1000 Nm) means the timing is not retarded when control begins.

Ignition Timing Control PID

The closed loop component of the ignition timing control system requires careful consideration during initial setup and will often require fine tuning for optimisation. The proportional gain component reacts to how far over the Ignition Timing Control Aim the Engine Speed is, with the gain expressed in degrees per rpm of error. This means that with a proportional gain of 0.05 deg/rpm, the ignition timing would be retarded 7.5 degrees if Engine Speed exceeded the Ignition Timing Control Aim by 150 rpm.

The integral component adds retard over time while Engine Speed stays above Ignition Timing Control Aim. Ignition Timing Control Integral Gain is set in deg/(rpm.s): degrees of retard per rpm of error for each second the error is held.

For example, with an Ignition Timing Control Integral Gain of 0.05 deg/(rpm.s), if Engine Speed stays 150 rpm above Ignition Timing Control Aim for 1 second, the integral progressively adds 7.5 degrees of retard (0.05 x 150 x 1) during that second, or until Ignition Timing Control Integral Limit is reached.

Ignition Timing Control Integral Limit is an absolute ignition timing (dBTDC). The integral and feed forward components combined are never retarded past this timing. For example, if the limit is -20 dBTDC and the feed forward is -15 dBTDC, the integral can only add 5 degrees of retard. The proportional and derivative components can still retard further, down to Ignition Timing Control Limit. This prevents integral wind up, which matters most in states that control engine speed for a long time, such as Launch Staging. Traction events are usually short. The integral is reset each time Ignition Timing Control State changes.

The derivative component reacts to how fast the engine is accelerating or decelerating relative to the aim. Ignition Timing Control Derivative Gain is shown in deg/rpm, but it acts as degrees of retard per rpm/s. With a gain of 0.001, an extra 1 degree of retard is applied when the engine is accelerating at 1000 rpm/s. Ignition Timing Control Derivative Filter filters Engine Speed before the acceleration is calculated. Increase it if the derivative is noisy, and decrease it if it lags.

Ignition Timing Control Cut Margin

This defines the Margin the Engine Speed can reach above the Ignition Timing Control Aim before Ignition Cut is applied by the Engine Speed Limit system. This will prevent the Engine Speed from going out of control if the Ignition Timing reaches the Ignition Timing Control Limit or if the PID component is poorly calibrated. The margin can also be set low if the user wishes to implement ignition cut in part of the engine speed control strategy for the corresponding control state.

KNOCK CONTROL

Much like our standard GP Packages, the Knock Control strategy is used to reduce the effects of engine damaging knock or pinging. A knock sensor is fitted to the engine block and the ECU effectively listens for the sound produced by knock. GPRP Pro adds a series of advanced control parameters that allow for greater control and the ignoring of false knock events, such as after a gear shift.

Knock Frequencies

Knock makes the engine block ring. The sound is strong at some frequencies and weak at others, so the knock sensor signal is band pass filtered to reduce noise from other frequencies. The M1 ECU can filter four frequencies at the same time, set by Knock Frequency A to Knock Frequency D. Each band is about 1 kHz wide and the lowest usable frequency is 1193 Hz. Some cylinders can have more background noise at the frequency that works best for the others. Knock Cylinder N Mode selects the band used for each cylinder: Frequency A, Frequency B, Frequency C, Frequency D, or Frequency A B C D, which uses the highest of the four levels. Set it to Disabled for no knock control on that cylinder.

Knock Count

Each engine cycle, the knock level above Knock Threshold is added to Knock Count Cylinder N. Before it is added, it is multiplied by Knock Count Compensation (see Knock Ignore and Knock Cut). If no knock is detected, the count reduces by Knock Count Recovery (see Knock Recovery). The count is limited to Knock Count Limit (typically 200%) so that it does not take an unnecessarily long time to recover. Small continuous knock can build up a high count and apply a large amount of control. Larger knock events build the count faster and apply control more quickly.

Ignoring single knock events: Knock Count Ignore Threshold lets the first knock event after a quiet period be ignored. The first event is only added to Knock Count Cylinder N Total. If another knock event occurs while the total is still above the threshold, the full total is copied to Knock Count Cylinder N and fuel and ignition action is taken. Lower thresholds keep subsequent knock from being ignored for longer. Start with 0%, which disables this feature, then review logged Knock Count Cylinder N Total data before increasing it.

Knock Control

Ignition retard is the main method used to control knock on each cylinder. Knock Ignition Timing Limit sets the maximum retard from Ignition Timing Normal. It has Engine Speed and Engine Load Normalised axes, the same as Ignition Timing Main, plus Fuel Composition, so the maximum retard can vary with operating condition. Knock Ignition Timing Retard sets the retard applied, as a percentage of this limit, for each value of Knock Count Cylinder N. For example, with a limit of 10 degrees and a retard of 50% at the current count, 5 degrees of retard is applied to that cylinder. The result is reported in Ignition Cylinder N Trim Knock.

Additional Knock Control Strategies

As Knock is uncontrolled combustion, two by-products of this are high cylinder pressures and additional heat. The high cylinder pressure breaches the gaseous boundary layer that protects the piston crown from combustion heat, which allows the combustion heat to heat up the piston crown; in extreme or continued knock events this can cause the piston crown and ring land area to soften. To combat this, GPRP Pro offers two methods to assist in cooling temperatures.

The first method is Knock Fuel Trim. This table sets the fuel trim applied to a cylinder for its Knock Count Cylinder N, and the result is reported in Fuel Cylinder N Trim Mixture Aim Knock. Extra fuel cools the cylinder, and a richer mixture is often less prone to knock. Adding fuel reduces torque less than retarding the timing, but it is not as effective at stopping knock.

As a failsafe above this, a Knock Ignition Cut Threshold can be set. If the knock count exceeds this value, the next ignition event for that cylinder will be cut. This is designed as a final strategy for knock control and will only cut after the Knock Ignition Cut Threshold is exceeded – if no knock is detected on the following event, ignition will resume on the next cycle, even if the Knock Count is above the threshold.

Knock Ignore and Knock Cut

A gear shift can cause a single knock event that does not need knock control, even when no fuel or ignition cut is used for the shift. This is caused by the rapid change in engine speed and torque. Fuel and ignition cut used to reduce torque can also cause a single knock event straight afterwards.

Knock Cut Event reports the highest current level of ignition cut, fuel cut or Engine Speed Limit cut. During a gear shift, Knock Cut Event Gear Shift is also used as a cut level. Knock Cut Event Filter (start with 50 ms) holds the value up for a short time after the cut ends. Knock Cut Event Compensation uses Knock Cut Event as its axis and reduces the knock level added to the count. Set it to 100% (no compensation) at low cut levels, and lower at high cut levels to partly or fully ignore knock.

Set Knock Cut Event Gear Shift to 0% for knock control to react normally during gear shifts. Higher values reduce the reaction, by the amount set at that value in Knock Cut Event Compensation.

Pressure transients are the other common cause of single knock events that need no action. Knock Transient Event is the rate of change of Inlet Manifold Pressure in kPa/s, filtered by Knock Transient Event Filter (start with 100 ms). Knock Transient Event Compensation uses this as its axis and reduces the knock level added to the count. It covers both rising and falling pressure. Set it to 100% (no compensation) at low rates of change, and lower at high rates.

Knock Recovery

In GPRP Pro, knock recovery is based on engine cycles rather than time. A time based recovery (degrees per second) can take a long time to remove large knock retard at high engine speed, but the cylinder recovers over a number of engine cycles, not a time period. Knock Count Recovery is set in %/ratio/cycle. With a value of 10%, the knock count reduces by 10% of its current value each cycle.

For example, a knock count of 50% will reduce by 5% to 45% in one cycle, and by 4.5% to 40.5% on the next cycle, and so on. This allows for a quicker initial recovery of Ignition Timing to maximise performance.

TRACTION CONTROL

The Traction Control system has both passive and active components to aid in power delivery for two and four wheel drive vehicles by means of engine speed limiting. For the best possible acceleration and vehicle dynamics, some slip of the driven wheels is required. The engine speed limiting can be achieved by means of ignition cut, ignition retard, throttle based torque limiting, or a combination of multiple strategies.

Traction control needs a good measure of true ground speed. Traction Source selects where it comes from:

- Vehicle Speed Estimate (recommended): uses Vehicle Speed Estimate, which can combine wheel speed, GPS, Race Time and engine speed with acceleration and deceleration limits and the Vehicle Speed Estimate Model (see Vehicle Speed Estimate). Launch, Gear Shift, Transfer and Vehicle Speed Limit use the same speed, so all of these systems work from the same ground speed.
- Vehicle Speed: uses Vehicle Speed directly. It is only suitable when wheel speed always shows the true ground speed, for example with non-driven wheel speed sensors on a 2WD car.
- Vehicle Speed Drive: uses the speed calculated from Engine Speed and the current gear. It is not available when the gear is not known.
- GPS Speed: uses GPS Speed while a valid GPS signal is received. GPS speed typically lags the true speed when accelerating.

The result is Traction Vehicle Speed, which is never allowed to rise faster than Traction Vehicle Acceleration Maximum. If the selected source becomes unavailable, for example when the GPS signal is lost or the gear is not known, Traction Vehicle Speed continues from the last known speed, rising at Traction Vehicle Acceleration Maximum, so some traction control remains while the source recovers.

In some conditions the wheel speeds cannot show the true ground speed. Examples are a rear wheel drive car doing a wheel stand at launch, where the non-driven wheels are off the ground, or a 4WD car with all four wheels slipping. In these cases use Vehicle Speed Estimate with Vehicle Speed Estimate Mode set to Estimate Slower or Race Time, so that a time based speed from Race Time Vehicle Speed, or an acceleration limited speed, is used instead.

Operational Requirements

There are several requirements for the traction system to work:

- Driver Traction Switch must be On or Model Calculate. If no switch is assigned, it defaults to On.
- Traction Mode needs to be set to a mode other than Not In Use.
- Gear State must be In Gear (not Neutral). The Gear system must be set up and calibrated correctly, with a valid Vehicle Total Drive Ratio.
- Traction Vehicle Speed must be greater than or equal to Traction Activate Vehicle Speed. The speed source selected by Traction Source must be working correctly.
- The circumference of the driven wheels, as defined by Vehicle Drive Type, must be valid (Wheel Speed Front Circumference and/or Wheel Speed Rear Circumference).
- The Traction Aim Main table should have non-zero percentage slip values.

Operation

Traction Control limits Engine Speed so that the driven tyre surface speed is limited to Traction Aim Speed. This is Traction Vehicle Speed plus Traction Aim Slip. Traction Aim Slip is Traction Vehicle Speed multiplied by Traction Aim, where:

- Traction Aim = Traction Aim Main x Traction Aim Compensation, plus Traction Aim Offset converted to a percentage of the current speed.
- Traction Aim Main has Traction Model Driven Wheel Maximum Longitudinal Force and Driver Traction Aim Switch as axes.
- Traction Aim Compensation = Traction Aim Compensation Vehicle Acceleration Lateral x Traction Aim Compensation Gear.
- Traction Aim Offset (km/h, typically 0) adds a fixed speed difference. It is useful on loose surfaces such as gravel.

Traction Aim Type sets which wheel is controlled. Average Driven Wheel controls the average of the driven wheels. Fastest Driven Wheel controls the fastest driven wheel, and needs both driven wheel speed sensors working.

From Traction Aim Speed, the driven wheel circumference and Vehicle Total Drive Ratio, the ECU calculates Traction Engine Speed Limit. This is the target for the selected Traction Mode. Where Clutch Slip is measured, it is added to the limit so the engine can rev with the clutch disengaged. If a clutch switch or sensor shows the clutch is disengaged, the limit is removed. In Engine Speed Limit and Ignition Timing Control Engine Speed modes, Traction Engine Speed Limit Filter slows how fast the limit falls. This allows a little extra slip just after a gear shift instead of a large torque cut. Set it to 0 to disable.

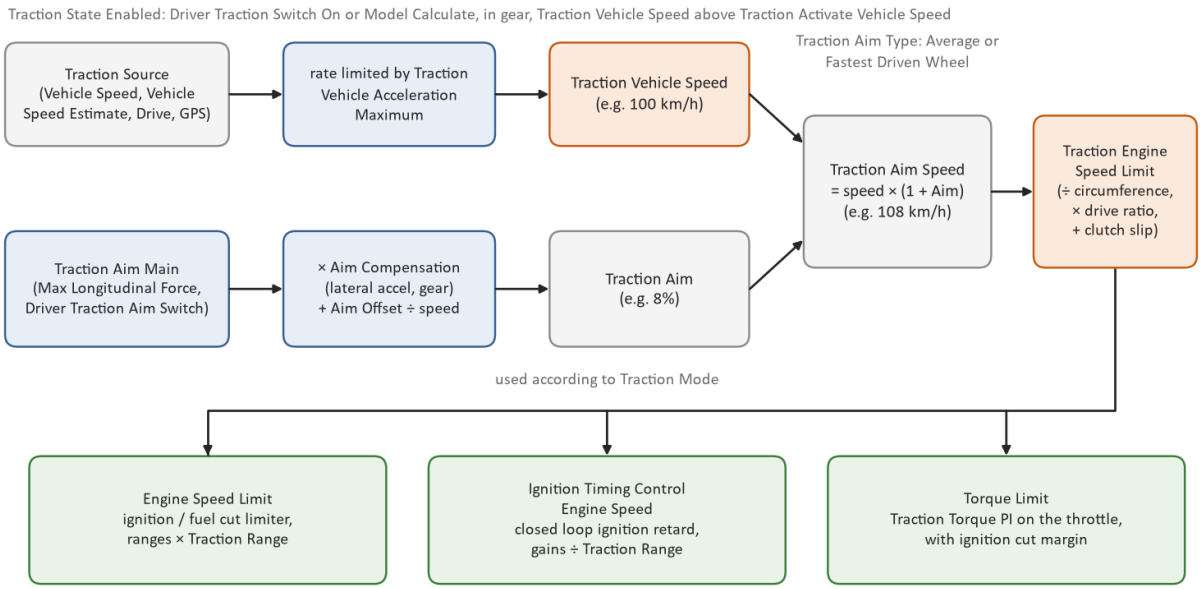


Figure 15. Traction control. Traction Vehicle Speed and Traction Aim set the Traction Aim Speed, which is converted to the Traction Engine Speed Limit and applied according to Traction Mode.

Engine Speed Limit Mode

When Engine Speed Limit Mode is utilised, a progressive ignition and/or fuel cut based engine speed limiting strategy is used for managing wheel slip. This is done through use of the Traction Range table, which is multiplied to the Traction Engine Speed Limit to determine the rpm range that the Fuel and Ignition cuts will progress from 0% to 100% cut. As the Traction Range is a percentage, the Ignition and Fuel Cut ranges will increase at higher engine speed to allow for a broader working range before 100% cut is ever employed. There is also a Fuel Margin parameter in which to offset the Traction Engine Speed Limit Fuel Range in relation to the Traction Engine Speed Limit Ignition Range.

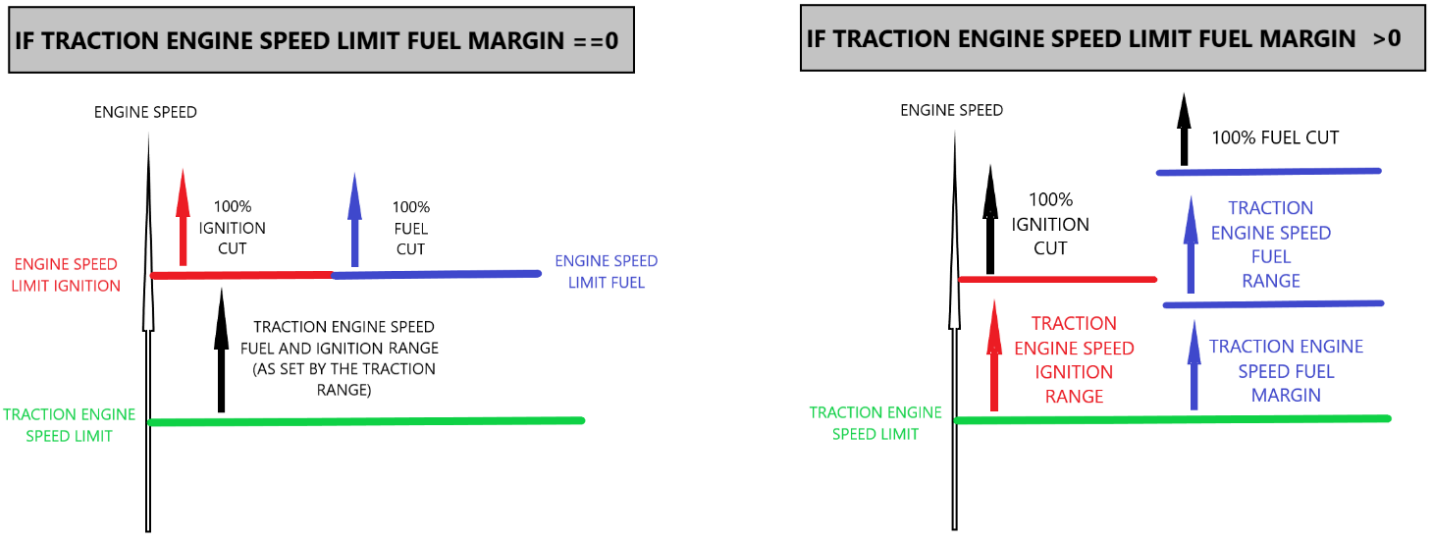


Figure 16. Interaction of the Traction Range with the Engine Speed Limit System.

In this mode, items under the Traction Torque group or Ignition Timing Control group (for traction control) are not used.

Torque Limit

In Torque Limit mode, the Traction Torque system uses throttle based torque limiting. When Engine Speed first exceeds Traction Engine Speed Limit, the ECU records the engine torque at that moment. A PI controller acting on the engine speed error then calculates Traction Torque Reduction, a percentage of that recorded torque, and sets Traction Torque Limit. The throttle servo achieves the reduction. An ignition cut limit of Traction Engine Speed Limit + Traction Torque Cut Margin is a safety net in case the PI control does not control the slip, or Traction Torque Inlet Mass Flow Minimum is reached.

Traction Torque Integral Start is applied as soon as slip exceeds the aim, so a sudden break away can be controlled. While slip is reducing, the integral reduces at Traction Torque Integral Decay, and it keeps decaying once slip is below the aim. A high decay rate returns torque sooner.

Traction Range divides the PI gains and multiplies Traction Torque Cut Margin, so the driver can adjust the aggressiveness of control with Driver Traction Range Switch. Values below 10% are treated as 10% in this mode. Tune the system with Traction Range set to 100% first.



Figure 17. Traction Torque Limit Parameters.

The Traction Torque Inlet Mass Flow Minimum is the setpoint of the minimum amount of Inlet Mass Flow that is allowed for a given Boost Pressure. This is to ensure that the turbo is not run into surge from torque reduction. In some cases, particularly at higher pressure ratios, this may prevent sufficient torque reduction from taking place to adequately reduce wheel slip, in which case the cut margin can be used as a safety net to reduce torque.

The Torque Reduction system can improve the response of throttle based traction control. Throttle closing and manifold pressure take time to reduce the torque. When the requested torque is lower than the modelled torque by more than Torque Reduction Threshold, the ECU retards the ignition timing, down to Torque Reduction Ignition Timing Limit, to make up the difference. If more reduction is needed, cut is added up to Torque Reduction Cut Limit. Torque Reduction Cut Type selects ignition or fuel cut. Torque must also be above Torque Reduction Activate Torque.

For example, torque is 600 Nm and Traction Torque suddenly requests 300 Nm. The throttle cannot move instantly, so the ECU retards the timing (and cuts if the timing limit is reached) to make up the difference. As the throttle closes and modelled torque falls to, for example, 450 Nm, less reduction is needed and the timing returns towards normal. This usually takes 20 to 30 ms. Set Torque Reduction Threshold to 100% to disable this feature.

Additionally, the Torque Limit Response system can be used to prevent the throttle opening to 100% once manifold pressure is above the Activate Inlet Manifold Pressure parameter. The throttle is instead held at a value that will deliver the Torque Limit Response Maximum setting. If this is set to 97%, for example, only 97% of full torque is allowed. In a boosted application, the maximum boost can usually be increased to offset the difference so there is no actual loss of performance. Typically the throttle will be controlled from 30% to 60% depending on engine speed. This means when Traction Control then requests lower torque and the throttle needs to close to say 40%, it moves from 60%, which is much faster than moving from 100%, increasing the torque reduction response of traction control.

This system uses a Proportional and Integral component to calculate the percentage of torque reduction required. The calculation works in the same way as the timing control. The proportional gain component reacts to how far over the Traction Engine Speed Limit the Engine Speed is, with the gain expressed in percentage of torque reduction per 1000 rpm of error.

This means that with a proportional gain of 50%/1000 rpm, the proportional component of the control would request a 30% reduction in torque for the engine speed exceeding the Traction Engine Speed Limit by 600 rpm. It is worth noting at this point that if wheel slip first occurs below the Traction Torque Inlet Mass Flow Minimum, this is still the point from which the torque reduction is calculated.

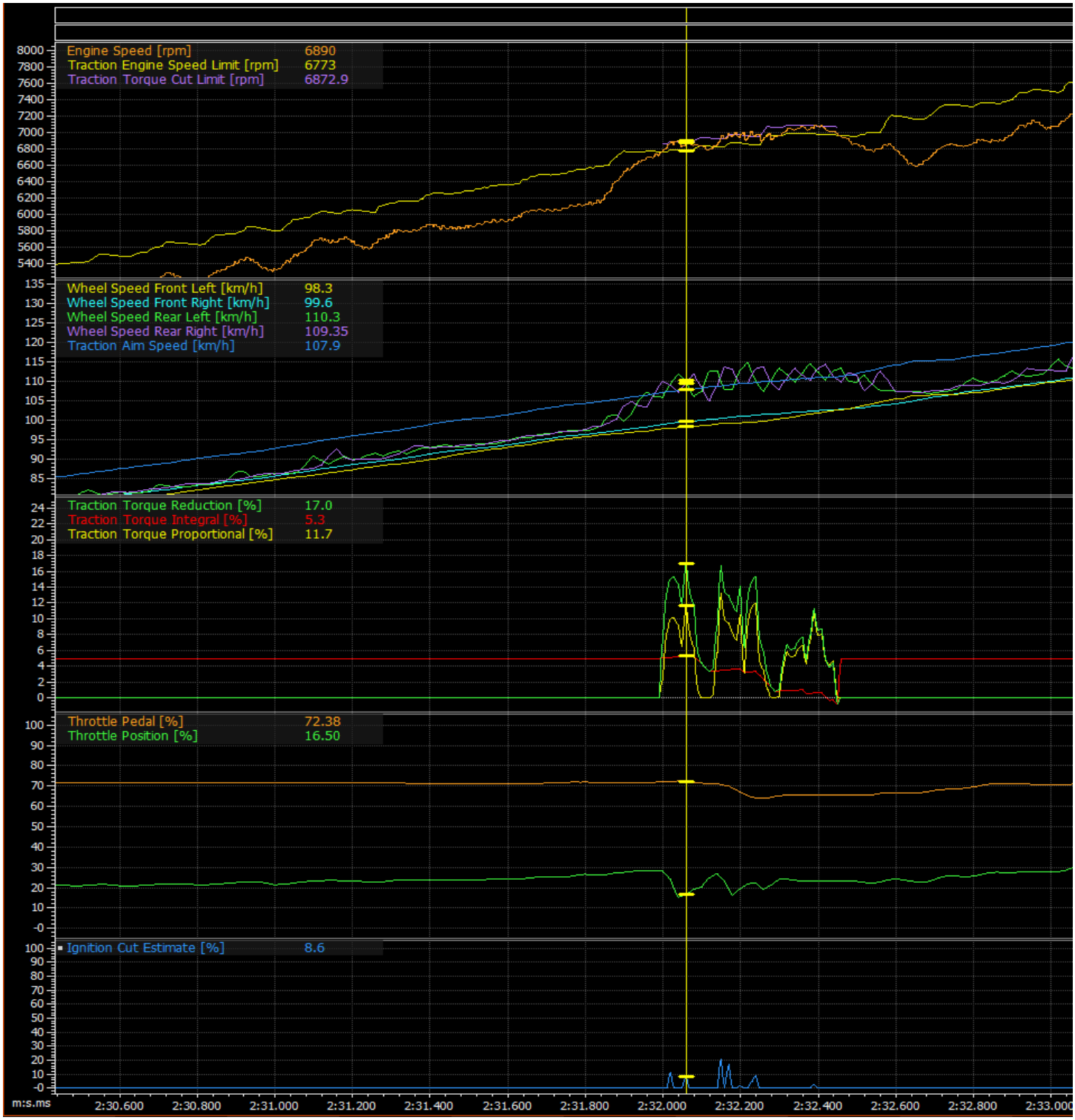


Figure 18. Traction Torque Limit PI control responding to wheel slip and reducing throttle servo.

Ignition Timing Control Engine Speed

When the Ignition Timing Control Engine Speed mode is utilised, closed loop ignition retard is used via the Ignition Timing Control system. In this mode, the Traction Range is applied to the PID gains to set the aggressiveness of the control and the rpm range it occurs over with a Driver Switch. The system should be initially tuned with Traction Range set to 100%.

An ignition cut limit of Ignition Timing Control Aim + Ignition Timing Control Cut Margin is applied while the system is active. This covers aggressive slip events that retard alone cannot control, or a poorly tuned PID controller. In this mode the Cut Margin is multiplied by Traction Range. The margin can also be set small to deliberately use some ignition cut. Traction Engine Speed Limit Fuel Margin and the Traction Torque group are not used in this mode.

To tune this system, several items in the Ignition Timing Control need to be set. The example settings that follow simplify the operation somewhat, as the setting of the Ignition Timing Control Feed Forward Torque and the Traction Range are used in conjunction with these:

- Ignition Timing Control Limit: This is the most retarded the timing can be, for example, -5 degrees after top dead centre. This limits the overall amount of torque reduction, which can prevent excessive torque reductions.
- Ignition Timing Control Feed Forward Torque: set a torque higher than the engine can produce, for example 1000 Nm or more, so the timing is not retarded when control begins.
- Ignition Timing Control Proportional Gain: Expressed as degrees per rpm. So for a setting of 0.04, the timing is retarded by 4 degrees for every 100 rpm over the limit (until the Ignition Timing Control Limit is reached).
- Ignition Timing Control Integral Gain: set in deg/(rpm.s). With a setting of 0.05, if Engine Speed is 100 rpm over the limit for 1 s, the timing is progressively retarded by 5 degrees during that second. This is added to the proportional retard, until Ignition Timing Control Integral Limit is reached.
- Ignition Timing Control Integral Limit: the most retarded absolute timing that the integral and feed forward together can reach. It prevents integral wind up, although traction events are usually short.
- Ignition Timing Control Derivative Gain: shown in deg/rpm, acting per rpm/s. If the engine is accelerating at 1000 rpm/s, a value of 0.001 retards the timing by 1 degree.
- Ignition Timing Control Cut Margin: for example 300 rpm. Ignition cut is applied if Engine Speed is more than 300 rpm over the limit (at a Traction Range of 100%). At 6000 rpm this is about an extra 5% of wheel slip. Ideally it is never reached. It is only a safety net.

Traction Model

The Traction Model is the open loop, or feed forward, part of the traction control strategy. It limits engine torque with the throttle so that the force at the driven tyres does not greatly exceed the available grip. It does not monitor wheel slip. Grip is set by Traction Model Tyre Friction Coefficient, which the driver can adjust. With torque already limited, this helps the closed loop Traction control as it only needs a small amount of retard, cut or throttle reduction to control any excessive slip.

Because the model only assists the closed loop control, tune it to allow wheel torque slightly beyond the available grip. A model that is too conservative reduces the vehicle's maximum acceleration.

Each step of the calculation is reported in its own channel, so the model can be compared with sensor data. Model values can also be used by other systems (see Using the Traction Model with Other Systems).

Mode and driver switch

Set Traction Model Mode to Enabled to calculate the model. Traction Mode must also be set to a mode other than Not in Use, so that the Traction Model settings can be accessed. Driver Traction Switch then controls whether the model's torque limit is applied, as well as enabling Traction slip control:

Driver Traction Switch	Traction slip control	Traction Model torque limit
Off	Disabled	Not applied
On	Enabled	Applied
Model Calculate	Enabled	Not applied (model still calculated)
Model Only	Disabled	Applied

Settings

The model relies on accurate values for these settings and signals:

- Vehicle Mass.
- Vehicle Mass Split: the percentage of vehicle mass over the rear wheels. Used with Vehicle Drive Type to find the static mass over the driven wheels.
- Vehicle CoG Height Ratio: the centre of gravity height as a ratio of the wheelbase. Used to calculate weight transfer towards the driven wheels (RWD) or away from them (FWD). Weight transfer is not included for AWD, because what is removed from one axle is added to the other.
- Vehicle Aero Drag, Vehicle Rolling Drag and Vehicle Down Force (front and/or rear depending on Drive Type).
- Vehicle Drive Circumference, Vehicle Total Drive Ratio and Vehicle Drive Train Efficiency.
- Traction Vehicle Acceleration Lateral and Traction Vehicle Acceleration Vertical.
- The torque calculations, including Torque Ideal Correction Inertial.

Most of these can be measured, so set them from measurements rather than tuning them from data.

The model assumes that:

- The relationship between vertical and maximum horizontal tyre force is linear. This is mostly true unless the tyre is overloaded.
- Vehicle mass is constant. Fuel load changes are not included at this time.
- Differentials are effectively locked. Side to side weight transfer in a corner (where an open diff lets the inside tyre slip) and AWD systems with limited torque delivery to one axle are not modelled.

Calculation channels

Each step of the calculation is reported in its own channel:

Channel	Description
Traction Model Driven Wheel Static Mass	Static mass over the driven wheels, from Vehicle Mass, Vehicle Mass Split and Vehicle Drive Type.

Channel	Description
Traction Model Driven Wheel Down Force	Vehicle Down Force, Down Force Front or Down Force Rear, depending on Drive Type.
Traction Model Driven Wheel Vertical Force	Force on the driven wheels when accelerating at the grip limit. Includes vertical acceleration, down force and (for 2WD) weight transfer, at the current lateral acceleration.
Traction Model Driven Wheel Maximum Lateral Force	Maximum cornering force before excessive slip angle. Weight transfer is not included, as maximum lateral force occurs with no longitudinal acceleration.
Traction Model Driven Wheel Normalised Lateral Force	Current lateral force as a percentage of Maximum Lateral Force. This is the axis of the Ellipse table.
Traction Model Driven Wheel Maximum Longitudinal Force	The maximum drive force before excessive slip.
Traction Model Torque Limit Wheel	Combined axle torque at the driven wheels that delivers the Maximum Longitudinal Force (plus rolling drag). It is never less than Traction Model Torque Limit Wheel Minimum.
Traction Model Torque Limit	Torque Limit Wheel converted to engine torque using the total drive ratio, drive train efficiency and inertia correction. This is the limit applied to Torque Limit.
Traction Model Maximum Acceleration	The longitudinal acceleration the vehicle should reach at the grip limit.
Traction Model Maximum Deceleration	The equivalent maximum deceleration under braking, assuming all four wheels brake.

Traction Model Torque Limit Wheel Minimum stops the model removing too much torque. For example, if Normalised Lateral Force exceeds 100% the calculated limit would be 0 Nm, which may not be wanted.

Tyre Friction Coefficient

Traction Model Tyre Friction Coefficient is the ratio of horizontal force to vertical force at which the driven tyres, combined, begin to slip excessively. This is the mechanical grip. As a simple starting point, if the vehicle starts to slide sideways when Traction Vehicle Acceleration Lateral reports 1.2 G (at constant speed, with no down force, on a level surface), start with 120%.

For an AWD vehicle, maximum longitudinal G is roughly comparable to the coefficient. For a 2WD vehicle it is not. For example, if half of the vehicle mass is on the driven wheels at maximum acceleration, a coefficient of 100% only allows about 0.5 G.

Typical starting values are:

- Road tyres on tarmac: dry 100%, wet 70%.
- Race radial tyres on tarmac: dry 120%, wet 80%.
- Race slicks on dry tarmac: 150%.
- Race wet tyres, or wet tarmac: 100%.

Grip changes with tyre temperature, road surface and rain, so use Driver Traction Model Switch to adjust the coefficient on demand while driving. A value above the ideal can also be useful.

On rough surfaces some slip is desirable because grip changes very quickly, and allowing a little slip means the closed loop control only needs a small amount of cut or retard.

Traction Model Ellipse

Often referred to as a tyre force ellipse/circle or a friction ellipse/circle, this is used to represent the non-linear tyre forces (or available grip) when lateral force (steering) is applied under acceleration. In GPRP Pro, this is shown as a quarter ellipse and the table is mirrored for lateral force in the opposing direction. As the traction system only deals with acceleration, we only look at half of the tyre friction circle.

The table sets how much longitudinal force (acceleration) can be applied for a given lateral force (cornering), using Traction Model Driven Wheel Normalised Lateral Force as the axis. This is calculated from Traction Vehicle Acceleration Lateral, a filtered value of Vehicle Acceleration Lateral. If no resource is assigned for Vehicle Acceleration Lateral, Normalised Lateral Force stays at 0%. In a straight line it should be close to 0%, and at maximum cornering it should be close to 100% if the Tyre Friction Coefficient suits the conditions. The 100% site should always be 0%.

The table can be set to a default shape by pressing Q (Reset Shape) on the table. Traction Model Ellipse Shape sets the shape and Traction Model Ellipse Ratio sets the longitudinal scaling, which is the value at the 0% site. At 75% Normalised Lateral Force, the allowed longitudinal force is 25% with a Shape of 1.0 (diamond), 66% with 2.0 (ellipse) and 83% with 3.0 (more square). Typical settings are a Shape of 2.0 and a Ratio of 1.0. Set the Ratio below 1.0 if the tyre has more lateral grip than longitudinal grip, and above 1.0 if it has less. Pressing Q overwrites any previous tuning in the table.

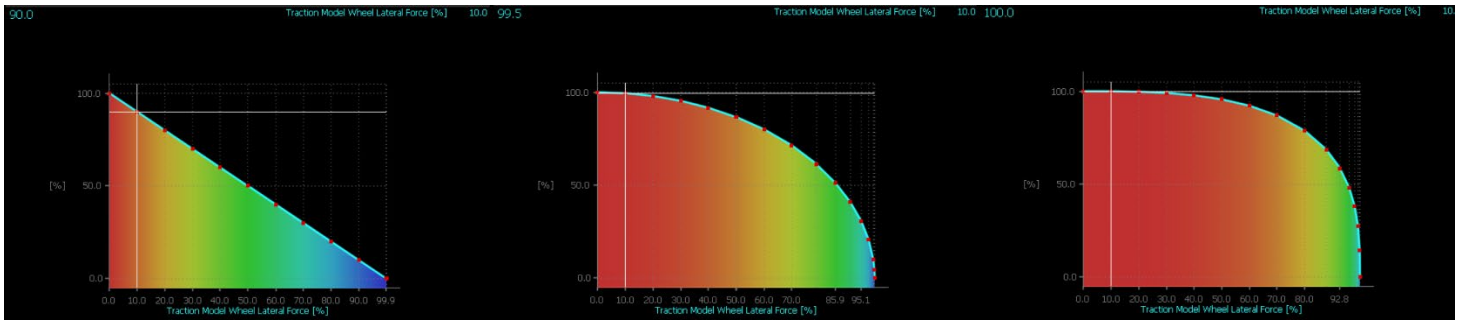


Figure 19. Ellipse variations with a Shape Value of 1.0, 2.0 and 3.0 (left to right). Ratio is set to 1 for all three examples.

This ellipse can be manually modified to more accurately represent the tyre's behaviour or effectively apply limits to the amount of torque reduction applied.

Tuning the Traction Model from Data

Tune the model from logged data with Traction Model Mode set to Enabled and Driver Traction Switch set to Model Calculate, so the model is calculated without limiting torque while slip control stays active. Log the calculation channels above together with Vehicle Acceleration Longitudinal, Vehicle Acceleration Longitudinal Torque, Traction Vehicle Acceleration Lateral, Traction Vehicle Acceleration Vertical and the wheel speeds.

Work through these steps in order, because each step relies on the ones before it:

Step 1: Check the measured settings. Confirm Vehicle Mass, Mass Split, CoG Height Ratio, Drive Type, gear and final drive ratios, Drive Circumference and Drive Train Efficiency. These scale every calculation in the model.

Step 2: Check the torque and drag. At part throttle with no wheel slip, Vehicle Acceleration Longitudinal Torque should match Vehicle Acceleration Longitudinal. If it does not, correct the torque model, drive ratios, Aero Drag and Rolling Drag first. The Traction Model converts force to torque with the same calculations, so its torque limit cannot be accurate until this matches.

Step 3: Set the friction coefficient from cornering. In steady cornering at the grip limit, Traction Model Driven Wheel Normalised Lateral Force should reach close to 100%. If it peaks well below 100%, the coefficient is too high. If it passes 100% before the car reaches the limit, the coefficient is too low. If the error changes with speed, check Vehicle Down Force rather than the coefficient.

Step 4: Check acceleration at the grip limit. In a hard straight line acceleration where the driven wheels are just starting to slip excessively, Traction Model Maximum Acceleration should match Vehicle Acceleration Longitudinal.

Step 5: Check braking. Under maximum braking, Traction Model Maximum Deceleration should match Vehicle Acceleration Longitudinal. Braking uses all four wheels, so this checks the coefficient and down force without weight transfer to the driven wheels. This is a useful cross check on 2WD vehicles, and also works on slopes and in corners with little understeer or oversteer.

Step 6: Shape the ellipse. When accelerating out of corners, compare Maximum Acceleration with the measured acceleration at the point where slip starts, at intermediate Normalised Lateral Force values. Adjust the Ellipse sites at those values.

Step 7: Apply the limit. Set Driver Traction Switch to On (or Model Only for the model without slip control). Aim for the model to allow slightly more torque than the available grip, so the closed loop control only trims small amounts of slip.

Use this table to decide what to adjust:

What the data shows	Likely adjustment
Maximum Acceleration is higher than measured at the grip limit, at all speeds	Tyre Friction Coefficient is too high, or Vehicle Mass is too low.
Maximum Acceleration is lower than measured at the grip limit, at all speeds	Tyre Friction Coefficient is too low, or Vehicle Mass is too high.
Matches at low speed, but the error grows with speed	Check Vehicle Aero Drag and Vehicle Down Force. Too much model acceleration at speed means drag is too low or down force is too high.
Acceleration (2WD) is wrong but braking matches	Weight transfer is wrong. Check Vehicle CoG Height Ratio and Vehicle Mass Split.
Error only over crests and dips	Check the source and scaling of Traction Vehicle Acceleration Vertical.
Normalised Lateral Force well below 100% at the cornering limit	Tyre Friction Coefficient is too high for these conditions.
Normalised Lateral Force above 100% before the cornering limit	Tyre Friction Coefficient is too low, or the static mass over the driven wheels is wrong (Mass Split, Drive Type).
Straight line is correct, but torque is limited too much on corner exit	Increase the Ellipse values at intermediate Normalised Lateral Force, or use a larger Ellipse Shape.
Torque limit falls to near 0 Nm at high lateral G	Set Traction Model Torque Limit Wheel Minimum.

Using the Traction Model with Other Systems

The model values are calculated whenever Traction Model Mode is Enabled, whatever the Driver Traction Switch position. With the switch at Model Calculate (or Off), the torque limit is not applied but other systems can still use the model values.

Traction Aim Main. Traction Aim Main has Traction Model Driven Wheel Maximum Longitudinal Force as an axis, together with Driver Traction Aim Switch. For a given tyre, the force it can carry before peak grip is closely related to the slip ratio it needs. With high grip in a straight line the tyre twists more before peak grip and needs more slip. When cornering hard, or on a wet surface, only a small longitudinal force is possible and less slip is needed. With a well configured model, the aim slip adjusts automatically for the driver grip setting, down force, weight transfer, vertical acceleration and cornering. If the Traction Model is not used, the axis falls back to the current wheel force based on Torque Wheel, which gives a similar result based on the current wheel force rather than the modelled maximum force.

Vehicle Speed Estimate. Traction Model Maximum Acceleration and Traction Model Maximum Deceleration can be selected as Vehicle Speed Estimate Acceleration Source and Vehicle Speed Estimate Deceleration Source. The selected value, plus Vehicle Speed Estimate Acceleration Offset or Vehicle Speed Estimate Deceleration Offset (typically 0.2 G and −0.2 G), limits how fast the speed estimate can rise or fall. This filters noisy or slipping wheel speeds, and stops a brief lockup under braking from being latched and causing unwanted traction intervention afterwards.

VEHICLE SPEED ESTIMATE

Vehicle Speed Estimate gives a better estimate of the vehicle's true ground speed than Vehicle Speed alone, using other inputs such as GPS, Race Time or engine speed and gear. It is the speed input to the Traction, Launch, Gear Shift, Transfer, Vehicle Pitch Control and Vehicle Speed Limit systems. Vehicle Speed Estimate State reports the source in use.

Vehicle Speed Estimate Mode

Vehicle Speed Estimate Mode selects the speed source. It can be linked to a driver switch, which allows quick changes for a sensor failure (for example GPS in a tunnel), a change of surface such as tarmac to gravel, or a change of use such as circuit or drag racing. For a fixed mode, set the switch Index to Default and choose the mode with the Mapping Default setting.

Mode	Use when
Vehicle Speed	Wheel speed always gives a good ground speed, 2WD vehicles. Vehicle Speed is used directly.
Estimate Slower	Vehicle Speed can read faster than ground speed, for example with only driven wheel or tail shaft speed sensors, or an AWD car spinning all four wheels. The slower of Vehicle Speed and Race Time Vehicle Speed or GPS Speed is used. Without this, traction control would see no slip and would not work.
Race Time	Race Time Vehicle Speed is used directly, ignoring wheel speed. Used with no wheel speed sensors, or for rate of change traction control for drag racing. Falls back to Vehicle Speed when Race Time is not running or reaches the top of its table.
GPS	GPS Speed is used when a valid signal is received, otherwise Vehicle Speed. GPS typically lags ground speed when accelerating, so use it with the Vehicle Speed Estimate Model for best results.

Mode	Use when
Drive	Vehicle speed calculated from engine speed and gear is used, together with the acceleration limit, to limit the rate of change of engine speed through Traction. Falls back to Vehicle Speed when the gear is not known.

When Race Time Vehicle Speed or GPS Speed is used with Traction, set the speed tables carefully from the vehicle's best runs. For example, if the vehicle normally reaches 100 km/h 2.00 s after a launch, set 100 km/h at 2.00 s, or slightly more so a better than normal run is not held back. Setting it much higher allows excessive wheel slip.

Acceleration and Deceleration Limits

The rate at which Vehicle Speed Estimate can rise and fall can be limited. This filters noisy wheel speeds, reduces the error when the speed source is a slipping driven wheel, and allows rate of change traction control. Vehicle Speed Estimate State reports Acceleration Maximum or Deceleration Maximum while a limit is active.

Vehicle Speed Estimate Acceleration Source and Vehicle Speed Estimate Deceleration Source select where each limit comes from:

- Maximum: a tuned value, Vehicle Speed Estimate Acceleration or Vehicle Speed Estimate Deceleration Maximum.
- Vehicle Acceleration Longitudinal or Vehicle Acceleration Longitudinal Torque, plus the offset.
- Traction Model Maximum Acceleration or Traction Model Maximum Deceleration, plus the offset (see Traction Model).
- All (acceleration only): the lowest of the sources above.

The measured sources include some gravity on slopes and may not be perfectly accurate, so Vehicle Speed Estimate Acceleration Offset (typically 0.2 G) and Vehicle Speed Estimate Deceleration Offset (typically −0.2 G) are added. This stops a limit that is too tight from holding the estimate too low, which could slow the car through Traction, or too high, which could allow too much slip. While a limit is active, its offset grows slowly so the estimate cannot stay far from the source speed for long, for example if the G sensor has been knocked out of position. The offset returns to its setting once the limit is no longer active.

The deceleration limit is particularly important under braking. A brief wheel lockup would otherwise pull the estimate down, and the acceleration limit would then hold it low, causing unwanted traction intervention when the driver gets back on the throttle.

Vehicle Speed Estimate Model

The Vehicle Speed Estimate Model improves a speed signal that is slow, delayed or noisy, such as GPS or a noisy wheel speed sensor. It predicts the change in speed from the vehicle's acceleration and corrects the prediction from the input speed, giving a faster and cleaner result, mainly for Vehicle Speed Limit and Traction.

Vehicle Speed Estimate Model Mode selects how acceleration is predicted:

- Torque: from Vehicle Acceleration Longitudinal Torque. All vehicle details (mass, gear ratios, gear detection, drag and the torque calculations) must be set up correctly.
- Longitudinal Acceleration: from Vehicle Acceleration Longitudinal Sensor.

The input is the speed selected by Vehicle Speed Estimate Mode. The source actually used is reported by Vehicle Speed Estimate Model Source, and its value by Vehicle Speed Estimate Model Input. Set the following for each input source:

Setting	Description	Typical
Vehicle Speed Estimate Model Input Update Rate	How often the input speed updates. Supported rates are 100, 50, 25, 20, 10, 5, 2 and 1 Hz. The model runs at 100 Hz and uses this to ignore cycles where the input has not updated yet.	Wheel speed on CAN 50 Hz, GPS 10 Hz
Vehicle Speed Estimate Model Input Delay	The delay on the input signal. Find it by comparing the input speed with a signal that reacts immediately to a speed change, such as a longitudinal G sensor or brake pressure.	GPS 500 ms, wheel speed on CAN 50 ms, direct sensor or Drive 0 ms
Vehicle Speed Estimate Model Input Filter	Filter on a noisy wheel speed input. Higher values can cause speed errors; lower values leave some noise.	Wheel speed 100 to 1000 ms, GPS 0 ms
Vehicle Speed Estimate Model Speed 100Hz	For wheel speed inputs, the speed at which 100 teeth per second pass the sensor. For example 5 teeth and a 2 m circumference gives 144 km/h. For high tooth count (ABS) sensors, enter a low value such as 5 km/h.	
Vehicle Speed Estimate Model Acceleration Offset Filter	Filter for the learned acceleration offset (below). Too large and slope changes are learned slowly; too small and the offset is noisy.	3 s

Vehicle Speed Estimate Model Acceleration Offset Estimate is learned continuously. It reports the acceleration left over after aero and rolling drag, mainly from the slope of the road (about 0.1 G on a 5.7 deg slope) and head or tail wind, plus any modelling or setup error. If the model and vehicle are well tuned, it should equal the difference between Vehicle Acceleration Longitudinal and Vehicle Acceleration Longitudinal Estimate.

The acceleration and deceleration limits are applied to the result of the model, not to its input. Race Time Vehicle Speed is not used with the model.

TRANSFER (AWD CENTRE DIFFERENTIAL)

The Transfer system controls the transfer case clutch on AWD vehicles with an electronically controlled centre differential. It drives an actuator (PWM valve, solenoid or motor) to set the torque through the clutch pack, which may transfer all of the drive torque to one axle or act as a lockup over a centre differential.

The torque is not measured directly. It is controlled through pressure (hydraulic clutch packs) or current (solenoid systems), because the clutch torque is proportional to the clutch pressure or the solenoid current. The system can also run open loop from the actuator duty cycle alone, with reduced accuracy.

Transfer Torque

Transfer Torque is the torque requested at the transferred axle. It is built up as follows:

- Base torque: Transfer Torque Accelerate or Transfer Torque Brake, depending on Brake State, multiplied by Transfer Torque Steering Angle Trim. The trim usually removes torque when turning sharply at low speed, for example −80% trim at 90 deg of steering. The result is Transfer Torque Normal.
- **Slip torque:** added from the difference between the average front and rear axle speeds (not a slip ratio). Slip over Transfer Torque Slip Threshold is multiplied by Transfer Torque Slip Accelerate or Transfer Torque Slip Brake. For example, front axle 100 km/h, rear 115 km/h, a 10 km/h threshold and 50 Nm/km/h gives 250 Nm. The steering trim is not applied to slip torque.
- **Launch:** Transfer Torque Launch overrides the tables above while Launch State is Staging or Launch, or until Vehicle Speed Estimate reaches the top of the table if its axis is enabled.
- **Handbrake:** when the handbrake switch is On, Transfer Torque is set immediately to Transfer Torque Handbrake, ignoring the Decay rate. This releases the centre diff instantly for handbrake turns.

Changes in Transfer Torque are rate limited:

- Transfer Torque Increase Step (typically 100 Nm) is the most torque that can be added instantly, which helps catch wheel slip.
- Transfer Torque Increase Rate (typically 1000 Nm/s) limits further increases, preventing a sudden lockup, for example when the handbrake is released. Too low may allow more slip than wanted.
- Transfer Torque Decay (typically 300 Nm/s) limits how fast torque is removed, preventing a sudden release and oscillation.

Transfer Torque Clutch Maximum limits the torque through the clutch. Transfer Torque Clutch is Transfer Torque divided by the final drive ratio of the transferred axle. Transfer Torque Drive reports the percentage of wheel torque sent to the transferred axle. At 50% the clutch is treated as locked, although the real split depends on which wheels have more grip.

Transfer Control

The closed loop Transfer Control system uses one feedback sensor:

- **Pressure control:** configure Transfer Control Pressure Sensor. Transfer Control Pressure Aim sets the pressure for the requested clutch torque, and Transfer Control Pressure Feed Forward sets the duty cycle for that pressure. Tune the feed forward so that Transfer Control Integral stays close to 0.
- **Current control:** configure Transfer Control Current Sensor. Transfer Control Current Aim sets the solenoid current for the requested clutch torque. The feed forward is calculated from Ohm's law using Transfer Actuator DC Resistance and is corrected for battery voltage. Set the resistance so the integral is close to 0 when driving at least 2 A.

If neither sensor is configured, the system runs open loop from the current feed forward. If the sensor in use fails, it falls back to the feed forward only. Configuring both sensors is invalid.

The PID gains are unitless because the error is in bar or amps. For example, with a 5 bar aim and 3 bar measured, a Proportional Gain of 0.1 adds 20% to the control, and an Integral Gain of 0.1 adds 20% each second. The integral is limited to ±10%. The derivative is normally not needed for current control. Transfer Control is 0% when the system is not running and 1% to 100% when running, and is the axis of the actuator output duty cycle table.

Transfer Control Diagnostic reports why the system is not operating correctly:

Diagnostic	Cause
Sensor Fault	The feedback sensor in use is reporting a fault. The fault torque limit is applied.
Wheel Speed Fault	A front or rear drive wheel speed diagnostic is reporting a fault. The fault torque limit is applied.
Aim Tracking Fault	The control error is greater than Transfer Control Diagnostic Tolerance. The fault torque limit is applied.
Aim Tracking Warning	The integral has been at its ±10% limit for longer than the diagnostic delay. This can indicate incorrect tuning or a failing solenoid or wiring. Correct the pressure feed forward or the actuator DC resistance.
Transfer Switch Off	The Driver Transfer Switch is Off.
Gear State Neutral	The gearbox is in Neutral.
Transfer Aim Zero	The pressure or current aim is 0 and control is disabled.
Invalid Configuration	Both feedback sensors are configured, or Vehicle Drive Type is a 2WD setting.

Set Transfer Control Diagnostic Torque Limit to an engine torque that prevents wheel slip when the expected lock is not available. Set it to 0 Nm to disable.

Accumulator and Temperature

Hydraulic systems with an accumulator tank use Transfer Accumulator. The pump relay switches on when Transfer Accumulator Pressure falls below Transfer Accumulator Pump Threshold, and off above the threshold plus Transfer Accumulator Pump Hysteresis. A pressure switch can be used instead of a sensor: set both sensor diagnostic voltages to 0 V, set the translation so the two switch voltages give two pressures, and put the threshold between them with a small hysteresis.

Transfer Temperature measures the transfer case, clutch or lubricant temperature and can trigger the Transfer Temperature Warning.

TORQUE REDUCTION

Torque Reduction reduces torque quickly by retarding ignition timing and, if needed, adding an ignition or fuel cut. Throttle and manifold pressure cannot reduce torque instantly. A large plenum, for example, can take several engine cycles to empty after the throttle closes. Ignition based reduction fills that gap. However, Torque Reduction cannot increase torque faster than the throttle opens or boost builds.

Torque Reduction is the running percentage difference between Torque Modelled and Torque Reduction Limit, in terms of generated torque. 0% means no difference, and 25% means the Limit is 300 Nm when Torque Modelled is 400 Nm.

When Torque Reduction is greater than Torque Reduction Threshold, ignition timing is retarded so that Torque Modelled Corrected equals Torque Reduction Limit Corrected. As the throttle closes and Torque Modelled falls, timing returns to normal.

For example, with a Threshold of 15%, if Torque Modelled is 400 Nm and Torque Reduction Limit quickly drops to 300 Nm, the 25% difference is above the threshold. Timing is retarded, based on the Torque Ideal ignition timing, to bring torque down to 300 Nm. As the throttle closes and Torque Modelled falls towards 300 Nm, timing is advanced back to normal.

Torque Reduction Limit follows Torque Limit, but only for subsystems where high torque reduction response is useful. These include:

- Pedal, Torque Limit Maximum and Gear.
- Wheel, Traction Model and Traction.
- Vehicle Speed and Vehicle Speed Limit.
- Clutch Slip Control and Clutch Slip Warning.

Settings

Setting	Description
Torque Reduction Threshold	Torque Reduction must exceed this before timing and cut are used. Set to 100% to effectively disable the system. Anti Lag overrides this threshold.
Torque Reduction Activate Torque	Torque Modelled must be above this before Torque Reduction can be used.
Torque Reduction Ignition Timing Limit	Table (Engine Load Normalised axis) that sets the most retarded timing allowed. Any reduction still needed at this limit comes from cut. Set it more advanced than Ignition Timing Optimal to use all cut, or very retarded to use all retard.
Torque Reduction Cut Type	Ignition Cut or Fuel Cut. Ignition cut with a lot of retard tends to cause backfiring. Fuel cut with port injection, especially split primary/secondary injection, can cause partial fuelling issues. Where possible, Fuel Injector Secondary Contribution is automatically set to 0% or 100% to reduce this. Fuel cut works well with direct injection.
Torque Reduction Cut Limit	Limits the total amount of cut. Set to 0 to disable cut.

Torque Reduction Diagnostic reports the current operating condition:

Diagnostic	Meaning
Disabled	Torque Reduction is not operating.
Ok	Torque Reduction is retarding ignition timing.
Timing Limit	Timing has reached the Ignition Timing Limit and cut is being applied.
Timing Cut Limits	The timing and cut limits have both been reached. Torque is not being fully reduced.
Anti Lag	Anti Lag is operating and ignition timing is being reduced.
Anti Lag Timing Limit	Anti Lag is operating and timing is limited by Anti Lag Ignition Timing. Torque is not being fully reduced.

Torque Reduction Limit Corrected allows for Ignition Timing Normal being retarded from Ignition Timing Optimal, so it can be compared directly with Torque Modelled Corrected. For example, if Normal is 10 degrees retarded from Optimal, torque may be reduced by about 13%. With Torque Modelled at 400 Nm, Torque Modelled Corrected is about 348 Nm. A Torque Reduction Limit of 300 Nm then gives a Limit Corrected of about 261 Nm, and timing is retarded until Torque Modelled Corrected equals 261 Nm.

Anti Lag also uses this system to calculate its ignition timing (see Anti Lag). While Anti Lag is active, other than in Speed Limit mode:

- Torque Reduction Activate Torque is ignored, so Anti Lag can start when the engine is making low torque.
- Torque Reduction Threshold is ignored, because small reductions may be needed for good driveability.
- Torque Reduction Ignition Timing Limit is replaced by Anti Lag Ignition Timing.
- Torque Reduction Cut is not used. Any cut comes from Anti Lag Ignition Cut and Anti Lag Fuel Cut, so the two systems do not compete.

ANTI LAG

Anti Lag keeps air flowing through the engine so the turbos build or hold boost while the driver is off the throttle, making boost available as soon as it is needed. Boost is made by opening the throttle and removing the extra torque with ignition retard and ignition or fuel cut, rather than by closing the throttle.

Anti Lag works in conjunction with the Torque Reduction system so that the torque the engine delivers follows the driver's pedal while Anti Lag is active. Ignition timing is calculated automatically to match Torque Pedal, and the Anti Lag cut and timing tables use Torque Reduction as an axis. The driver can drive the car normally while the engine flows extra air and holds boost.

Anti Lag has three modes of operation:

- **Overrun or part throttle anti lag:** the traditional mode, active when the pedal is lifted.
- **Torque Aim Latch:** holds boost through a short lift of the throttle pedal.
- **Speed Limit:** builds boost while held at a pit lane or zone speed limit, or before a rolling launch.

Control Strategy

Turn the system on with Anti Lag Mode. Anti Lag State reports the current state:

State	Meaning
Disabled	Anti Lag is not active.
Armed	Anti Lag will start when the enable conditions are met.
Enabled	Anti Lag controls Ignition Timing, Ignition Cut, Fuel Cut, camshaft aims, Fuel Volume Trim, Boost Aim and Torque Aim.
Latch	Torque Aim Latch is active. Ignition Timing, Ignition Cut, Fuel Cut and Torque Aim are controlled.
Recover	Controlled systems are returning to normal over the Anti Lag Recover time.

Arming

Anti Lag State changes from Disabled to Armed when:

- Driver Anti Lag Switch is On (or Speed Limit or On And Speed Limit, see Speed Limit Mode).
- Throttle Pedal has been above Anti Lag Arm Throttle Pedal for Anti Lag Arm Delay. Typically 80% and 1000 ms. The delay stops short presses of the pedal from arming the system.
- Anti Lag Diagnostic is OK.

If Anti Lag ends because the shutdown time is reached, the pedal must fall below Arm Throttle Pedal before the system can arm again. Setting Arm Throttle Pedal to 0% means the system always arms immediately. This is not recommended unless Anti Lag is controlled by a driver switch.

Enabling

Anti Lag State changes from Armed to Enabled when all of the following are true:

- Throttle Pedal is below Anti Lag Enable Throttle Pedal, typically 20%.
- Torque Pedal is below Anti Lag Torque Aim. If the driver is already asking for more torque than the aim, no extra air flow or torque reduction is needed. If Anti Lag Torque Aim is 0 Nm, Anti Lag cannot start.
- Torque Aim State is not Cruise Control or Engine Speed Control (for example a downshift blip).
- Exhaust Temperature is below Anti Lag Shutdown Exhaust Temperature and Coolant Temperature is below Anti Lag Shutdown Coolant Temperature. A fault on either sensor also prevents operation. Set a shutdown temperature to 0 to disable that check.
- The Anti Lag Delay time has passed. Use the delay to reduce fuel use and heat during long braking events, and to keep the brake booster charged with vacuum.

Ending

Anti Lag ends when any of the following happen:

- Throttle Pedal rises above Anti Lag Enable Throttle Pedal, or Torque Pedal rises above Anti Lag Torque Aim.
- Exhaust Temperature or Coolant Temperature exceeds its shutdown value, or the sensor reports a fault.
- Anti Lag Time exceeds Anti Lag Shutdown Time. Anti Lag Time counts up while Enabled and counts down while Armed. Set Shutdown Time to 0 for no time limit.
- Driver Anti Lag Switch is turned Off.

When Anti Lag ends, Ignition Timing, Ignition Cut and Fuel Cut return to normal over Anti Lag Recover (typically 200 ms) while the state reports Recover. This smooths the transition as Torque Aim State returns to Pedal.

If a higher priority torque request takes over, such as a downshift blip, the system returns straight to Armed.

Anti Lag Diagnostic reports the condition that may be preventing operation: Disabled, OK, Time Limit, Exhaust Temperature High, Exhaust Temperature Diagnostic, Coolant Temperature High, Coolant Temperature Sensor Diagnostic or Torque Reduction Limited. Torque Reduction Limited is for information only and does not end Anti Lag. It means the timing has reached the Anti Lag Ignition Timing limit and torque is not being fully reduced (see Tuning).

How Anti Lag controls torque

While Anti Lag is Enabled:

- Torque Aim is set to Anti Lag Torque Aim. This opens the throttle so that, if ignition timing and cuts were restored, the engine would make this torque. While boost is low the throttle opens further. As boost builds the throttle progressively closes to hold the required mass flow, and boost may rise to Anti Lag Boost Aim.
- Torque Reduction Limit is set from Torque Pedal. The difference between Torque Modelled and Torque Pedal shows up as Torque Reduction.
- Anti Lag Ignition Cut and Anti Lag Fuel Cut are applied from their table values. If the cuts do not reduce torque enough to meet the limit, Torque Reduction retards ignition timing so that Torque Modelled Corrected matches Torque Reduction Limit Corrected, down to the Anti Lag Ignition Timing limit.
- Boost Aim is set to Anti Lag Boost Aim, provided it is below Boost Aim Main at 100% throttle with Boost Limit applied.
- Anti Lag Fuel Volume Trim is applied, and the Inlet and Exhaust Camshaft Aims are applied if their modes are enabled.

The driver feels the torque requested by the pedal, while the engine flows extra air and holds boost.

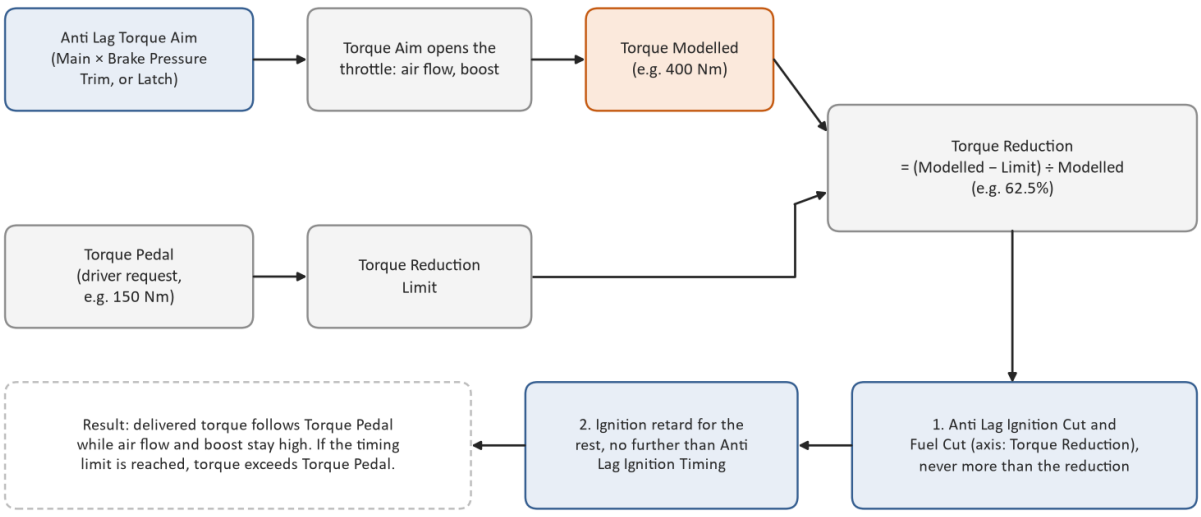


Figure 20. Anti Lag with Torque Reduction. Anti Lag Torque Aim sets the air flow, Torque Pedal sets the Torque Reduction Limit, and the difference is removed with cut first, then ignition retard.

Tuning

All of the main Anti Lag tables have Driver Anti Lag Mode Switch (A, B, C and Speed Limit) as an axis, so different calibrations can be selected by the driver. Tune in this order: torque aim (air flow), cut, timing limit, then brake pressure trims, latch and Speed Limit mode.

Anti Lag Torque Aim Main

Anti Lag Torque Aim Main (axes Engine Speed and Torque Pedal) sets the air flow through the engine while Anti Lag is active. It is set in terms of the torque the engine would make if no cut or retard were applied, so it can be thought of as the torque instantly available when the pedal is pressed. Higher values give more air flow and boost, but more heat, and need more torque reduction. Set Anti Lag Boost Aim (axis Engine Speed) to suit.

Anti Lag Ignition Cut Main and Anti Lag Fuel Cut Main

These tables have axes of Engine Speed and Torque Reduction. Torque Reduction is high when Torque Pedal is low and Torque Modelled is high, which is when the most reduction is needed. Put the most cut at high Torque Reduction and reduce it as Torque Reduction falls, to manage the balance between cut and retard.

- Cut and Torque Reduction are on the same scale: 20% cut gives 20% torque reduction (before allowing for any existing retard of Ignition Timing Normal from Optimal). Whatever reduction the cut does not provide is made up with retard. For example, with 50% Torque Reduction and 30% cut, retard provides the remaining 20%. At a typical 1.3% of torque per degree, that is about 15.4 degrees of retard.
- If the cut would reduce torque below Torque Pedal, it is reduced automatically. All of the reduction then comes from cut and timing is not retarded.
- Fuel and ignition cuts overlap when both are used. For example, 25% of each gives a total of 43.75%, not 50%, because 25% of the cut events overlap (25% of 25% is 6.25%).
- If the total cut is more than the reduction needed, Fuel Cut is reduced first, then Ignition Cut. For example, with 50% Torque Reduction, 40% Ignition Cut and 30% Fuel Cut requested, Fuel Cut is reduced to about 16.7% so the total is 50%.

Anti Lag Fuel Cut Exhaust Temperature Trim trims Fuel Cut Main based on exhaust temperature. Typically more fuel cut is applied as exhaust temperature rises.

Anti Lag Ignition Timing Main

Anti Lag Ignition Timing Main (axes Engine Speed and Torque Reduction) does not set the timing directly. It is the most retarded absolute timing that Torque Reduction may use while Anti Lag is active. Limiting retard can reduce exhaust temperature or improve combustion quality. Final timing cannot be more advanced than Ignition Timing Normal, even if a more advanced value is entered.

If timing reaches this limit, the engine makes more torque than Torque Pedal. Torque Reduction Diagnostic reports Anti Lag Timing Limit and Anti Lag Diagnostic reports Torque Reduction Limited.

Important: Make sure the combination of cut and timing limit can remove enough torque for the vehicle to slow down with Throttle Pedal at 0%. If it cannot, the engine may drive the vehicle forward when overrun is expected. A higher Torque Aim means more air flow, which needs more reduction. Check Anti Lag Diagnostic for Torque Reduction Limited during testing.

Ignition cut pattern

Anti Lag Ignition Cut Mode A, Mode B and Mode C select the cut pattern for each Driver Anti Lag Mode Switch position:

- Normal: the M1 randomises the cut pattern to give the correct cut percentage. At 50% cut this mostly cuts every second cylinder.
- Alternate: cut and fire events are grouped, with the group length randomised between Anti Lag Ignition Cut Alternate Minimum Length and Anti Lag Ignition Cut Alternate Maximum Length. For example, with 50% cut, a minimum of 3 and a maximum of 10, the system might cut 3 and fire 3, then cut 10 and fire 10. Grouping changes the engine sound, backfires and flames.

Fuel and camshafts

Anti Lag Fuel Volume Trim (axes Engine Speed and Inlet Manifold Pressure) trims fuelling while Anti Lag is Enabled. Anti Lag Inlet Camshaft Aim Main and Anti Lag Exhaust Camshaft Aim Main (axes Engine Speed and Torque Reduction) apply when their Mode is Enabled. They can be used to help air pass through the cylinders, for example with large valve overlap. Cam timing affects Engine Efficiency and therefore fuelling, so correct any fuelling error with the Fuel Volume Trim.

Brake Pressure Trims

Three tables (axis Brake Pressure Front) can scale Anti Lag back under heavy braking to reduce fuel use and heat, and blend it back in as the brake is released, ready for the throttle to be pressed on corner exit:

- Anti Lag Torque Aim Brake Pressure Trim trims Anti Lag Torque Aim Main. At −100% trim, Anti Lag Torque Aim Main cannot start Anti Lag. The trim is also applied to Anti Lag Torque Aim Latch.
- Anti Lag Ignition Cut Brake Pressure Trim trims Anti Lag Ignition Cut Main.
- Anti Lag Ignition Timing Brake Pressure Blend blends the timing limit between Ignition Timing Normal (0%) and Anti Lag Ignition Timing Main (100%). At 50% the timing limit is half way between them.

Torque Aim Latch

Torque Aim Latch holds the throttle open through a short lift of the pedal, so boost that has already built is not lost.

While the pedal is steady, Anti Lag Torque Aim Latch follows Torque Pedal less a 5 Nm margin. When Torque Pedal falls below this value, it is held for Anti Lag Torque Aim Latch Hold, then reduces at Anti Lag Torque Aim Latch Decay until it reaches Torque Pedal or Anti Lag Torque Aim Latch Minimum. If the latched value (with the Brake Pressure Trim applied) is greater than Anti Lag Torque Aim Main, it becomes the Anti Lag Torque Aim and the state moves to Latch. Cut and retard then reduce torque to Torque Pedal while Torque Modelled is kept high.

- Anti Lag Torque Aim Latch Maximum limits the torque that can be latched. Set it to 0 to disable the latch feature.
- Anti Lag Torque Aim Latch Minimum: the latch does not hold until Torque Pedal is above this value. If Torque Pedal falls below it while holding, the value is still held until the latch decays below it.

In the Latch state, Anti Lag Fuel Volume Trim, Anti Lag Boost Aim and the Anti Lag camshaft aims are not applied. This keeps the engine stable at what is already a high boost operating point. The latch needs Anti Lag to be Armed, with Throttle Pedal below Enable Throttle Pedal, and is not used in Speed Limit mode.

Speed Limit Mode

Speed Limit mode builds boost while the vehicle is held at a pit lane or zone speed limit, or briefly before a rolling launch, so full boost is available the instant the limiter is released.

To use it:

- Set Driver Anti Lag Switch to Speed Limit or On And Speed Limit. With Speed Limit, Anti Lag is only available while a speed limit is active.
- A Cruise Control speed limit or Vehicle Speed Limit must be active.
- All gear ratios and wheel circumferences must be set correctly.
- Anti Lag must still be Armed in the normal way.

When Anti Lag becomes Enabled while a speed limiter is active:

- Anti Lag Engine Speed is calculated from the active limiter's set speed, plus Anti Lag Engine Speed Offset, using the current gear ratio and drive circumference.
- Driver Anti Lag Mode Switch is overridden to report Speed Limit, so a separate Anti Lag calibration can be tuned for this mode.
- The speed limiter's Torque Limit is ignored, so the throttle opens according to Torque Pedal or Anti Lag Torque Aim. Speed is held by Ignition Timing Control, which retards timing to hold Anti Lag Engine Speed. Feedback changes from wheel speed to engine speed, so speed control may be slightly different. Use the Offset to correct small differences.
- The Enable Throttle Pedal condition is inverted: Throttle Pedal must be above Anti Lag Enable Throttle Pedal (Speed Limit setting) for Anti Lag to enable. The Anti Lag Delay is not applied.

Anti Lag can be started in two ways:

- Use the Driver Anti Lag Switch to start Anti Lag while the speed limit is active.
- With the switch already at Speed Limit or On And Speed Limit, press the throttle past Anti Lag Enable Throttle Pedal while the speed limit is active.

To leave the speed limit with full boost, turn off the speed limiter with the throttle pedal at 100%. Driver Anti Lag Mode Switch then changes from Speed Limit back to A, B or C, disabling anti lag and the speed limiter together.

LAUNCH CONTROL

The Launch Control system holds a steady engine speed while the vehicle is stationary before a launch. On a turbocharged engine it also helps build boost. Launch State moves from Disabled to Staging, then to Launch, and back to Disabled when control ends. If a fault occurs while staging, Launch State changes to Abort.

During the Staging phase, the Ignition Timing Control subsystem is used to closed loop control the engine speed to match the Launch Engine Speed with the throttle open via ignition retard, provided the system is set with enough control range.

Like the Anti Lag system described earlier, the throttle will be used to manage air mass flow through the engine to meet the Launch Torque Limit Staging. In turbocharged applications this will mean larger throttle aims until boost builds, at which point it will reduce.

Activating launch. Launch State changes from Disabled to Staging when all of these are true:

- Launch Mode is not Not in Use and Driver Launch Switch is not Off.
- Launch Diagnostic is OK. This requires Ignition Timing Control Diagnostic to be Ok.
- Launch Trigger is Inactive, for example the brake is still on when Launch Mode is Brake Release.
- Engine State is Run.
- Vehicle Speed Estimate is at or below Launch Activate Vehicle Speed.
- Throttle Pedal is at or above Launch Activate Throttle Pedal.

Launch Mode sets what triggers the launch: Brake Release, Clutch Engage or Transmission Brake Release. When the trigger becomes Active, Launch State changes from Staging to Launch.

Ending launch. While staging, lifting the pedal below Launch Activate Throttle Pedal, stopping the engine or turning the launch switch off returns Launch State to Disabled. If Launch Diagnostic changes from OK while staging, Launch State changes to Abort and the launch torque limit closes the throttle so engine speed falls. Lift the pedal to reset to Disabled.

Once in Launch, lifting the pedal does not end launch control. This lets the driver lift to control the car while the engine speed control still limits wheel slip. Launch State returns to Disabled when Vehicle Speed Estimate exceeds the highest Vehicle Speed Estimate axis site of the Launch Engine Speed Main table. It also returns to Disabled after 3 seconds in Launch if the trigger is Inactive again and Vehicle Speed Estimate is still at or below Launch Activate Vehicle Speed (a failed launch).

If the Vehicle Speed Estimate axis of Launch Engine Speed Main is disabled, Launch State goes straight from Staging to Disabled on the trigger. No launch control is then applied once the vehicle moves, but Race Time can still be triggered.

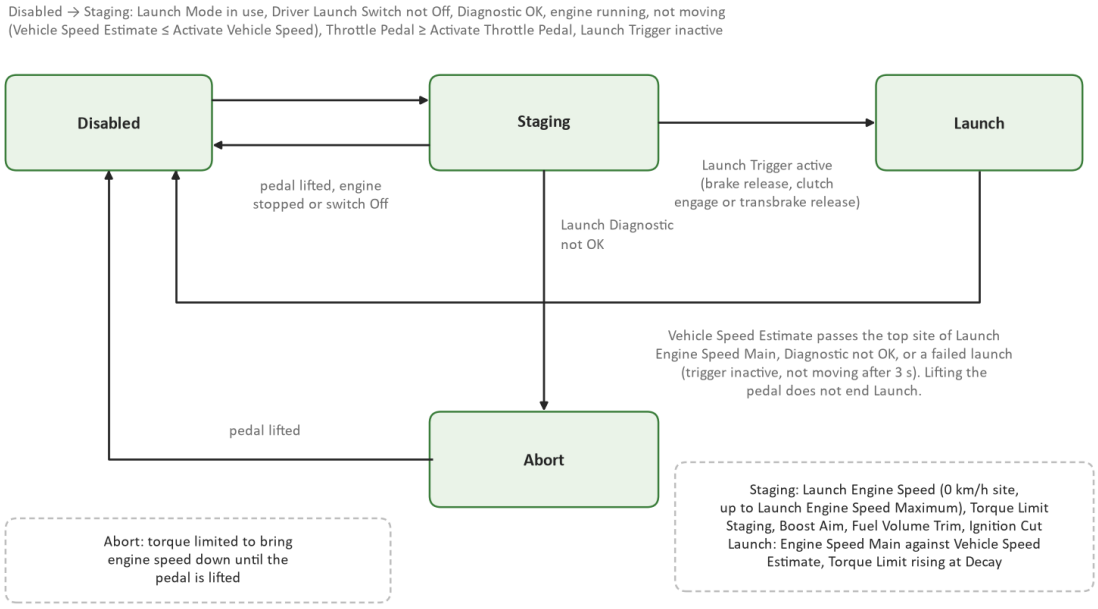


Figure 21. Launch State transitions and what is applied in each state.

Engine Speed

The Launch Engine Speed has a multi stage strategy. While Launch State is Staging, Launch Engine Speed can be raised above Launch Engine Speed Main up to Launch Engine Speed Maximum when Boost Pressure is low. As Boost Pressure rises towards Launch Boost Aim, the target falls back to Launch Engine Speed Main:

- Below Launch Boost Aim minus Launch Engine Speed Boost Margin minus Launch Engine Speed Boost Range, the target is Launch Engine Speed Maximum.
- Across the Launch Engine Speed Boost Range, the target falls progressively.
- At or above Launch Boost Aim minus Launch Engine Speed Boost Margin, the target is Launch Engine Speed Main.

If Launch Engine Speed Maximum is at or below Launch Engine Speed Main, the target is always Launch Engine Speed Main. While staging, only the 0 km/h site of Launch Engine Speed Main is used, so creeping or wheel speed noise cannot change the launch speed. Once the target has started to fall, it does not rise again if boost drops. This prevents engine speed and boost from hunting.

Launch Engine Speed Maximum helps spool a larger turbo more quickly, because the engine flows more air at higher engine speed. A high engine speed may not suit the launch itself, as it can exceed the available grip. This strategy allows higher boost at a lower launch engine speed, and less time spent staging. Launch Engine Speed Boost Margin is normally about 25 kPa. Setting it to 0 means Launch Boost Aim must be reached before engine speed falls to Launch Engine Speed Main. A larger Launch Engine Speed Boost Range gives a slower reduction with less ignition retard. A smaller range holds the high speed longer and builds boost faster, but needs more retard to slow the engine and may cause misfire.

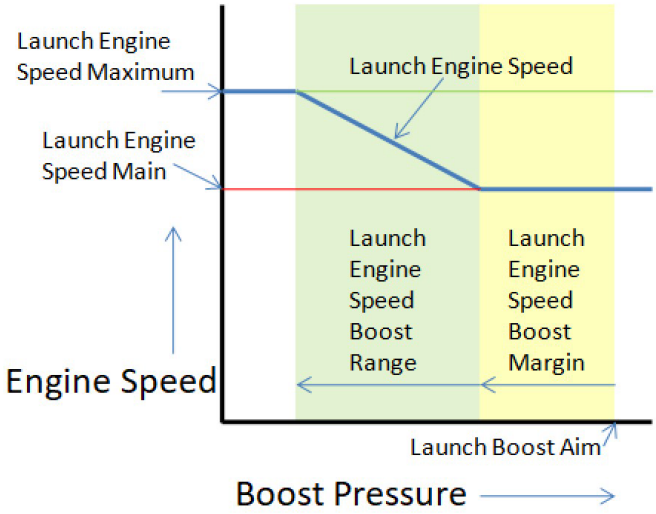


Figure 22. The transition from Launch Engine Speed Maximum to Launch Engine Speed Main based on the Boost Range and Margin.

Care is needed by the driver, particularly when there is a large difference between Launch Engine Speed Maximum and Launch Engine Speed Main. If the launch is triggered and Launch State changes from Staging to Launch while engine speed is still near Launch Engine Speed Maximum, the vehicle will launch at this engine speed, with potentially undesirable results. Always allow boost to reach Launch Boost Aim minus Launch Engine Speed Boost Margin before launching.

Strategy

While Launch State is Staging, Launch Torque Limit Staging limits the air flow through the throttle to produce the torque set in that table. Any other torque limit set lower will override it. Set it to a very high value to use only the other torque limits when launching.

For example: If the torque limit is set to 400 Nm, and the Launch Engine Speed is set to 4000 rpm, on application of the throttle pedal, the throttle/s will normally open to 100%, the engine speed will rise very quickly to 4000 rpm, where the ignition timing is retarded to closed loop control the engine speed.

The ignition timing might be around -30 deg (30 deg after TDC) or more to control this. At this point there is a lot of air flowing through the engine but the engine is not actually making power, just revving. The turbos begin to spool up and air flow increases.

When the boost reaches the point where the engine should be making 400 Nm (if the ignition was not retarded), the throttles begin to close to maintain a continuous air flow (constant manifold pressure) as boost continues to build up behind the throttle butterflies.

If held, the boost will rise to a level and be maintained. For example: 400 Nm at 4000 rpm may need 150 kPa in the manifold, but boost could be well over 200 kPa absolute behind partly open throttles after 1 to 2 seconds.

While staging, Boost Aim is set to Launch Boost Aim to limit the overall boost pressure. Launch Boost Aim is limited to Boost Aim Maximum. Launch Ignition Cut can also be applied while staging. On some turbo engines, some ignition cut with less ignition retard builds boost faster or builds more boost.

When Launch State changes from Staging to Launch, the launch torque limit rises from Launch Torque Limit Staging at the Launch Torque Limit Decay rate. For example, with 600 Nm staging and 100 Nm/s decay, the limit is 900 Nm 3 seconds after the trigger. The decay may be set to 0, a small amount or a lot, depending on how the car reacts. If launch control is to continue as the vehicle accelerates, set Launch Torque Limit Decay to at least 100 Nm/s so that torque rises and blends into the other torque limits.

The Ignition Timing Control system uses a separate set of tuning when Ignition Timing Control State is Launch Staging and Launched. Staging is unloaded (free revving), so Ignition Timing Control Feed Forward Torque is normally 0 Nm. After the launch the engine is loaded, so a very high feed forward torque is normally used, which starts from normal ignition timing.

Tuning Launch Control

Tuning the best torque and engine speed for take off needs some trial and error, because grip levels change the ideal combination and some drive types are more sensitive than others. Launch Engine Speed Main has a Vehicle Speed Estimate axis. This continues closed loop engine speed control as the vehicle accelerates, and can limit wheel slip. Vehicle Speed Estimate can come from wheel speeds, GPS, or Race Time for a target based on the best expected acceleration. Set the 0 km/h site to the staging speed. The 1 km/h site is used as soon as the launch is triggered, before the vehicle moves, so the launch speed can differ from the staging speed. Launch control ends when Vehicle Speed Estimate passes the highest axis site, so set this near the top of first gear to hand over to traction control. Take care that the table does not reduce engine speed so much that the vehicle cannot accelerate.

Parameter Overview

- Launch Fuel Volume Trim. Adjustment of the fuel applied while stationary and building boost with Launch Control.
- Launch Boost Aim. Target for the boost control system applied while stationary and building boost with Launch Control
- Launch Torque Limit Staging. Torque Limit applied while Launch State is Staging and building boost with launch control.
- Launch Torque Limit Decay. Rate at which the torque limit is raised from the Launch Torque Limit Staging value when the Launch State is Launch.
- **Launch Engine Speed Main.** Target engine speed for the launch closed loop engine speed control, by Vehicle Speed Estimate and Driver Launch Aim Switch. The 0 km/h site is used while staging and the 1 km/h site on the trigger. Launch ends above the highest Vehicle Speed Estimate site.
- **Launch Activate Throttle Pedal.** Throttle Pedal must be at or above this value to start staging. Dropping below it while staging cancels the launch. It has no effect once Launch State is Launch. Typically set low (about 5%) so that engine speed control starts immediately.
- **Launch Activate Vehicle Speed.** Vehicle Speed Estimate must be at or below this value to start staging. It is ignored once staging, to allow bumping to the start line. Recommended setting is less than 5 km/h.
- **Launch Mode.** Selects the launch trigger: Brake Release, Clutch Engage or Transmission Brake Release. Not in Use disables launch control.
- **Launch Engine Speed Maximum.** Higher staging engine speed used while Boost Pressure is low, to spool the turbo faster.
- **Launch Engine Speed Boost Margin.** Subtracted from Launch Boost Aim to set the boost pressure where the target reaches Launch Engine Speed Main. Normally about 25 kPa.
- **Launch Engine Speed Boost Range.** Boost pressure range over which the target falls from Launch Engine Speed Maximum to Launch Engine Speed Main.
- **Launch Ignition Cut.** Ignition cut applied while staging.
- **Launch Inlet Camshaft Aim Main** and **Launch Exhaust Camshaft Aim Main.** Camshaft targets applied while staging when the matching Launch Inlet Camshaft Aim Mode or Launch Exhaust Camshaft Aim Mode is Enabled. These can increase air flow that does not make torque, so less ignition retard is needed. Correct any fuelling change with Launch Fuel Volume Trim.
- Ignition Timing Control, see the relevant section in this guide.

GEAR SHIFT

In GPRP Pro, much of the Gear Shift strategy system is similar to GPRP, but there are some key differences:

- Torque aims, as opposed to throttle aims for blips.
- Option to use Ignition Timing for rev matching.
- Offset engine speeds for rev matching.
- Improved shift retry mechanism.
- Half shift to Neutral for sequential gearboxes.
- Engine speed matching that falls back, or switches off, when output shaft speed cannot be trusted.

Gear Shift Types

There are 4 different shift types. The common two are Up Shift Power On and Down Shift Power Off. The uncommon two are Up Shift Power Off and Down Shift Power On. Power On and Power Off are defined by the Gear Shift Power On Torque Threshold parameter. The four shift types need to be tuned independently as not all states are utilised for all of the shift types.

Gear Shift Phases

The gear shift operation is broken into phases, and Gear Shift State reports the current phase:

- **Pre Shift.** Prepares the engine before the gear is moved. Used on down shifts and on Up Shift Power Off. On Up Shift Power On it is only used for a throttle de-blip, when both a Pre Shift time and Gear Shift Torque Aim Main are set. Pre Shift is skipped when its time is 0 ms, and on up shifts when Gear Shift Torque Aim Main is 0 Nm. It ends when the Pre Shift time expires, or early if the gear changes.
- **Shift.** The actuator moves the barrel, and engine speed matching starts if it is in use. On up shifts the gear shift cut and retard tables are applied. On down shifts any cut and retard is removed so the throttle blip can raise engine speed. Shift ends when the new gear is engaged (down shifts also wait for Gear Shift Torque Aim Minimum Duration). If the gear does not change, a retry is started (see Shift Retries).
- **Post Shift.** Down shifts only. Cut and retard can be reapplied to stop the engine pushing the car as torque returns, but only when engine speed matching is not in use. The throttle blip continues at the Hold level.
- **Recover.** Torque is reintroduced. Gear shift cut and retard ramp out over the Recover time (on down shifts only when engine speed matching is not in use). The down shift blip ends here. The gear shift engine speed limit is held.
- **Rearm.** The wait before another shift can start. The gear shift engine speed limit is still applied. Once the gear lash is taken up and the wheels load the engine, engine speed is pulled to the new gear's speed. On power on shifts the wheels pull engine speed down, so the engine is driving the car. On power off shifts the wheels pull engine speed up, so the engine is not driving the car. Gear Shift State returns to Idle when the Rearm time has expired, the shift request has returned to Idle and Gear Shift Actuator State is Idle.

As the shift moves through these states, ignition timing, ignition cut, fuel cut, Torque Aim (throttle) and the gear shift engine speed limit are varied to complete the shift. The actuator outputs are timed separately in Gear Shift Actuator Timing. The Preload times reference the moment Gear Shift State changes to Shift: a positive Preload switches the actuator on before Shift starts, and a negative Preload switches it on after Shift starts. The latter is useful for fast actuators or gearboxes that take time to unload. Once the new gear is engaged the actuator stays on for the Hold time, then the Rearm time locks out the actuators while they settle.

The table below summarises what each phase does for the four shift types. Figure 23 shows the two common shift types with engine speed matching in use.

Phase	Up Shift Power On	Up Shift Power Off	Down Shift Power On	Down Shift Power Off
Pre Shift	Normally skipped. Optional throttle de-blip only.	Throttle blip (Torque Aim Main) to unload the gearbox. No cut, retard or speed limit.	Cut and retard to unload the gearbox. Throttle blip if set.	Cut and retard hold torque while the blip opens the throttle and builds manifold pressure.
Shift	Cut and retard from the tables. Speed matching: Release, then Match.	Cut and retard from the tables. Speed matching: Release, then Match.	Cut and retard removed. Blip continues. Speed matching: Release, then Match.	Cut and retard removed. Blip continues (Main, then Hold). Speed matching: Release, then Match.
Post Shift	Not used.	Not used.	Cut and retard (only without speed matching). Blip continues.	Cut and retard (only without speed matching). Blip continues.
Recover	Cut and retard ramp out. De-blip ramps back at Recovery Rate.	Cut and retard ramp out.	Cut and retard ramp out (only without speed matching). Blip ends.	Cut and retard ramp out (only without speed matching). Blip ends.
Rearm	Speed limit held. Wait for the next shift.	Speed limit held. Wait for the next shift.	Speed limit held. Wait for the next shift.	Speed limit held. Wait for the next shift.

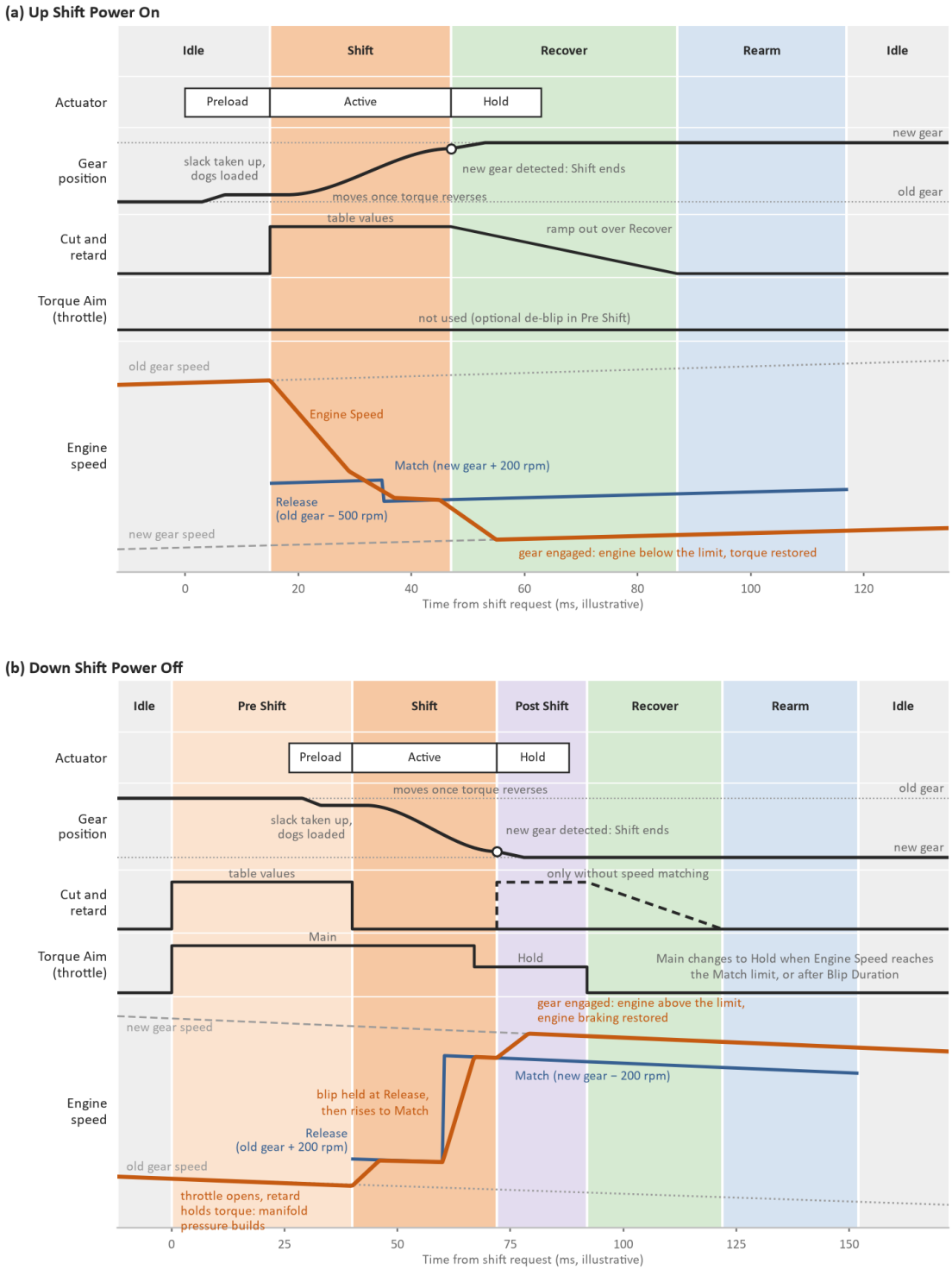


Figure 23. Gear shift sequence for (a) Up Shift Power On and (b) Down Shift Power Off, with engine speed matching in use. Gear position shows the barrel taking up slack when the actuator fires, pausing while the dogs are loaded, then moving to the new gear once torque reverses. Shift ends when the new gear is detected. The blue line is Gear Shift Engine Speed Limit: Release relative to the old gear, then Match relative to the new gear.

Up Shift Power On Gear Shift Operation Explained

To best explain each system, and to cover the primary shift operation in a paddle shifted car, the Up Shift Power On gear shift is detailed here. Pre Shift is normally not used for this shift type, so the Gear Shift Timing for Pre Shift can be set to 0 ms. It is only needed for a throttle de-blip. Post Shift is never used on up shifts.

The Gear Shift Timing for Shift sets the maximum time of the shift. The shift phase ends as soon as the new gear is engaged, so this time sets the maximum in case of a shift issue. Gear Shift Actuator Release Delay sets the longest time the barrel should take to leave the old gear after Shift starts. If the gearbox is still in the old gear after this time, or the Shift time expires without the gear changing, a retry is started (see Shift Retries).

With Gear Shift Engine Speed Limit Mode set to Ignition Retard, engine speed matching uses the closed loop Ignition Timing Control system, and the maximum amount of retard allowed is set there. Gear Shift Ignition Timing Retard sets a minimum amount of retard applied during Shift, retarded from Ignition Timing Normal.

If the Preload Upshift Power On value in Gear Shift Actuator Timing is positive, pulling the up shift paddle immediately turns on the up shift actuator output. Once the preload time has elapsed, Gear Shift State moves from Idle to Shift, engine speed matching starts and ignition timing is retarded. It takes time for the actuator valve to open and for air pressure to build and begin to move the barrel. It also takes time for the drivetrain to unload and for engine speed to fall enough for the selector dogs to disengage. The preload time sets this relationship, and can be positive or negative.

While in the Shift phase and the barrel is rotating, using engine speed matching, the engine speed should only fall to the desired amount, somewhere below the engine speed of the previous gear and above the engine speed of the new gear. This allows a low differential speed of the selector and new gear dogs so the selector can engage.

Once engaged, the Gear Shift State transitions to the Recover phase (skipping Post Shift). Engine speed matching is maintained and ignition timing is set by the Ignition Timing Control system, but the Gear Shift Ignition Timing Retard (advance limit) will be removed over this time. The engine will catch up and start driving the wheels. At this point the engine speed will fall so the closed loop engine speed control will increase the ignition timing to the maximum allowed and engine power is reinstated.

Engine Speed matching is maintained right through the rearm phase, but generally does not have any effect since the engine speed cannot reach the limit as it is driving the wheels. It can help with any post shift oscillations though.

Down Shift Power Off Operation Notes

Another worked shift example is on the down shift, where both the Pre Shift and Post Shift Gear Shift States are used. When Pre Shift is used, the Gear Shift Actuator Preload time still references the transition of the Gear Shift State to Shift.

For example: On a down shift, you may have 40 ms of Pre Shift and 10 ms of Gear Shift Actuator Preload. When the down shift paddle is triggered, the Gear Shift State moves to Pre Shift, the throttle is commanded open and ignition retard applied. The engine does not respond to the throttle opening as the timing is retarded. This just allows the manifold pressure to rise, preconditioning the engine for the gear shift. 30 ms through Pre Shift (10 ms before pre shift ends), the down shift actuator is turned on. When the Gear Shift State transitions to Shift, the ignition retard is removed and the engine revs up sharply, controlled to the desired engine speed by the engine speed matching. The preloaded actuator quickly moves the barrel to the lower gear.

In cases where the Gear Shift Actuator Preload time is greater than the Pre Shift timing, on selection of the down shift paddle the down shift actuator is turned on, with the Pre Shift phase occurring in the allotted time before the Gear Shift State transitions to Shift.

During the Shift phase, any ignition cut or ignition retard is removed, allowing the engine speed to increase with the air that the inlet manifold was charged with during the Pre Shift phase. This speed increase allows for better engine speed matching on engagement, and lower differential speed of the selector dogs.

The Post Shift phase can reapply ignition cut, fuel cut or ignition retard to stop the engine pushing the car as torque is reintroduced, and these then ramp out over Recover. They are only used when engine speed matching is not active. With matching, the negative Match speed does this job.

Shift does not end until the new gear is engaged and Gear Shift Torque Aim Minimum Duration has expired, so the blip has time to raise engine speed. Gear Shift Torque Aim changes from Main to Gear Shift Torque Aim Hold when Engine Speed reaches the Match speed, or when Gear Shift Torque Aim Blip Duration expires, and the blip ends at Recover. Gear Shift Torque Aim Maximum (typically 95% of Torque Maximum) stops the throttle opening further than needed, which can otherwise over-blip.

Engine Speed Matching

The use of engine speed matching is highly recommended for optimal shifting as it will usually perform better than trying to set the correct amounts of cut or retard for shift operations. The Engine Speed Matching function can use Ignition Retard or Ignition Cut as set in the Gear Shift Engine Speed Limit Mode. If Ignition Retard is utilised, it is best not to use any ignition cut since this can cause the engine to backfire.

The engine speed matching has two phases set in Gear Shift Engine Speed Release and Gear Shift Engine Speed Match. The transition time between these two phases is set in the Gear Shift Engine Speed Release Timing. This time is also referenced from the Gear Shift State of Shift.

Engine speed matching is used, and Gear Shift Engine Speed Mode reports Up Shift Speed Matching Enabled or Down Shift Speed Matching Enabled, when all of the following are true:

- Gear Shift Engine Speed Limit Mode is set to Ignition Retard or Ignition Cut.
- The shift is from a forward gear into a forward gear.
- Gear Shift Mode is not Fault or Output Shaft Speed Fault.
- The clutch is not disengaged, unless Gear Shift Torque Aim Clutch Lockout is Disabled.
- Gear Output Shaft Speed is available. Gear Shift Engine Speed Limit Fallback selects whether only trusted sources (output shaft or driven wheel speed sensors) are used (Use Trusted Only), or whether fallback sources such as non-driven wheels, engine speed and gear, or GPS can also be used (Allow Fallback). If trusted sensors are not configured, this must be Allow Fallback.

With Ignition Retard, Ignition Timing Control holds engine speed at the limit, and cut is also added if engine speed exceeds the Ignition Timing Control cut limit. With Ignition Cut, the Engine Speed Limit system is used with Gear Shift Engine Speed Limit Ignition Range, Gear Shift Engine Speed Limit Fuel Range and Gear Shift Engine Speed Limit Fuel Margin. In both cases the gear shift limit overrides other engine speed limits, such as traction and vehicle speed limits, until Rearm. During Rearm it is only used when it is the lower limit.

Some examples of match setting:

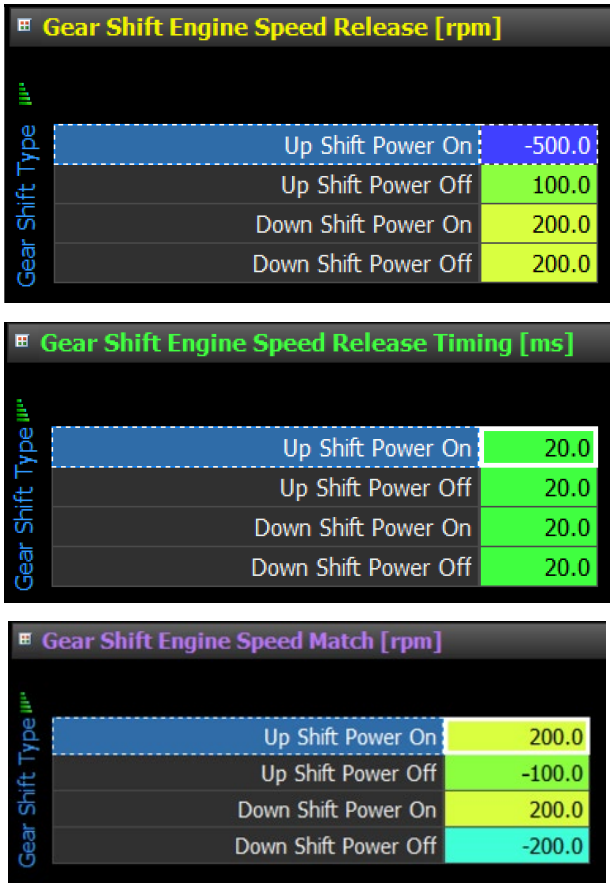


Figure 24. Example starting settings for Engine Speed Release and Match Parameters.

During the shift phase, the engine speed limit is set to the speed that the shift is coming from, plus the Release value. This is applied for the Gear Shift Engine Speed Release Timing time.

For example: Using the above values, if the engine speed before the gear shift is 6000 rpm, an up shift power on would set the engine speed matching to 5500 rpm for 20 ms of the Shift phase, allowing the dogs to release from the previous gear. While it is performing engine speed matching, generally full retard would be applied since the engine speed starts a lot higher than the limit speed.

Once the release time has elapsed, the engine speed limit changes to the match value, which is the engine speed of the new gear plus the match value. If the new gear's engine speed is 5200 rpm, the 200 rpm match value would make the match speed 5400 rpm. So this sets a constant speed difference of the engaging dogs.

The numbers in the example are a good starting point and make for a fairly conservative and soft shifting.

For up shifts, the most important setting is the Match speed. If it is too large, the selector may not have time to engage the gear: the shift is harsher but the total shift time is shorter. If it is too small, the overall shift is slow. Typically this value is around 200 to 600 rpm.

It is also very important to use the correct sign for these speeds. The Release speed for Up Shift Power On must be negative, so that engine speed is pulled below the old gear's speed to unload the gearbox.

The Match speed must be negative for both power off shift types, Up Shift Power Off and Down Shift Power Off. When the new gear is selected, engine speed is then below the new gear's speed, so the engine does not accelerate the car while it is decelerating. For the power on shift types the Match speed is positive, so drive torque is restored as soon as the gear engages. All other Release values are positive. If this is not followed, the gear shifting may function poorly.

Shift Retries

When Gear Shift Mode is Manual, Automatic or Paddle Fault, a failed shift is retried up to Gear Shift Retry Maximum times. There are two types of failure:

- **Stuck in the old gear.** Gear Position Diagnostic is OK and the gear has not changed when Gear Shift Actuator Release Delay has passed since Shift started, or the Shift time expires. The dogs are still loaded. The actuator is switched off for the Retry Wait time, then the whole shift starts again from Idle, including Pre Shift and the torque reduction, to unload the gearbox again.
- **Between gears (dog clash).** Gear Position Diagnostic reports Tolerance when the Shift time expires. The actuator is switched off for the Retry Wait time so the dogs can separate, then fired again. Gear Shift State stays in Shift and the Shift time restarts.

Retry Wait times are set separately for up and down shifts in Gear Shift Actuator Timing. If the retries run out, the shift is abandoned: up shifts move to Recover and down shifts to Post Shift, and the automatic shift request is locked out. Gear Shift Result reports the outcome, for example Gear Change, No Gear Change or Between Gears. No retries are made when Gear Shift Mode is Fault.

If a shift leaves the gearbox stuck between gears and Gear Shift Mode Switch Override is When Fault, Gear becomes Default and Gear Shift Mode changes to Fault so the driver can trigger the shift again. If it is re-triggered within Gear Shift Repeat Limit (typically 1.5 s) with the same shift type, engine speed matching is reinstated using the settings for the previous target gear.

Half Shift to Neutral

On some sequential gearboxes the barrel only moves about half as far to reach Neutral as it does for a full shift. The Gear Shift Neutral system drives the actuators with its own short timing, checks the result and retries if needed. Set Gear Shift Neutral Mode to where Neutral sits in the gearbox: Neutral Between Reverse First or Neutral Between First Second.

A half shift is requested when the gear is next to Neutral and either:

- Gear Shift Neutral Request Switch is On for Gear Shift Request Delay Neutral, or
- the Neutral Request Switch is not in use, the clutch is disengaged and the paddle towards Neutral is held for Gear Shift Request Delay Neutral.

Otherwise the paddles perform a full shift, which can also go straight past Neutral to the gear on the other side. If the Neutral Request Switch is used, it is the only way to select Neutral, and the paddles always request a full shift.

When a half shift is accepted, the Gear Shift Request reports Half Up Shift or Half Down Shift. No cut or throttle blip is used and there is no actuator preload. Gear Shift State moves straight to Shift and stays there while Gear Shift Neutral State steps through the sequence, then moves straight to Rearm when it finishes.

There are two methods:

- **Shift only:** the actuator pushes towards Neutral for the Shift time and is then switched off. After Gear Shift Neutral Wait Time, the gear is checked for Neutral.
- **Shift and arrest:** the actuator pushes towards Neutral for up to the Shift time. As soon as the gear reports Neutral it is switched off and the opposite actuator fires for the Arrest time to stop the barrel. After the Wait Time, the gear is checked. Arrest is used when the Arrest time is greater than 0 ms.

Gear Shift Neutral Timing Main sets the Shift Up, Shift Down, Arrest Up and Arrest Down times, which can also vary with Transmission Temperature. Suggested starting values are 5 ms for Shift and 2 ms for Arrest, with a Wait Time of 200 ms. Increase the Wait Time if the gear position sensor is still moving at the end of it.

If the gear is not Neutral at the end of the Wait Time, a retry is started:

Retry	Detected when	What happens	Adjust
Stuck	The gear has not changed.	The neutral sequence starts again.	Increase the Shift time.
Between gears	Gear Position Diagnostic reports Tolerance.	The opposite actuator fires for Gear Shift Neutral Timing Reset to return the barrel, then the sequence starts again.	Increase Reset (typically 150 ms) if the diagnostic reports Could Not be Reset.
Overshoot	The gear on the other side of Neutral is reported.	The sequence starts again in the opposite direction.	Reduce the Shift time, or use Arrest.

Retries continue up to Gear Shift Neutral Retry Maximum. Gear Shift Neutral Diagnostic reports the type of retry. With Gear Shift Neutral Timing Trim Mode set to Enabled, the timing is trimmed by Gear Shift Neutral Timing Trim Increment (suggested 2 ms) on each retry: reduced after an overshoot and increased when stuck. The trim is limited to Gear Shift Neutral Timing Trim Limit per cent of Timing Main, and is reset when the sequence ends. Enabled With Learning keeps the trim for the next request and through a power cycle.

BOSCH MOTORSPORT ABS UNIT INTEGRATION

GPRP Pro offers integration with Bosch Motorsport ABS units. Depending on the unit fitted to the vehicle, some channels are available for sensor source assignment throughout the Package on items where “Bosch ABS” is available as a selection. For example, wheel speeds, brake pressures and vehicle acceleration sensors.

With a Bosch M5 ABS unit, the ABS map switch position is received as Bosch ABS Map Switch Position. To link a system such as traction control to the ABS map switch, set that system's switch index (for example Driver Traction Switch Index) to Bosch ABS Map Switch Position. The Bosch ABS ABS Position Switch can also be linked to a driver switch. Its position is transmitted to the ABS unit when Bosch ABS Type is Bosch M5 or Bosch M5 v19 and the switch is not at its Default position.

Channels received from the Bosch Motorsport ABS unit can be logged in the ECU to allow integrated logging of vehicle dynamics from the ECU logging.

Set Bosch ABS CAN Bus to the CAN bus the ABS unit is connected to, and set Bosch ABS Type to match the unit fitted. The channels received depend on the type, as shown in the table below. For the Bosch M5 ABS unit, the serial number decides the type:

- Bosch M5: serial numbers below 0700 (ABS-M5 database v13).
- Bosch M5 v19: serial numbers 0700 and above (ABS-M5 database v19).
- Bosch M4: Bosch ABS M4 units.

Channel (Bosch ABS ...)	Bosch M4	Bosch M5	Bosch M5 v19
ABS Active	Yes	Yes	Yes
ABS Lamp	Yes	Yes	Yes
ABS Malfunction	–	Yes	Yes
Acceleration Lateral	Yes	Yes	Yes
Acceleration Longitudinal	Yes	Yes	Yes
Acceleration Vertical	–	Yes	Yes
Brake Pressure	Yes	Average of front and rear	Average of front and rear
Brake Pressure Front	Copy of Brake Pressure	Yes	Yes
Brake Pressure Front Balance	–	Calculated from front and rear	Calculated from front and rear
Brake Pressure Rear	–	Yes	Yes
Brake Switch	Yes	Yes	Yes
Diagnostic ABS Unit, Fuse Pump and Fuse Valve	–	Yes	Yes
Diagnostic Front Left, Front Right, Rear Left and Right Rear	–	Yes	Yes
Diagnostic Wheel Quality (each wheel)	–	One state per wheel	Eight flags per wheel (Signal Reduced Monitored, Reduced Accuracy, Interfered, Suspicious Plausibility, Suspicious Lost, Not Initialised, Invalid Generic, Invalid Individual)
EBD Lamp	Yes	Yes	Yes
Fill Level Front Axle and Rear Axle	–	–	Yes
Map Switch Position	Yes	Yes	Yes
Roll Rate	–	Yes	Yes
RTA Ok	–	Yes	–
Wheel Speed Front Left, Front Right, Rear Left and Rear Right	Yes	Yes	Yes
Yaw Acceleration	Yes	–	–
Yaw Rate	Yes	Yes	Yes

Setting Up Wheel Speeds with Bosch ABS

The Wheel Speed data can come from a number of sources. When using a Bosch Motorsport ABS unit, the Wheel Speed n Sensor Source is set to Bosch ABS and the Sensor Resource is set to Not in Use. The Resource refers to a direct connection to a wheel speed sensor, but it is not used in this case. Setting the Resource as Not in Use hides the unused settings, except for Pitch Threshold and Timeout settings, but these are also not used in this case.

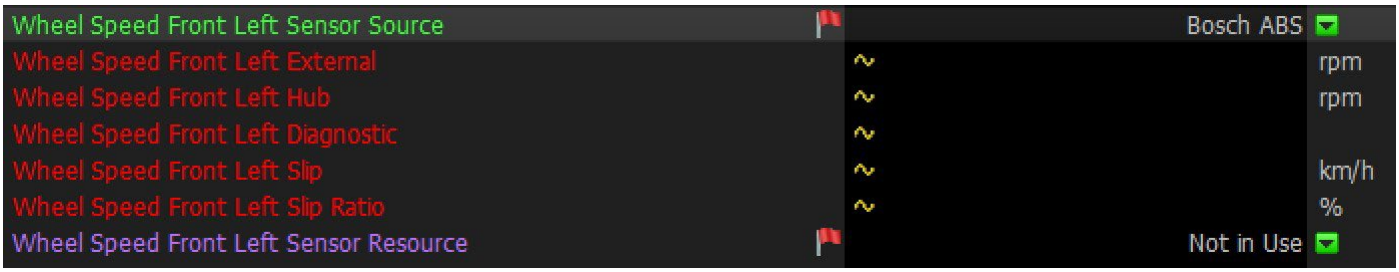


Figure 25. The correct setup when Bosch ABS wheel speeds are received from CAN, with Source set to Bosch ABS and Resource set to Not in Use.

The Bosch ABS transmits the wheel speed data on CAN and the values can be seen in the Bosch ABS Wheel Speed channels.

These values are converted to wheel rotational speed using Bosch ABS Front Circumference and Bosch ABS Rear Circumference. The rotational speed is written to the hub channels, for example Wheel Speed Front Left Hub. The hub speeds are then converted back to wheel speeds, for example Wheel Speed Front Left, using Wheel Speed Front Circumference and Wheel Speed Rear Circumference.

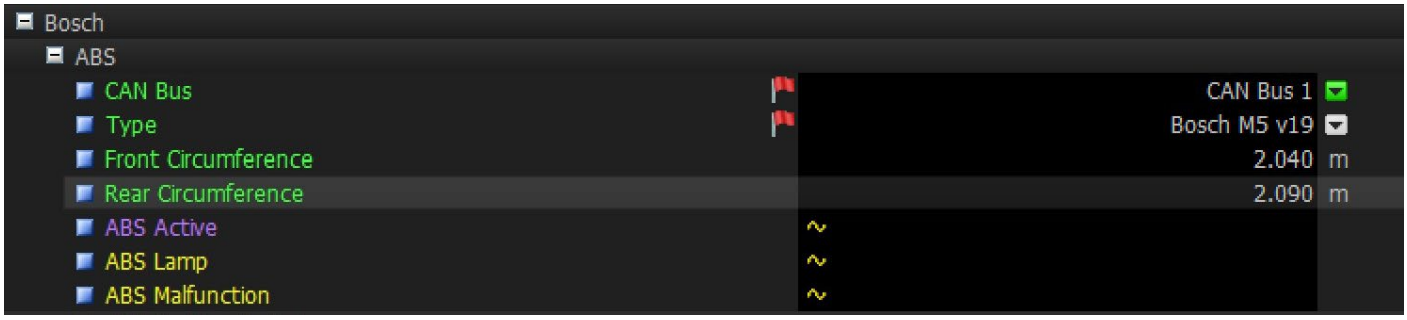


Figure 26. The circumference settings that MUST be set to the values programmed into the Bosch Motorsport ABS unit for correct operation.

Example of wheel speed front left:
Wheel Speed Front Left = Bosch ABS Wheel Speed Front Left / Bosch ABS Front Circumference * Wheel Speed Front Circumference.

The Bosch ABS Front/Rear Circumference setting MUST match the settings programmed into the ABS unit. This allows the ECU to know the wheel rotational speeds and correctly calculate engine speed from wheel speeds for systems like gear shift rev matching and traction control.

Wheel Speed Front Circumference and Wheel Speed Rear Circumference should always match the tyres fitted, which can differ from the Bosch ABS circumference settings.

For example, wet tyres may have a slightly different circumference to slicks. The ABS setting does not need to change, but the ECU wheel circumferences can be changed with Driver Wheel Circumference Switch, which is an axis of these tables, so that the wheel speeds are corrected.

LIN DEVICES

The ECU supports these devices on the LIN bus:

- Pierburg CWA400 coolant pump (Auxiliary Pump).
- Bosch WDA LIN wiper motor.
- LIN controlled alternators.

Assign the bus with LIN Bus 1 Port Resource and set LIN Bus 1 Port Baud, then select the bus in each device's LIN Bus setting. Several devices can share one bus, provided there are no baud rate or message ID clashes. LIN Configuration reports Invalid Configuration, and no LIN communication takes place, if a device is set to use a bus that is Not in Use.

Auxiliary Pump (Pierburg CWA400)

The Auxiliary Pump is a LIN controlled water pump that can be driven by one of these systems, by setting its mode to LIN Pump:

- Coolant Pump Mode
- Coolant Pump After Run Mode
- Intercooler Spray Mode
- Intercooler Coolant Pump Mode

Only one should be set. If more than one is set, the first in this list is used. Auxiliary Pump Control equals the control value of that system, and Auxiliary Pump LIN Speed Aim converts it to a pump speed. The pump reports Auxiliary Pump LIN Speed, Auxiliary Pump LIN Current and Auxiliary Pump LIN Temperature.

Bosch LIN Wiper

The Bosch Wiper system runs a Bosch WDA LIN wiper motor from three driver switches:

- Bosch Wiper Setting Switch: Off, Interval, Speed 1 or Speed 2.
- Bosch Wiper Interval Speed Switch: interval speed One to Four, used when the Setting is Interval.
- Bosch Wiper Single Stroke Switch: one wipe. If held On, the wiper keeps sweeping as in interval mode until it is released. Single Stroke overrides the Setting Switch.

Bosch Wiper State reports the command sent to the motor.

LIN Alternator

For alternators with LIN control, select the bus with Alternator LIN Bus. The alternator is sent Alternator Aim as its voltage set point, so the Alternator Aim settings below apply to both PWM and LIN alternators:

- Alternator Aim Main is the base battery voltage aim, referenced to 20 degC.
- Alternator Aim Temperature Coefficient lowers the aim as Ambient Temperature rises. Typically −18 mV/degC for a 12 V lead acid battery: for example 14.4 V at 35 degC becomes 14.13 V.
- Alternator Aim Throttle Pedal is added above 90% Throttle Pedal, typically −1 V, to reduce alternator load at full power.
- Alternator Aim Increase Rate limits how fast the aim rises. After engine start the system waits 2 s, starts the aim at the battery voltage and ramps it up at this rate. It also applies when the pedal is lifted after the throttle pedal reduction.

LIN specific settings:

- Alternator LIN Excitation Current Limit: maximum field current, 0.1 to 11.0 A. 0 A means no limit.
- Alternator LIN Ramp Rate: time for the field duty cycle to go from 0 to 100% during soft start and load steps. Default 3.0 s.
- Alternator LIN Ramp Cutoff: above this engine speed no ramp is used, except for the first ramp after start. Default 3000 rpm.

The alternator reports Alternator LIN Excitation Duty Cycle, Alternator LIN Excitation Current and Alternator LIN Diagnostic, along with its supplier and alternator ID. Alternator LIN Data Select selects additional data to read back.

GLOSSARY OF TERMS

Below is a list of commonly referenced channels and terms used throughout GPRP Pro firmware. As many of the channels listed below have very similar naming conventions, it is important to be able to make the distinction between them when tuning and configuring many subsystems.

Torque Ideal Generated	Total engine torque generated from the combustion process. This is the highest engine torque value, as no torque ideal corrections have been applied to the value.
Torque Ideal	Ideal engine torque at the flywheel. Resultant torque value after torque ideal corrections have been applied to Torque Ideal Generated. Presumes MBT timing, correct fuelling and no cut events.
Torque	Torque made by the engine: Torque Ideal Generated corrected for ignition timing retard and the fuel and ignition cut averages, plus Torque Ideal Correction and Nitrous Torque.
Torque Wheel	Torque at the wheel axle based on Torque and Vehicle Total Drive Ratio. Used for traction control and includes an inertial calculation and Vehicle Drive Train Efficiency.
Torque Reduction	The Torque Reduction system reduces torque quickly with ignition retard and, if needed, ignition or fuel cut. The Torque Reduction channel is the percentage difference between Torque Modelled and Torque Reduction Limit, in terms of generated torque. See Torque Reduction.
Torque Limiting	Prevention or limiting of higher than required torque being generated through limiting of the throttle. Torque Limits can only close the throttle.
Torque Aim	The torque requested from the throttle based torque control. Used for setting the Throttle Aim in normal operating conditions. Torque Aim can open the throttle.
Modelled	When a channel is listed as a modelled channel value, this means that this is calculated value without taking into account any corrections from measured sensor values. These channels are used in the Torque Control system as they provide more responsive and stable signals to allow for superior control.
Exhaust Mass Flow	Estimated exhaust mass flow, calculated from Inlet Mass Flow, Fuel Mixture Aim and Fuel Stoichiometric Ratio.
Inlet Mass Flow	Calculated inlet mass flow from the inlet plenum into the engine based on engine load, engine speed and number of cylinders. Inlet Mass Flow Modelled is used with Throttle Mass Flow to calculate Inlet Manifold Pressure Modelled.
Throttle Mass Flow	Calculated mass flow through the throttle, from the pressure difference between Boost Pressure (or Airbox Pressure) and Inlet Manifold Pressure Modelled, using Throttle Area and Throttle Mass Flow Area Factor.
Throttle Area	The ratio of the effective throttle area. This value represents the effective area of the throttle in relation to flow and not measured cross sectional area.

Throttle Area Factor	Throttle Mass Flow Area Factor: a throttle size factor used in modelling air flow through the throttle. Can be used for correcting error in Inlet Manifold Pressure Modelled for more accurate torque control, as well as adjusting an already tuned engine for a change in throttle diameter.
Torque Modelled	Flywheel torque calculated from Inlet Manifold Pressure Modelled. Torque Ideal would equal this value if both Kalman Gain tables were set to 0. The throttle based torque control works on this value, so Torque Aim directly controls it.
Torque Modelled Corrected	Torque Modelled including corrections for fuel cut, ignition cut, ignition retard and Nitrous Torque. It should closely match Torque. Torque Reduction retards timing so that this matches Torque Reduction Limit Corrected.
Torque Ideal Correction	Negative torque produced by the engine when the cylinders are not firing: internal friction and drive losses (Torque Ideal Correction Internal Loss table) plus external loads such as the alternator and A/C compressor. Torque Ideal = Torque Ideal Generated + Torque Ideal Correction.
Torque Pedal	Torque requested by the driver through the Throttle Pedal, equal to Throttle Pedal Torque Aim.
Torque Limit	The lowest of all active throttle based torque limits. Torque Limit State reports which limit is in control. It is infinity when no limit is active.
Inlet Manifold Pressure Modelled	Manifold pressure calculated from Boost Pressure, Throttle Position, Inlet Mass Flow Modelled and Inlet Manifold Temperature, without sensor corrections. Used for torque based throttle control because it responds faster and is more stable than the sensor.
Boost Pressure Ratio	Turbo compressor pressure ratio: boost pressure (absolute) divided by turbo inlet pressure, averaged across banks. The closed loop boost control works on pressure ratio, shown in pressure units in the Corrected channels.
Vehicle Speed Estimate	Best estimate of true ground speed, from Vehicle Speed, GPS, Race Time or engine speed and gear as selected by Vehicle Speed Estimate Mode. Used by the Traction, Launch, Gear Shift, Transfer, Vehicle Pitch Control and Vehicle Speed Limit systems.

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