GPRP PRO

SETUP & TUNING GUIDE

Version 1.3 Published: 20 July 2022

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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 that exist in GPRP Pro and GPRP-DI Pro, which will aid in configuring and tuning these Packages, as well as briefly covering the torque model and the control strategies that utilise it. It does not serve as a migration guide for transitioning from a tuned GPRP Package to GPRP Pro; there are many differences in control strategies which result in unsuccessful migration.

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.

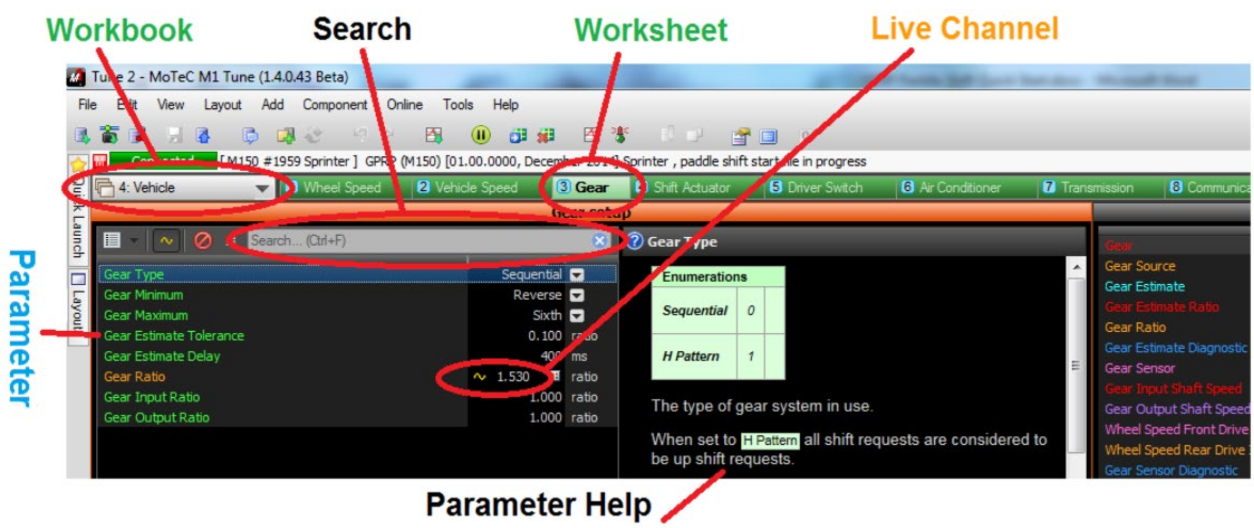

Figure 1.

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.

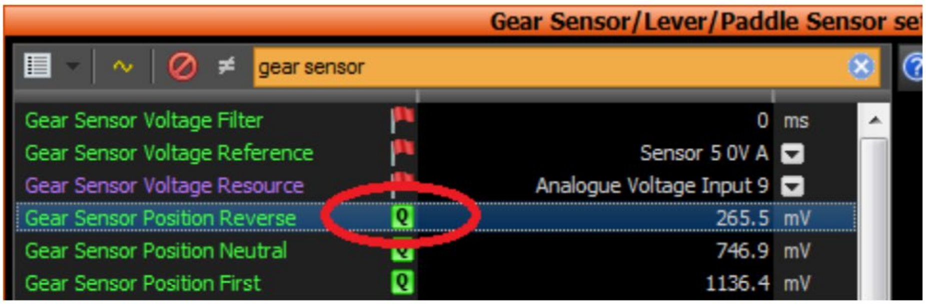

Figure 2.

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, all throttle commanded positions are derived from the Torque Aim system. For example, the Throttle Pedal in most systems sets a Throttle Servo Position Aim, but in GPRP Pro it sets a Torque Aim. This allows the throttle to give a more linear and consistent response. Likewise, in other GP Packages many systems that command a Throttle Aim, such as Anti Lag, now command a Torque Aim.

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 air per induction) which is calculated in the Engine Efficiency model for fuelling requirements. This is translated to torque using the Torque Ideal Generated scale, a user definable parameter to turn the torque ideal output into an accurate representation of measured engine torque output.

This parameter defines how many milligrams of calculated engine load are required to generate a newton metre (Nm) of torque. As this is all calculated per firing, the value is then multiplied by the number of cylinders to produce the Torque Ideal Generated value. This value includes all torque generated by combustion, not including internal frictional losses and driving of ancillary loads like the alternator, water pump, power steering pump, A/C compressor and transmission oil pump.

Torque Loss via Friction

The Torque Ideal Correction Internal Loss table is provided to correct for the engine's internal frictional losses and ancillary loads. This table compensates for an average load of most constant ancillaries referenced to Engine Speed and does not compensate for switched loads, such as the A/C compressor. The losses of these larger switched loads, or loads that vary independent of engine speed, are accounted for in the Torque Ideal Correction External Loss calculation. Because additional losses can occur due to high cylinder pressure, piston to bore friction from increased heat, and piston ring friction (particularly in cases where a gas ported piston is used), a Torque Ideal Correction Engine Load table is provided. This table should be calibrated to 0 Nm in overrun and light load conditions – these losses are covered by the Torque Ideal Correction Internal Loss table previously discussed.

Torque Ideal and Timing Gain

The resulting value is Torque Ideal, representing the torque produced based on the air inducted. The final Torque value includes compensations for ignition timing reductions (Torque Reduction) and Fuel and Ignition Cut Estimates.

The torque compensation due to ignition timing reduction is presumed to be linear to simplify the calibration. The Torque Ideal Ignition Timing Gain sets the percent of torque reduction per degree of ignition timing retard.

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.

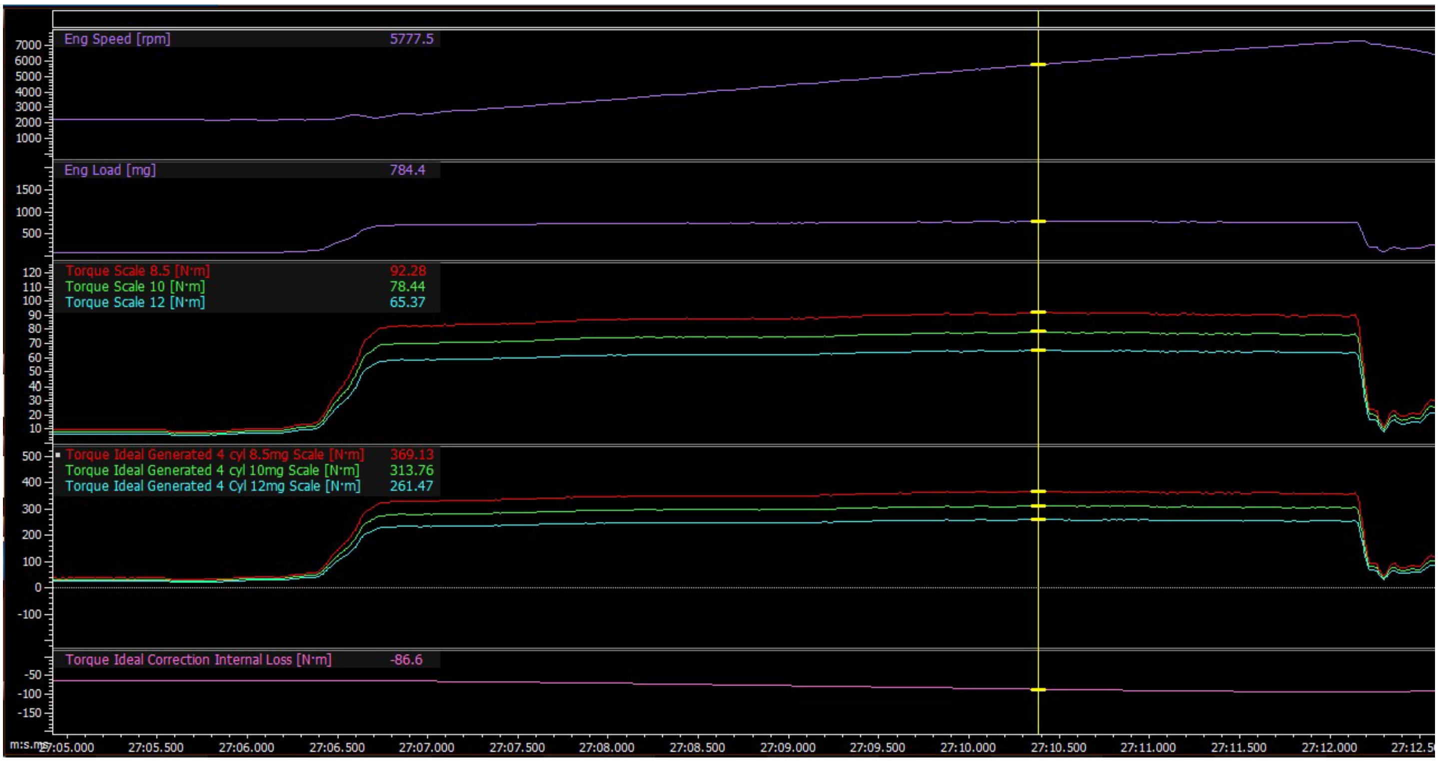

Figure 3. Example of the influence Torque Ideal Generated scale can have on Torque Output. Use case is a 4 cyl engine.

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:

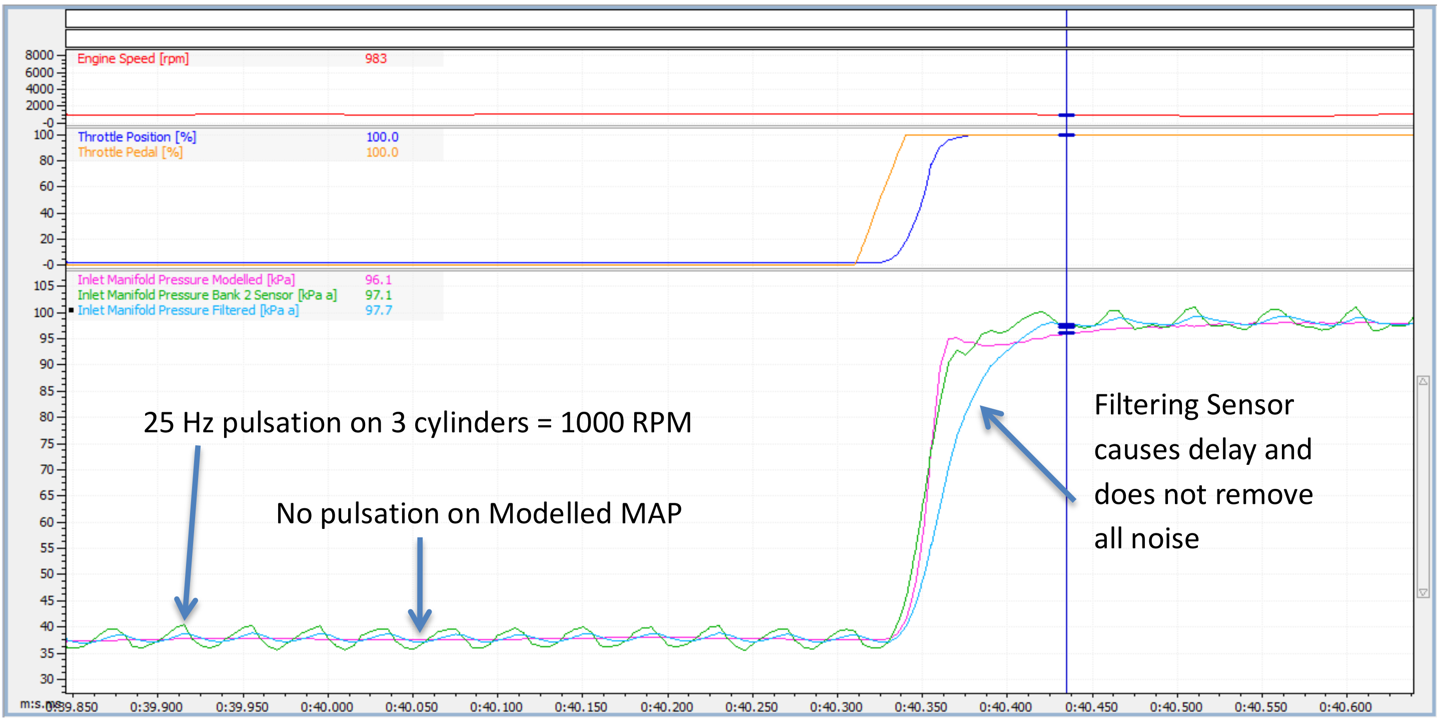

Figure 4. Example of a 6 cylinder dual plenum engine. One bank of 3 cylinders.

Basic Principle

The Inlet Manifold Pressure Modelled works on knowing the mass of air flowing into the manifold (represented as Throttle Mass Flow) and the mass of air flowing out of the manifold (represented as Inlet Mass Flow*)* into the cylinders.

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 *s*ensors 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. This is simply calculated from Engine Load derived from the Engine Efficiency calculation. The number of cylinders filled per second by the calculated mass per fill gives the Inlet Mass Flow.

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.

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 dimensionless 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.

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 much 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).

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, this should be scaled based on the change in area of the throttle. The Throttle Area table will likely need adjusting at low throttle openings, but high throttle opening is mostly corrected by this value.

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

GPRP Pro enables the user to adjust the Kalman filter against Inlet Mass Flow in order to achieve the best balance of response and stability for engine control. In particular, the setting of the Inlet Manifold Pressure Kalman gain should be considered, as the Inlet Manifold Pressure Modelled operates in place of the Manifold Pressure Estimate table. This is only factored for engine load calculations for fuelling etc.; it will not influence the Torque Control.

As such, it is recommended that this is set to predominately use the Inlet Manifold Pressure sensor only, particularly at higher engine load. The Throttle Mass Flow Kalman Gain table will only be referenced if an Airbox Mass Flow sensor is assigned and calibrated, otherwise the firmware will operate on a 0 mgain (Throttle Mass Flow = Throttle Mass Flow Modelled).

If Throttle Mass Flow Kalman Gain is 1000 mgain:

- The efficiency table is effectively ignored as Inlet Mass Flow always balances to the same as the Throttle Mass Flow that is locked to the Airbox Mass Flow values.
  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.

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:

- The mode selection Normal calculates the engine's standard Engine Load mass of air. That being, pressure of 101.325 kPa, volume displacement of one cylinder at 100% pumping efficiency and no fuel vapour correction, 20 degC with no charge cooling applied. Engine Load Normalised = Engine Load / Engine Load Standard.
  As the Engine Load calculation uses Engine Efficiency in the calculation, any tuning carried out on the efficiency table will alter the Engine Load Normalised at that point.
- The mode selection Inlet Manifold Pressure uses the calculation of Engine Load Normalised = Inlet Manifold Pressure (kPa) / 101.325.
- 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.

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.

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

Throttle Pedal Translation [%] (0.0 – 100.0)

Engine Speed [rpm] \ Throttle Pedal [%]	0.0	5.0	10.0	20.0	30.0	40.0	50.0	75.0	100.0
6000.0	0.0	5.0	11.0	22.0	33.0	44.5	55.5	80.0	100.0
4000.0	0.0	15.0	25.0	37.0	47.7	57.6	66.0	84.0	100.0
2000.0	0.0	23.0	37.5	53.0	64.5	73.0	79.0	90.0	100.0
1000.0	0.0	25.0	43.0	60.0	73.0	81.0	86.5	95.0	100.0

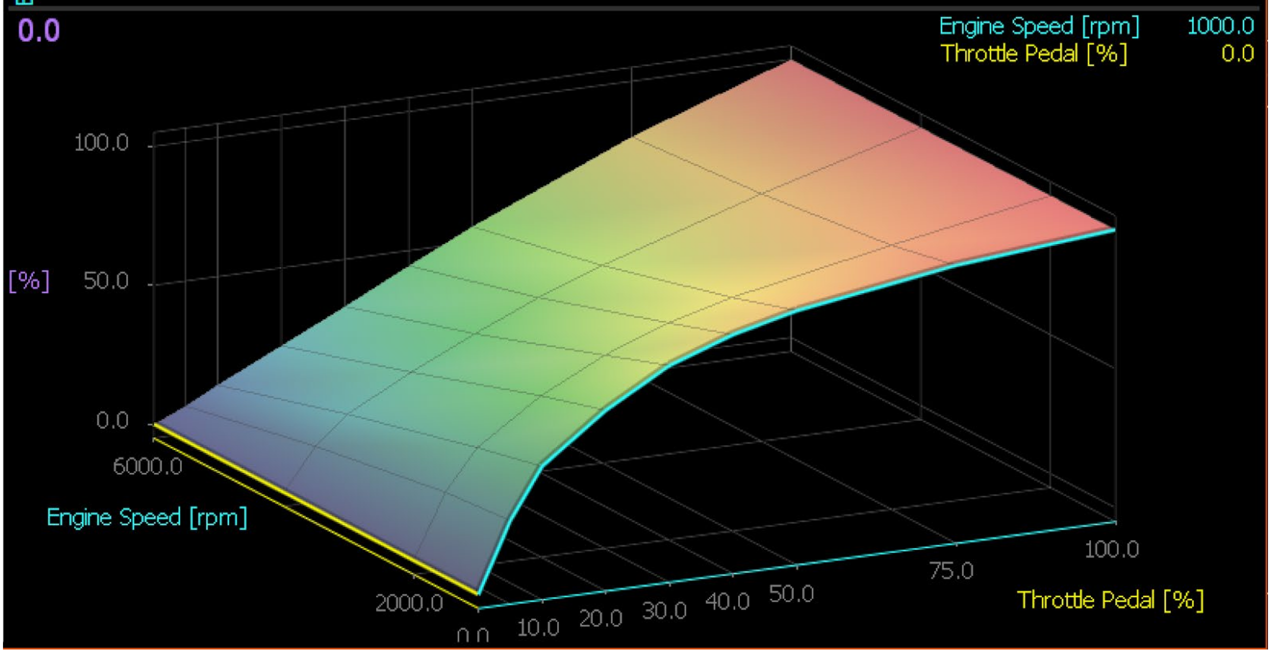

Figure 4. A Throttle Translation table from a Nissan GT-R with Throttle Pedal and Engine Speed axes.

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 previously stated, the Throttle Pedal requests a torque aim rather than a throttle servo opening, which is expressed as the Throttle Pedal Torque Aim. The calculation of Throttle Pedal Torque Aim = Torque Maximum * Throttle Pedal Translation.

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.

The Throttle Pedal Mode option changes the above calculation to 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.

Throttle Pedal Take Off

The Throttle Pedal Take Off is an assistant style 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.

This is effectively a soft launch control for normal driving, but it can also be set up quite aggressively, for pit stop take off and the like. An Engine Speed Limit is tuned versus Throttle Pedal Position, using ignition timing to limit the engine speed. The Ignition Timing Control system also needs to be tuned. A rising engine speed may be tuned with a rising pedal position, e.g. 10% = 2000 rpm, 20% = 2500 rpm etc. When the pedal is pressed to a position, the engine can only rev to the engine speed tuned for this position. The low torque aim means the timing only needs to be retarded slightly, but it could still make a small amount of boost, or if the pedal is pressed further make more boost. When the clutch is released and engine speed slows, the timing is automatically advanced, delivering more torque to get the car moving and decrease the chance of stalling.

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.

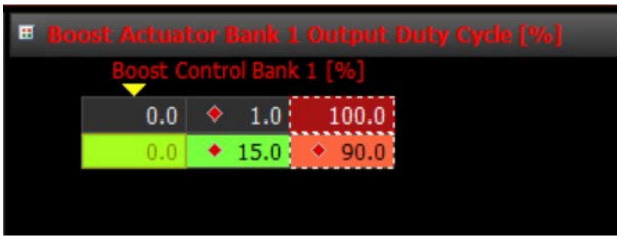

Figure 5.

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

In any internal combustion application, the placement of the lambda sensor in the exhaust can have an effect on its accuracy when used in various control strategies due to the transport delay of exhaust gas from the combustion chamber to the lambda sensor. This transport delay is not fixed – at a higher exhaust flow the delay period is shorter. This is handled in GP firmware utilising a lambda delay period versus Exhaust Mass Flow table.

GPRP Pro introduces an evolved lambda model with the option to use a special algorithm in the response time calculation of a lambda sensor fitted in the exhaust. This refined system allows the response time to be more accurately modelled against Engine Speed and Inlet Manifold Pressure, as opposed to the calculated Exhaust Mass Flow.

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).

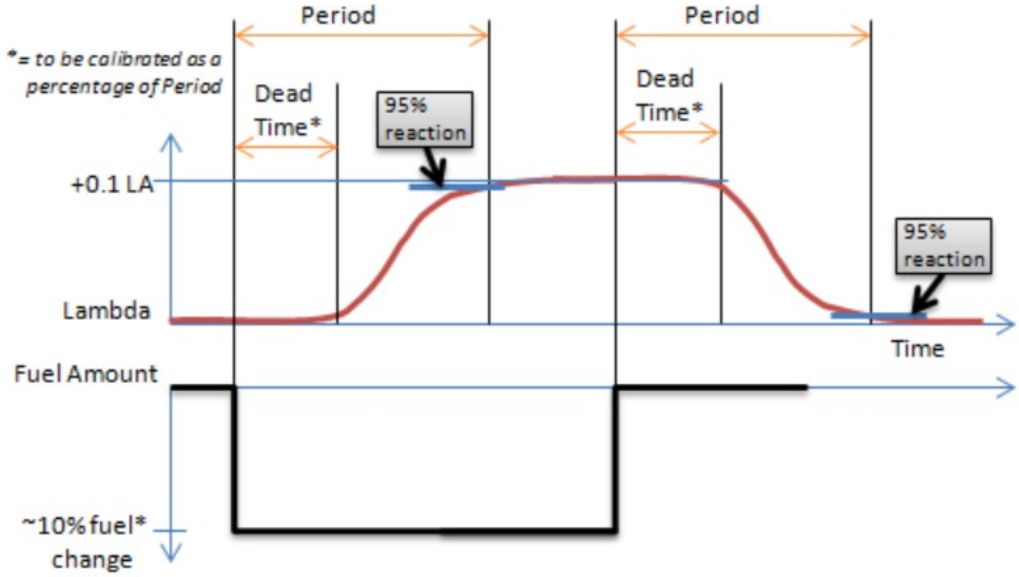

Figure 6. Graphical depiction of the Dead Time and Period areas in the change in Lambda.

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 where the lambda starts showing a reaction (for example, in the magnitude of 5% of the expected lambda change). The value is expressed as a percentage of Period. If using a fuel volume trim to achieve a 0.1 LA change, it should be noted that the correlation between fuel and lambda is non-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.

Both the Delay and Lag channels are used outside of this class to calculate the sensor position for functions like Efficiency Adaption, and they are also used in the Primary Lambda Control to determine Control Trim Integral Gain Calculated, if in use.

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 the normal Engine Efficiency Main so it can be enabled, disabled or applied to the Engine Efficiency Main table. This system can be used to quickly populate an efficiency table on the first tune of an engine (with accuracy relative to the setup of the lambda response period and dead time), to fix a poorly tuned efficiency table, or to act as a long term fuel trim, dependent on the selected sensitivity and sensitivity settings.

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 the 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

Modifying any of these settings may require the Engine Efficiency Adaption to be reset and run again. As outlined in the Exhaust Lambda Response section of this Tuning Guide, a more advanced response model has been implemented to accurately calculate the transport delay of exhaust gases to determine what the engine operating parameters were at the point of the presently measured exhaust gases.

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. Other settings can be used for a dual bank engine running a lambda sensor on each bank, however, the Exhaust Lambda Bank 2 Response must 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 will become more refined with use. For example, the Coarse setting will become finer as more data is collected. If the Efficiency Adaption Advanced settings are enabled, the user also has the ability to adjust the correction factor versus samples of a load site.
- Engine Efficiency Adaption Enable: The Engine Efficiency Adaption only functions when Engine Efficiency Adaption Enable is Enabled. The Engine Efficiency Adaption Enable can be determined based on Engine Speed, Inlet Manifold Pressure, Ambient Pressure, Inlet Air Temperature, Coolant Temperature and Lap Distance. Each of these enables can be varied with the position of the Driver Engine Efficiency Adaption Setting Switch. This allows for a quick change of the enable conditions.
- Engine Efficiency Adaption: The axes of the Engine Efficiency Main, Engine Efficiency Adaption, Engine Efficiency Adaption Trim and Engine Efficiency Adaption Samples must all have identical axes and axis site values, and when the Engine Efficiency Adaption Reset is Enabled, these axes will be automatically set.
- Engine Efficiency Adaption Aim Tolerance: Set this value to limit the correction trims that are calculated by the Engine Efficiency Adaption function. This tolerance is the maximum allowable difference between the Engine Efficiency table value, and the calculated Engine Efficiency Adaption value for the value to be accepted.
  Note that when Engine Efficiency Adaption Sensitivity is set to Coarse, for use with an engine that is not tuned, this tolerance may need to be quite large (i.e. 300% Trim).

Correcting Efficiency

While the engine is running and the enable conditions are met (Engine Efficiency Adaption Enable is Enabled), the Engine Efficiency Adaption calculates how much the engine efficiency needs to be corrected so that the Exhaust Lambda Bank N equals Fuel Mixture Aim. This resulting value is shown in the 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 in place to ensure changes are only implemented with accurate data present. To keep track of this, there is an Engine Efficiency Adaption State channel that can be monitored.

Engine Efficiency Adaption and Samples Tables

The Engine Efficiency Adaption and Engine Efficiency Adaption Samples tables are viewable in M1 Tune when the Adaption function is enabled only when connected to the ECU. The Engine Efficiency Adaption table is initially populated and the axes are set up when the Engine Efficiency Adaption is enabled, and the Engine Efficiency Adaption Reset is enabled. This pulls the values from the Engine Efficiency table and any adaptions are applied to this table. When the Engine Efficiency Adaption is enabled, this is the efficiency table that the M1 references for all calculations, not the Efficiency Main table.

The Engine Efficiency Adaption Samples show how many corrections have occurred over each site. This helps the user see how well areas of the map have been adapted and, based on the Engine Efficiency Adaption Advanced Factor (if advanced mode is enabled), how much any of the sites can be adjusted by the adaption system based on the number of samples taken at a site.

Figure 7. An example of the Engine Efficiency Adaption Samples table updating on the number of samples taken.

Applying Corrections and Resetting

The corrected Engine Efficiency values, which are stored in the Engine Efficiency Adaption table, are saved on the M1 ECU but not within the Package. This means these corrections will be cleared if a new firmware version is sent to the M1. To permanently apply these corrections to the Engine Efficiency Main table, navigate to the Engine Efficiency Adaption Apply and enable it by pressing the **Q** key.

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).

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

If the Efficiency Adaption Reset is enabled, the Engine Efficiency table will be reloaded into the Engine Efficiency Adaption, and the Engine Efficiency Samples and Engine Efficiency Trim tables will be reset.

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 2 banks to be controlled independently by enabling Boost Control Bank 2 Mode. Once enabled, the user can define an independent feed forward table, PID control settings and feed forward offset to control a boost control output/s, while targeting a single boost aim. This allows for independent closed loop control in systems with completely independent banks with dual plenums and no balance pipework between banks. The dual bank boost control extends 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)
- Twin turbo, independent bank plenums:
  - Dual boost valves
  - Dual wastegate pressure control
  - Dual servo control

Turbo Speed Control

The turbo speed limit system effectively reduces the Boost Aim to lower the turbo speed via the closed loop boost pressure control. Given this is a closed loop system that is setting the Aim for another closed loop system, there can be some negative interactions, so to keep it simple the system only includes an integral component.

The turbo speed control system uses a calculated turbocharger pressure ratio to convert boost pressure into a % value. The calculation is Boost Pressure (absolute) divided by Ambient Pressure (absolute). For example, if Ambient Pressure is 100 kPa then Pressure Ratio % is equal to Boost Pressure kPa (absolute). Note that the Boost Pressure channel in the ECU is in gauge pressure, so Ambient Pressure is added to this to calculate the absolute value.

The Turbocharger Bank N Speed Boost Limit Control Integral is in terms of Pressure Ratio, so it can be considered to be setting the Boost Aim directly. For example, if Ambient Pressure is 100 kPa, when the Integral is 180% it will set the Boost Aim to 80 kPa (gauge). It sets the Boost Aim via the Boost Limit system, so this 180% is converted into the Boost Limit terms.

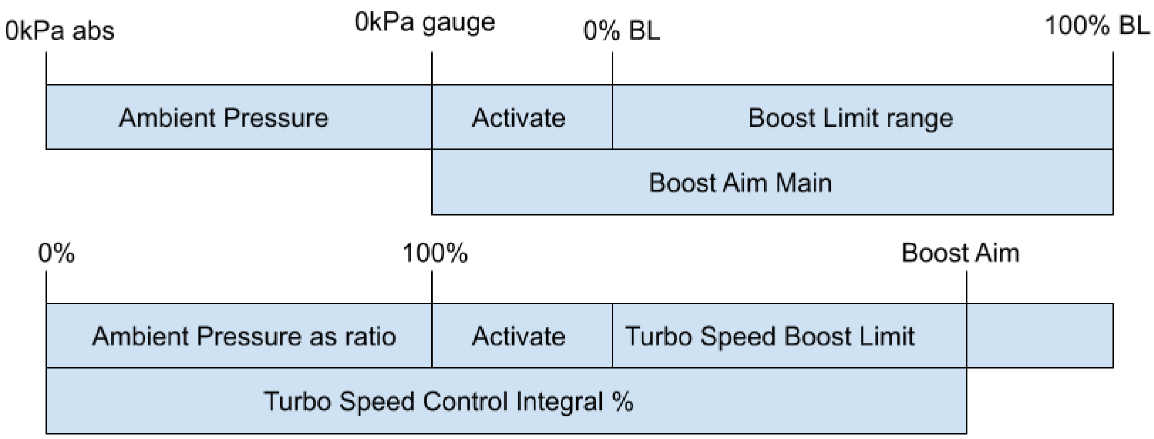

Figure 8. The interaction of Turbo Speed Control Integral against Pressure Ratio.

The first part of the diagram above describes the boost limit calculation where a Boost Limit less than 100% sets the Boost Aim within the range from Boost Control Activate pressure to Boost Aim Main. A Boost Limit of 0% therefore sets the Boost Aim to the Boost Control Activate pressure and Boost Limit of 100% sets the Boost Aim to Boost Aim Main.

The second part describes how the turbo speed control sets the Boost Aim. The Turbocharger Bank N Speed Boost Limit Control Integral is a percentage value where 100% is equal to Ambient Pressure. 200% would be double ambient pressure, for example. This absolute pressure ratio then sets the Boost Limit where it falls on the scale and this is converted back to the final Boost Aim. The diagram shows an integral value that is reducing the Boost Aim from the Boost Aim Main.

The idea of the Boost Control Activate setting is that it tells the ECU the minimum Boost Pressure that the hardware can achieve at full throttle. For example, a traditional wastegate actuator operated by boost pressure has a minimum amount of boost set by the spring in the actuator, e.g. 50 kPa. If Boost Aim is set to 30 kPa, the Boost Control system would not be able to achieve 30 kPa since the minimum is 50 kPa. 30 kPa is outside of the ECU’s control range. So if the Boost Control Activate is set to 50 kPa, the Boost Aim would never be below 50 kPa and this is the Boost Aim requested when Boost Limit is 0%. It doesn't make a big difference to the control, but a reduction in boost may not be seen when expected. If Boost Limit is 0%, there is no expectation of further reduction.

With a vacuum or servo operated wastegate, boost pressure may be reduced much lower so the Activate might be set to 10 kPa for example. Or perhaps boost pressure this low will never be wanted, so the Activate can be set to 50 kPa and this sets the minimum Boost Aim.

The Turbocharger Bank N Speed Boost Limit Control Integral is calculated constantly but the maximum is limited to the Turbocharger Bank N Speed Boost Limit Control Margin above the current pressure ratio (boost pressure). With a 10% Margin and low turbo speed, the Integral will effectively always be requesting 10% more than the current Boost Pressure. In this condition, the speed limit control is not applied and boost pressure is controlled by the Boost Control system.

When turbo overspeed does happen, the Integral value falls. When the Integral is equal to the current Pressure Ratio, the control starts and effectively sets the Boost Aim to the current Boost Pressure, lowering or raising the Boost Aim to control the turbo speed to the Turbocharger Speed Limit.

If the Boost Pressure is lower than Boost Aim when turbo overspeed occurs, the aim could drop quite suddenly when the Boost Aim is set to the current Boost Pressure. This would also suddenly reduce the Boost Control Proportional and actuator duty cycle and the system may remove too much boost, resulting in the speed control starting and stopping.

If Boost Pressure is much closer to Boost Aim when overspeed occurs, the Boost Limit will begin close to 100% and the control will be much smoother. This requires good tuning of the Boost Control system.

If there is a delay in starting control and some overspeed occurs, this can be due to the Integral winding back from the 10% Turbocharger Bank N Speed Boost Limit Control Margin. Increasing the Integral Gain will help with this, but decreasing the Margin will also help.

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 amount of torque (air flow) required is learned and stored in the Idle Torque Nominal channel. This is integrated into the Throttle Pedal Torque Aim for seamless transition out of idle control when the throttle pedal is pressed.

  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.

Ide 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 is below Idle Aim (Idle Aim Main + Idle Activate Engine Speed Margin).

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.

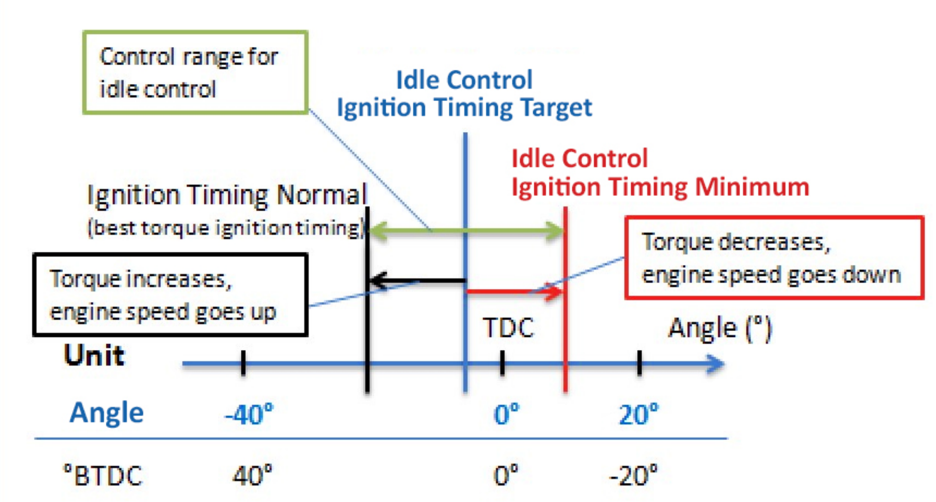

Figure 9. Interaction of Ignition Timing, Engine Speed and the resultant Torque.

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.

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.

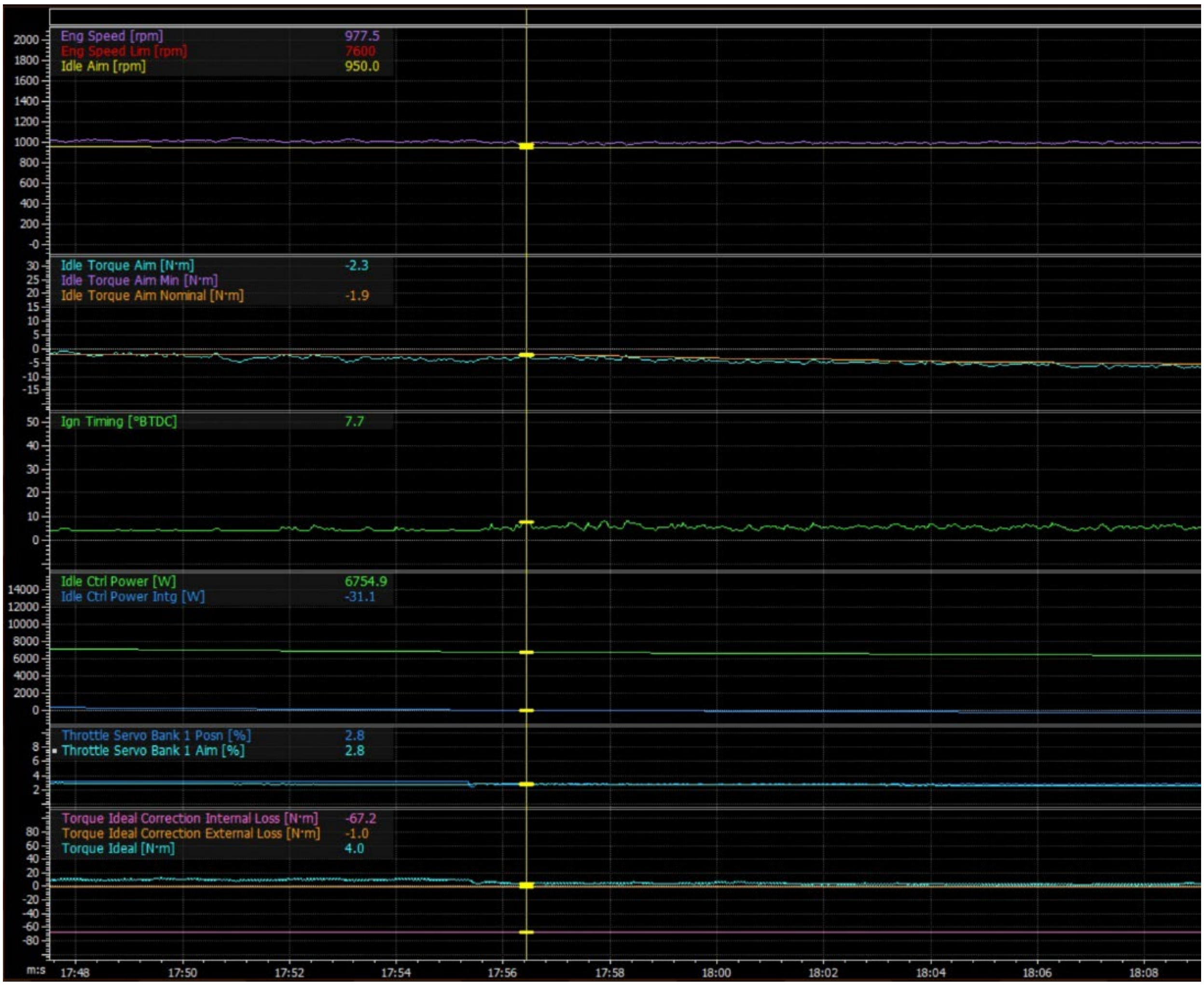

Figure 10. When the Torque Ideal Correction Internal Loss and Throttle Area are accurately populated, the Idle Torque and Torque Ideal numbers should be stable and near 0 Nm.

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.

ENGINE OVERRUN

The Engine Overrun system aims to softly transition into and out of Fuel Cut (full engine braking), without a noticeable bump or it allows the user to choose how much total engine braking is achieved in overrun. The Throttle Pedal Damper achieves the softening effect within the damper system by filtering the pedal requested torque values when they are below a set 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.

The engine overrun system activates when the Throttle Pedal is at 0% and the engine speed is above Idle Aim speed by the Idle Activate Margin.

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

- Reduce air inlet flow to minimum. The minimum Torque Aim is set by Engine Overrun Torque Aim Normal to maintain some air flow.
- Retard ignition. Engine Overrun Ignition Timing Normal is the minimum ignition timing (maximum retard) set by Engine Overrun Ignition Timing.
- Activate fuel cut, when Throttle Pedal Torque falls below Engine Overrun Torque Threshold.

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

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 represents the Torque likely to be applied to the engine once the Engine Speed meets the Ignition Timing Control Aim speed. This means in free revving control states, such as staging or down shifts, a value of 0 Nm can be requested and conversely, a high value should be set for states such as Traction Control and Launched. This can also be set to a higher value than the engine can achieve so that timing is not initially 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 of the timing control system adds a time constant to the calculation to apply additional retard to help the Engine Speed meet the aim when the Ignition Timing Control Aim is exceeded. This is expressed as deg/deg, which represents degrees/(degrees per second*s).

To put this into a worked example, if we had an Ignition Timing Control Integral Gain of 0.05 deg/deg, as per our previous example, and we maintained an Engine Speed 150 rpm over our Ignition Timing Control Aim for 1 second, we would continue to progressively retard the Ignition Timing by 30 degrees during that 1 second period, or until the integral limit is achieved.

The Ignition Timing Control Integral Limit is the limit of integral component of the Ignition Timing Control Component. This serves to prevent integral wind up, which is useful in states where the system may be controlling engine speed for a sustained period of time, such as Launch Staging, whereas traction events are typically short in duration.

The derivative gain component looks at the rate of engine acceleration. This is degrees of retard/rpm per second. So with a gain of 0.001 deg/rpm, an additional 1 degree of retard would be applied if the engine was accelerating at 1000 rpm per second.

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

The sound of knock can cause the engine block to ring and this can create a strong sound at some frequencies and weaker sounds at other frequencies, so the sound wave is filtered to reduce noise from other frequencies. In certain applications one or more cylinders can have more background noise on the frequency that offers the best signal-to-noise ratio for other cylinders. The M1 ECU has the ability to filter to 4 different frequencies simultaneously. In GPRP Pro, users can assign the single best frequency to each cylinder out of the four chosen frequencies.

Knock Count

The intensity or level of a knock event is added to a Knock Count value per cylinder. The count is incremented by the level above a threshold. Each engine cycle after this, the count is decremented if no knock is present or incremented further if knock occurs again. The count value is then used to apply control to the cylinder to prevent further knocking. This means small continuous knock can build up a high count and apply a large amount of control. Larger knock events will build up faster and apply control more quickly.

Knock Control

Primarily, ignition retard is used to control knock at an individual cylinder level. The maximum amount of retard that can be applied can be varied based on the operating condition of the engine. This is set using a table with Engine Speed and Engine Load Normalised axes, the same as used on the Ignition Timing Main Table.

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 to help manage temperature and assist in reducing knock is a Knock Fuel Trim. This allows the user to set the amount of individual cylinder fuel trim for a given Knock Count in a global Knock Fuel Trim table. Aside from more cooling from more fuel, a richer mixture can often be less prone to detonation, although it is not as effective as reducing timing (even though the enrich method results in less torque reduction).

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

Due to the nature of a gear shift event, the rapid transient of the engine speed, and reduction and reintroduction of torque can cause a singular knock event that doesn't need the intervention of the knock control system – even when fuel or ignition cut is not used during the gear shift. This is handled with a single value Knock Cut Event Gear Shift.
If this is set to 0%, the knock control will react to knock events on gear shift. If it is set to 100%, the knock system will not intervene for the Knock Cut Event Filter. If any other values are used, the Knock Cut Event Compensation table will be referenced to calculate how much to reduce the amount of Knock Count applied to a cylinder when a knock event is detected. This Knock Cut Event Compensation table is also referenced when ignition or fuel cut strategies are employed to reduce engine torque, as singular knock events can occur immediately afterwards. Also provided is a Knock Cut Event Filter that allows the user to define the period after a cut event that the Knock Cut Event Compensation is utilised.

As the other prime instances of singular knock events that do not require intervention are transients, a Knock Transient Event Compensation table is provided. This table enables a reduction in the amount of Knock Count applied, relative to the rate of change of the Inlet Manifold Pressure in kpa per second. This allows for Knock reduction in positive and negative transients, and, like the Knock Cut Event system, also has a Knock Transient Event Filter that can be utilised.

Knock Recovery

Another change that has been implemented in GPRP Pro is the knock recovery strategy. In standard GP Packages, this is a time based recovery that occurs in degrees per second. The drawback is that large knock events at high rpm can take a long time for the Knock Ignition Trim to reduce back to 0, when in reality the cylinder will normalise in engine cycles, not a time period. In GPRP Pro, the recovery is %/ratio/cycle. Therefore, with a value of 10%, it will reduce the knock count by 10% of its value per 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.

In some operational conditions, such as a during a launch, where the non-driven wheels of a rear wheel drive car will not be in contact with the road surface during a wheel stand, or in a 4WD car where slip cannot be detected due to slip affecting all 4 wheels, a time based vehicle speed estimate from the race time system or maximum acceleration setting can be used for a better estimate of true ground speed based on data input from the typical best acceleration of the vehicle.

Operational Requirements

There are several requirements for the traction system to work:

- The Driver Traction Switch must be set to On. If no switch is present, the Driver Traction Switch will default to On.
- Traction Mode needs to be set to a mode other than Not In Use.
- Gear must not be Neutral or Reverse. This requires the Gear system to be set up and calibrated correctly, with a valid Vehicle Total Drive Ratio.
- The Vehicle Speed Estimate needs to be greater than the Traction Activate Vehicle Speed. The Vehicle Speed Estimate system must be operating correctly.
- The circumference of the wheels, Wheel Speed Front Circumference and Wheel Speed Rear Circumference.
- The Traction Aim Main table should have non-zero percentage slip values.

Operation

Traction Control operates by limiting Engine Speed to a value, resulting in the driven wheel tyre surface speed being limited to the Traction Aim Speed, which is the current Vehicle Speed Estimate + Traction Aim Slip. This allowable slip margin is user assigned in the form of the Traction Aim Main, which is defined in GPRP Pro against Torque Wheel. As the driven wheel circumference and Vehicle Total Drive Ratio are known, a resulting Traction Engine Speed Limit is calculated, which is targeted by the chosen Traction Control strategy.

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.

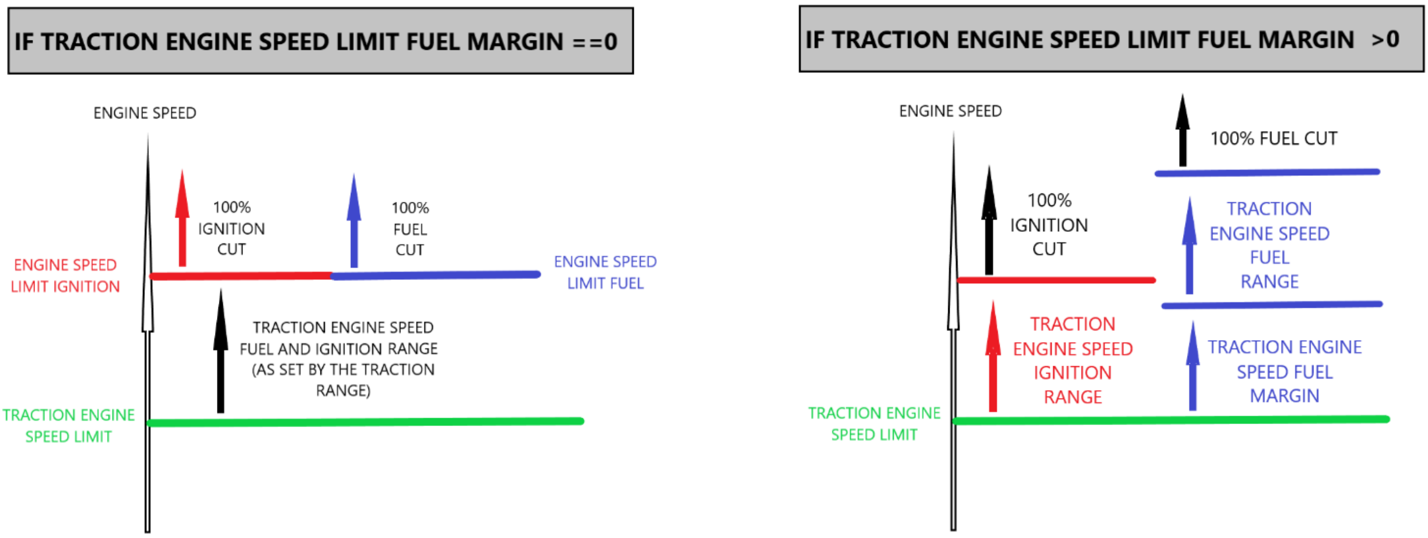

Figure 11. Interaction of the Traction Range with the Engine Speed Limit System.

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

Torque Limit

When the Torque Limit (throttle control) method is utilised, the Traction Torque group is used to tune a PI controller, setting a Torque Limit based on Engine Speed. This system captures the current engine torque at the moment the wheel slip exceeds the allowed slip and reduces torque below this value based on the P and I settings. This torque reduction is achieved through control of the throttle servo, with an ignition cut margin as a secondary strategy in case the PI control does not reduce the wheel slip, or the Traction Torque Inlet Mass Flow Minimum is reached and wheel slip is not under control.

The Traction Range is applied to the PI 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%.

Figure 12. 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 Limit Ignition Cut Threshold parameter defines when the difference in aim to actual torque is greater than the threshold, ignition cut is also applied.

For example: Torque is 600 Nm and Traction Torque requests a sudden drop to 300 Nm. The throttle can't move instantly so the ECU will apply 50% ignition cut to make up the difference. As the throttle closes and torque (based on air flow) drops to say 450 Nm, the ECU will reduce the ignition cut to 25% to obey the 300 Nm limit. This usually happens over 20-30 ms, requiring only a few cylinder cuts before the throttle catches up. This feature can also be turned off if desired by setting the threshold to 100%.

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.

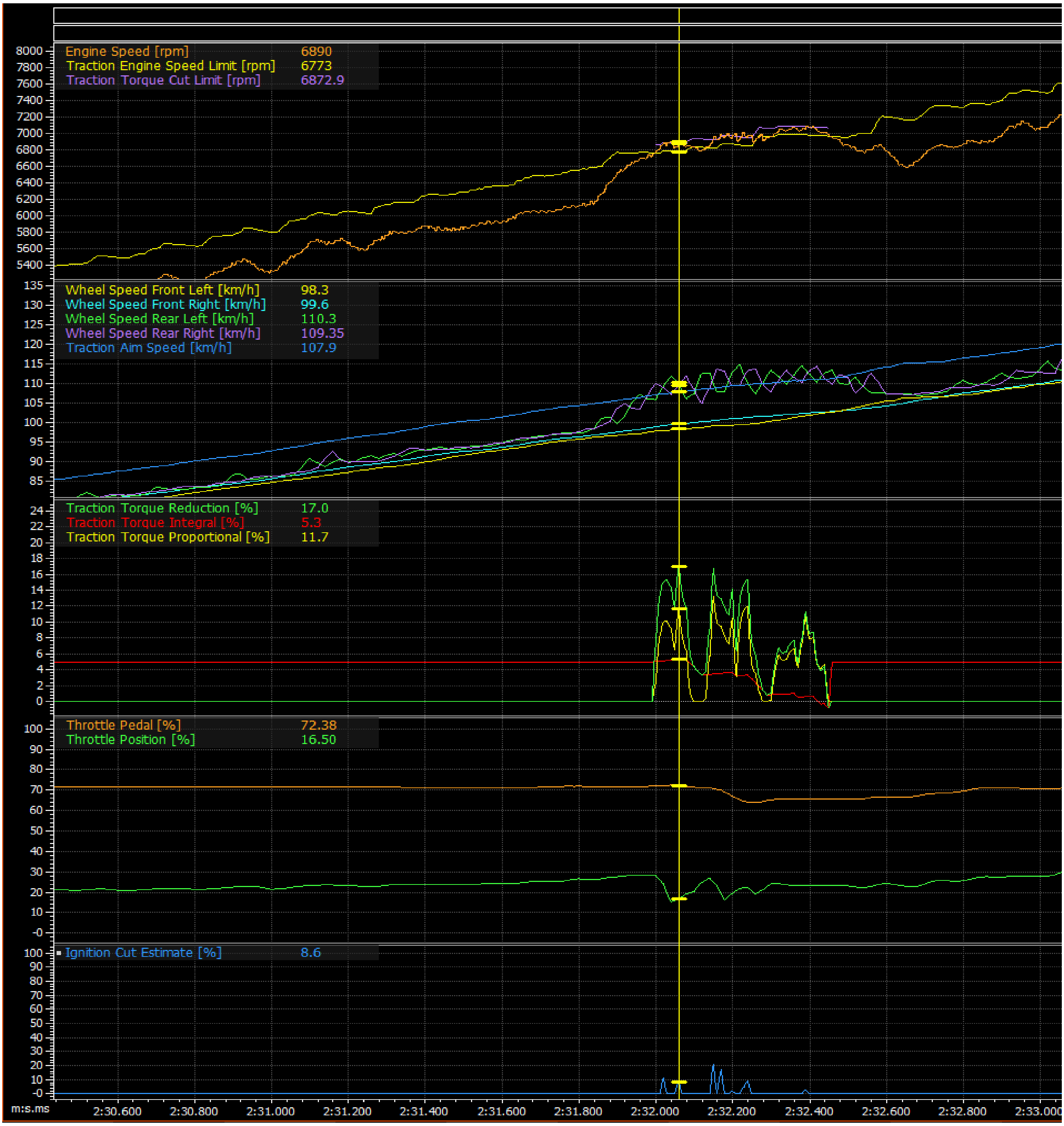

Figure 13. Traction Torque Limit PI control responding to wheel slip and reducing throttle servo.

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%.

To help account for aggressive wheel slip events where the Engine Speed cannot be brought under control via Ignition Retard alone, or to account for a poorly tuned PID controller, a Cut Margin is defined in which Ignition Cut is introduced. This margin can be set up to deliberately use some ignition cut for the Engine Speed control if desired. In this mode, the Traction Engine Speed Fuel Margin or Traction Torque group are not used.

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: Setting a torque value higher than the engine can achieve will mean that timing is not initially retarded when control begins, i.e. 1000 Nm+.
- 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: This is expressed as deg/deg, which represents degrees/(degrees per second*s). In a worked example this means if there is 100 rpm over the limit for 1s, the timing will be progressively retarded by 30 deg during that 1s period for a setting of 0.05 deg/deg (on top of the retard calculated by the proportional component and provided the Ignition Timing Control Integral Limit is not reached).
- Ignition Timing Control Integral Limit. This is the absolute timing retard for the integral component of the Ignition Timing Control. Prevents integral wind up, but typically traction events are very short duration anyway.
- Ignition Timing Control Derivative Gain: The unit is deg/rpm/s. If the engine is accelerating at 1000 rpm/s, this would retard the timing by 1 deg for a value of 0.001 deg/rpm/s.
- Ignition Timing Control Cut Margin: 300 rpm. Ignition cut will be introduced if the Engine Speed is more than 300 rpm over the limit. At 6000 rpm this equates to an additional 5% of wheel slip. Ideally this would never be reached; it is only a safety net.

Traction Model

This is the open loop or passive component of the traction control strategy, which is optional. This system aims to represent the level of grip available, set through the Tyre Friction Coefficient, where the Engine Torque is limited by throttle control so that the force applied to the tyre does not exceed the level of grip by a large amount.

To aid in this calculation, there are several parameters that need to be set in order for the system to work correctly:

- Vehicle mass: So the total mass of the vehicle is known.
- Vehicle mass split: The amount of vehicle mass, expressed as a percentage over the rear wheels. This is used in conjunction with the vehicle drive type to calculate the static mass over the driven wheels.

- Vehicle CoG Height Ratio: This is the centre of gravity height as a ratio of the distance to the rear wheels. It is not used in an all-wheel drive car and should be set to 0. This value is used for calculating the weight transfer to the driven wheels, or away from the driven wheels in a front wheel drive application.
- The longitudinal force that the engine applies to the drive tyres' surface takes into account many factors, including: Vehicle Mass, Vehicle Lateral Acceleration, mass transfer due to acceleration, Aero Downforce and Vehicle Vertical Acceleration. The user can allow this model to be as simple or complex as they choose. Items such as Acceleration Vertical Scale, Traction Model Downforce and CoG Height Ratio can be set or zeroed to reduce or increase the number of factors taken into account for the calculation. Since the Tyre Friction Coefficient can vary greatly with tyre temperature or wet weather, it is recommended that the friction coefficient is set using a driver rotary switch.
- This Traction Model Tyre Friction Coefficient table is a representation of the ratio applied in the vertical axis to the force applied in the horizontal as to where the tyre would begin to slip excessively in relation to the drive tyres combined.

  A simplified example: If you start to slide sideways when the Traction Vehicle Acceleration Lateral reports 0.8 G (holding a constant speed, without downforce and on a level surface), then 80% is a reasonable value to put in this table to begin tuning. The tyre friction coefficient can change while driving, with tyre temperature, road surface change or rain, for instance. Use the Driver Traction Model Switch to adjust the tyre friction coefficient on demand and while driving.

  A value different to what is considered ideal can be used in this table. On rough road surfaces, some wheel slip may be desirable since the available grip changes very quickly and this could not be taken advantage of with limited torque. Also, since this system is only to assist the closed loop part of Traction Control based on slip, actually allowing the tyre to slip is desirable. The benefit here is only a small amount of closed loop cut/retard is required to then control slip.

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 (turning the other way). As the traction system only deals with acceleration, we only look at half of the tyre friction circle.

The table represents how much Acceleration (longitudinal force) can be applied for a Cornering (lateral force), using the axis of Traction Model Wheel Lateral Force. This is generated by the Traction Vehicle Acceleration Lateral, which is a filtered value of the Vehicle Acceleration Lateral. If no resource is assigned for the Vehicle Acceleration Lateral, the Traction Model Wheel Lateral Force Value will remain at 0%.

The table can be set to a default shape - the diamond and variants of an ellipse. This is set by the Traction Model Ellipse Shape Ratio value. The maximum longitudinal scaling is set by the Traction Model Ellipse Ratio. When these two parameters are set, the shape of the Traction model Ellipse is generated by selecting the table and pressing the **Q** function.

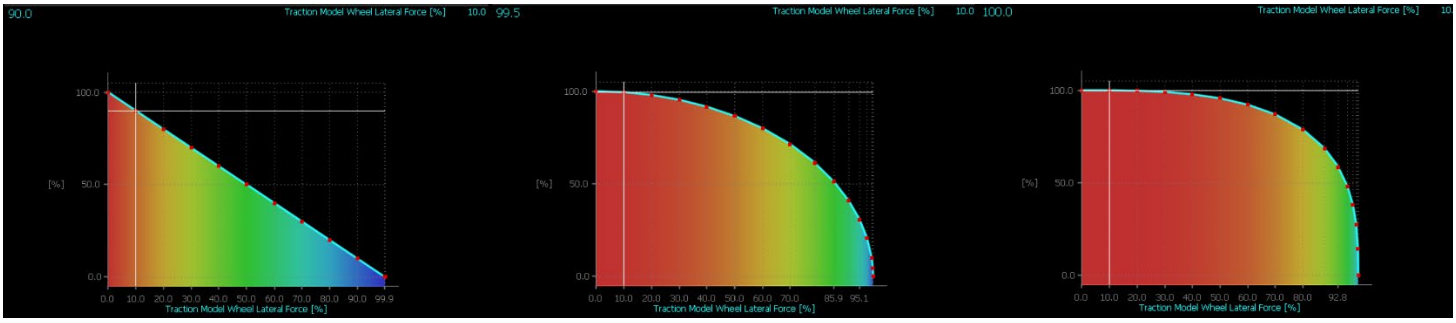

Figure 14. Ellipse variations with a Shape Value of 1.0, 2.0 and 3.0 (left to right). Ratio is set to 1 for all three examples.

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.

ANTI LAG

Anti Lag is a control strategy designed to allow the turbos to create boost while not making engine torque so that boost is instantly available when required. Although largely the same as the standard GPR firmware, there are several additional items for increased flexibility in GPRP Pro, including mode dependent ignition cut strategies, alternate camshaft aim positions when anti lag is active, as well as torque aim in place of throttle position.

The effect of the system is to maintain the required air mass flow through the engine in such a way that when ignition timing is restored, the engine torque is close to the Anti Lag Torque Aim. This means while boost pressure is low, the throttle will open to allow more air to flow. As the Boost Pressure increases, the throttle will progressively close to maintain the required mass flow, and boost may rise to the Anti Lag Boost Aim, provided it is below the Boost Aim Main at 100% throttle with the Boost Limit applied.

Control Strategy

Boost is achieved not by closing the throttles completely but by removing engine power through ignition timing retard and ignition cut. This allows air flow to drive the turbines and build or keep positive boost pressure.

To activate Anti Lag many conditions must be met, for safety of the engine and the driver. The Anti Lag State must first change to Armed. This happens when the following conditions are met:

- Anti Lag Mode = Enabled
- Anti Lag Switch = On
- Exhaust Temperature is less than Anti Lag Shutdown Exhaust Temperature
- Coolant Temperature is less than Anti Lag Shutdown Coolant Temperature
- Throttle Pedal is greater than Anti Lag Arm Throttle Pedal for more than Anti Lag Arm Delay time.

Once Armed, the Anti Lag State changes to Enabled when:

- Anti Lag Ignition Cut Main is greater than 0%. Table value is based on Engine Speed and Throttle Pedal.

The Anti Lag Ignition Timing Main and Anti Lag Ignition Cut Main table values are applied to the ignition system at this time. The Anti Lag Torque Aim Main table value is applied to the Torque Aim system at this time. This opens the throttle to allow air flow into the engine, controlled to deliver the torque level set when the ignition retard and cut is removed.

The Anti Lag State transitions back to disabled when and if the following conditions are met:

- Anti Lag Shutdown Time expires
- Anti Lag Ignition Cut Main is 0%
- Anti Lag Switch = Off
- Exhaust Temperature is greater than Anti Lag Shutdown Exhaust Temperature
- Coolant Temperature is greater than Anti Lag Shutdown Coolant Temperature

The system will return to armed if the Torque Aim State value is less than the Anti Lag Torque Aim, such as when a down shift blip is requested.

Tuning

There are two main items to tune for Anti Lag to function. These set the amount of torque/boost desired while off throttle and the power reduction through ignition retard and cut.

- Anti Lag Torque Aim Main. This table effectively sets the throttle position to maintain the required airflow through the engine when anti lag is active. It is set in terms of the torque the engine would make if no ignition cut or retard was applied and can be considered the torque instantly available when the throttle is pressed. The Anti Lag Boost Aim needs to be set accordingly and considered when setting this.
- The Anti Lag Torque Aim value can be adjusted based on Engine Speed and Throttle Pedal axes for 3 different settings.
- Anti Lag Ignition Timing Main and Ignition Cut Main. These tables set the amount of ignition retard and cut applied respectively when anti lag is active.

The tables have the axes of Engine Speed and Throttle Pedal and the Throttle Pedal axis is normally used. One or both tables can be used to provide the desired torque reduction when off throttle. It is very important to set the level of retard and/or cut high enough to allow the vehicle to decelerate when the Throttle Pedal is 0%. Failure to do so can lead to the vehicle accelerating when Anti Lag is active. The level required depends on the Anti Lag Torque Aim, as a higher aim will have more air flow and require more retard/cut to remove the torque adequately.

This system can also be tuned to achieve “rolling anti lag” functionality. If the Anti Lag Switch is configured and the Activate Throttle Pedal is set low (~2%), Anti Lag can be activated by the switch while cruising at low speed. Depressing the switch will apply throttle and retard/cut as defined and turbos will begin to make boost. If the cut/retard is set proportionally to Throttle Pedal, the vehicle speed can still be maintained by the Throttle Pedal via the ignition controls, even though the throttle butterflies are controlled by the torque aim system.

When the race begins, the driver only needs to fully press the Throttle Pedal to override the throttle control and retard and cut should be reduced to 0 at higher Throttle Pedal values in their tables. The Anti Lag switch can be released after some time, but before slowing down again or Anti Lag may re-enable.

LAUNCH CONTROL

The Launch Control system allows the holding of a steady engine speed and, on a turbocharged engine, assists in building boost while the vehicle is stationary before a launch event. The system transitions through three main phases: from Disabled to Staging, then to Launch.

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.

Engine Speed

Although not exclusive to GPRP Pro, the Launch Engine Speed system has a multi stage strategy. When a Launch Boost Aim greater than 0 kPa g is set, the targeted Launch Engine Speed will be the Launch Engine Speed Maximum when the Launch Engine Speed Maximum is greater than the Launch Engine Speed Main and the Launch State is Staging and the Boost Pressure is low.

The purpose of the Launch Engine Speed Maximum is to help spool up a larger turbo quicker, as higher inlet mass flow is achieved at higher engine speeds. However, higher engine speeds can be unsuitable for launching as they can exceed the available grip level. It also allows for higher boost levels to be achieved at lower launch engine speeds. The system will target the Launch Engine Speed Maximum to maximise inlet mass flow to spool the turbo and begin to reduce the Launch engine speed down to the Launch Engine Speed Main based on the Launch Engine Speed Boost Margin and Launch Engine Speed Boost Range.

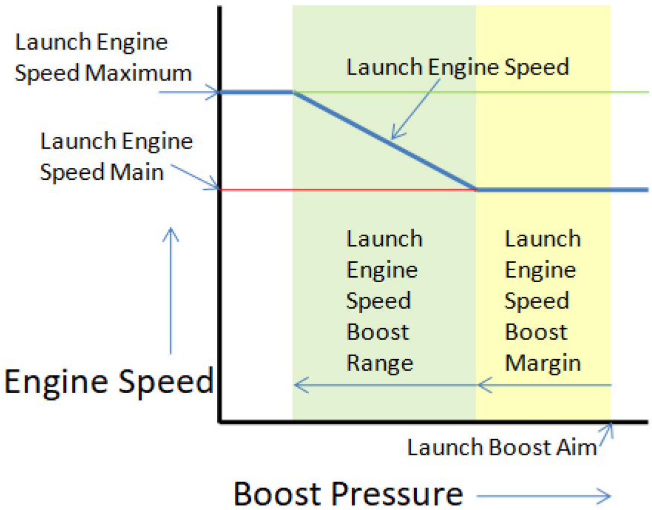

Figure 15. The transition from Launch Engine Speed Maximum to Launch Engine Speed Main based on the Boost Range and Margin.

Care needs to be exercised by the driver, particularly if there is a large margin between the Launch Engine Speed Maximum and the Launch Engine Speed Main. If the Launch State transitions from Staging to Launched while the Engine Speed is still at the Launch Engine Speed Maximum, the vehicle will launch at this engine speed, with potentially undesirable results.

Strategy

When launch control is activated, the Launch Torque Limit Staging limits the air flow through the throttle to produce the torque level that is set in that table.

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 throttles will 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.

Launch Boost Aim is set as the Boost Aim during staging to limit the overall Boost Pressure.

When the Launch State is transitioned from Staging to Launched, the torque limit begins to rise at the Launch Torque Limit Decay (rise) rate. This 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, the Launch Torque Limit Decay should be set to at least 100 Nm/s to ensure that torque rises and blends into other torque limits that may be set.

Tuning Launch Control

Tuning the optimum torque and engine speed for take off requires some trial and error because differing grip levels can vary the ideal combination, with some drive types more sensitive than others. The Launch Engine Speed can also be varied with Vehicle Speed Estimate. This allows closed loop control of the engine speed as the vehicle accelerates and can control wheel slip because Vehicle Speed Estimate is calculated from wheel speed values, or a best theoretical acceleration when used in conjunction with the Race Time system. Typically, Launch Control will end before the change from 1st to 2nd gear.

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. The target engine speed for the launch closed loop engine speed control. This can be set based on Vehicle Speed Estimate to allow the engine speed control to continue after take off.
- Launch Activate Throttle Pedal. The Throttle Pedal must be above this value before launch will activate. Typically set to a low value (~5%) so that engine speed control starts immediately.
- Launch Activate vehicle Speed. The Vehicle Speed must be below this to enter launch. Typically set to 5 km/h.
- 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.

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 down into several phases to ensure that the phases of gear shift are shown in Gear Shift State:

- Pre Shift. This is the pre conditioning of the engine before the shift begins, generally for down shift.
- Shift. The gear is shifting and torque reversal is in progress, e.g. when the ignition timing is retarded on an up shift and the actuator executes the gear shift.
- Post Shift. This is optional wait time after the new gear is selected; only used for down shifts to aid in matching the engine speed after completion of a gear shift that was executed after a pre shift blip.
- Recover. The phasing back to normal operation. This sets the period of time that torque is reintroduced to the drive wheels from the shift phase, particularly on an Up Shift Power On to prevent unnecessary drivetrain whip or wheel slip.
- Rearm. This is the time to wait before the next shift can begin.

As the shift sequence moves through these states, the ignition timing, ignition cut, fuel cut, throttle position and engine speed matching are varied to complete the gear shift. This does not include timing of the Gear Shift Actuator outputs. The Gear Shift Actuator Timing is a separate table where the actuator preload times that are entered reference the time where Gear Shift State transitions to Shift. The preload may be a positive value (before Shift) or a negative value (after Shift).

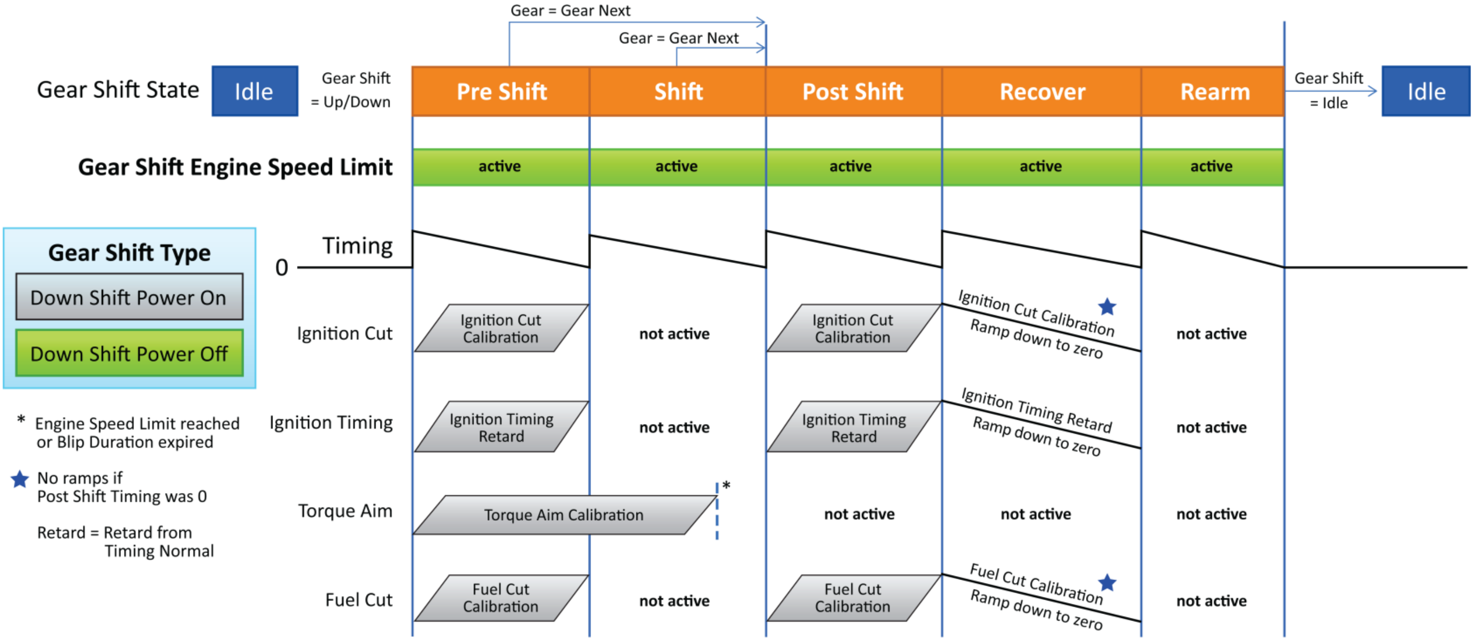

Figure 16. The Gear Shift Phases During a Down Shift.

Up Shift Power On Gear Shift Operation Explained

To best explain each system, and to cover off the primary shift operation in a paddle shifted car, the Up Shift Power On gear shift will be detailed. Generally the Pre Shift phase is not used for this shift type so Gear Shift Timing for Pre Shift can be set to 0 ms. Post shift is not used either so the timing can be set to 0 ms here too.

The Gear Shift Timing for Shift sets the maximum time of the shift. If this time is reached before a barrel has moved to the new gear's position, a shift retry is triggered. Otherwise, the shift phase ends as soon as the new gear is selected so this time is not critically important.

Using engine speed matching via ignition retard, the close loop control of Ignition timing is configured in the Ignition Timing Control group. The maximum amount of retard allowed is set here. The Gear Shift Ignition Timing Retard table defines the minimum amount of retard to apply; generally this would be set to around 15 deg (retarded from the Ignition Timing Main table).

If the Gear Shift Actuator Timing Preload Up Shift Power On is set with a non-zero value, pulling the up shift paddle will immediately turn on the Up Shift Actuator output. After the Gear Shift Actuator Preload Up Shift Power On time period has elapsed, the Gear Shift State moves from Idle to Shift. Engine speed matching is started and ignition timing is retarded. It takes time for the actuator valve to open, for air pressure to build and begin to move the barrel. It also takes time for the drivetrain to unload and engine speed to fall enough for the selector dogs to disengage. The actuator preload time is where this relationship is set.

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 of 15 deg 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 includes reintroduction of ignition or fuel cuts, or ignition retard to prevent the engine from producing torque that could drive the wheels. If Engine Speed Matching is active, the Ignition Timing Control system will precisely control the ignition timing to assist in engine speed matching through the Shift and Post Shift Phases.

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.

Some examples of match setting:

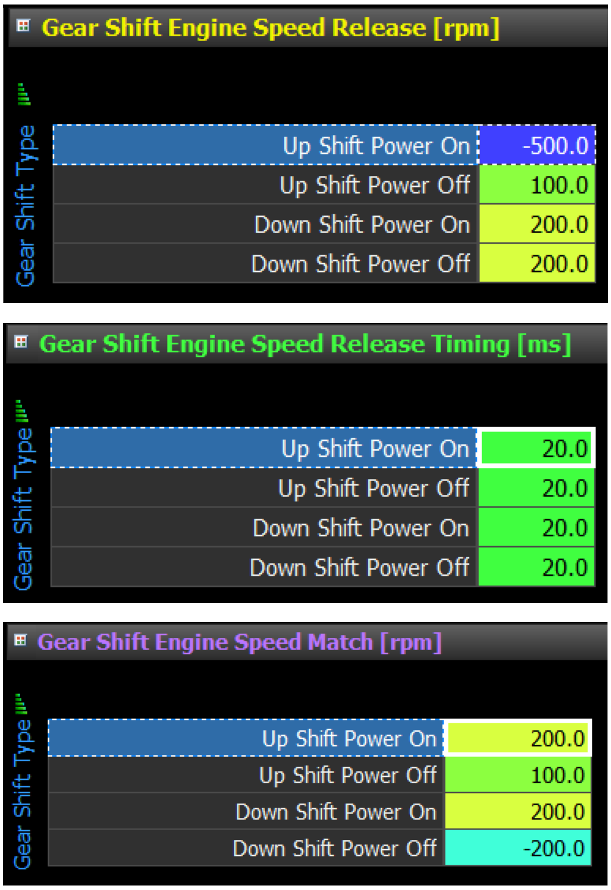

Figure 17. Example starting settings for Engine Speed Release and Match Parameters.

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 shift, the most important setting is the match speed. Too fast and the selector may not have time to engage with the gear. This makes the shift harder but total shift time is faster. Too slow will make for slow overall shift times. Typically this number needs to be around 200 to 600 rpm.

It's also very important to note the positive and negative speeds used in Fig 17. The release speed for Up Shift Power On must be negative, and the Match Speed for Down Shift Power Off must also be negative. All others are positive values. If this is not followed, the gear shifting may function poorly.

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.

In the case of the Bosch M5 ABS unit, the Bosch ABS Map Position Switch can be assigned to a Driver Switch Index to tie in ABS behaviour with applicable systems such as traction control.

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.

The following channels are received from the corresponding model of ABS unit over CAN. For the Bosch M5 ABS unit, the distinction between the V13 and V19 models can be made via the serial number, with a serial number of 700 or greater utilising the V19 database.

Channel	Bosch M4	Bosch M5	Bosch M5 v19
ABS Active	✓	✓	✓
ABS Lamp	✓	✓	✓
ABS Malfunction	-	✓	✓
Acceleration Longitudinal	✓	✓	✓
Acceleration Lateral	✓	✓	✓
Acceleration Vertical	-	✓	✓
Brake Pressure	✓	-	-
Brake Pressure Front	-	✓	✓
Brake Pressure Rear	-	✓	✓
Brake Pressure Front Balance	-	✓	✓
Brake Switch	✓	✓	✓
Diagnostic ABS Unit	-	✓	✓
Diagnostic Fuse Pump	-	✓	✓
Diagnostic Fuse Valve	-	✓	✓
Diagnostic Front Left	-	✓	✓
Diagnostic Front Right	-	✓	✓
Diagnostic Rear Left	-	✓	✓
Diagnostic Right Rear	-	✓	✓
Diagnostic Wheel Quality Front Left	-	✓	✓
Diagnostic Wheel Quality Front Right	-	✓	✓
Diagnostic Wheel Quality Rear Left	-	✓	✓
Diagnostic Wheel Quality Right Rear	-	✓	✓
EBD Lamp	✓	✓	✓
Map Switch Position	✓	✓	✓
RTA Ok	-	✓	-
Roll Rate	-	✓	✓
Wheel Speed Front Left	✓	✓	✓
Wheel Speed Front Right	✓	✓	✓
Wheel Speed Rear Left	✓	✓	✓
Wheel Speed Right Rear	✓	✓	✓
Yaw Rate	✓	✓	✓

Figure 18. CAN Channels received into the M1 from Bosch Motorsport ABS units based on model and serial number.

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.

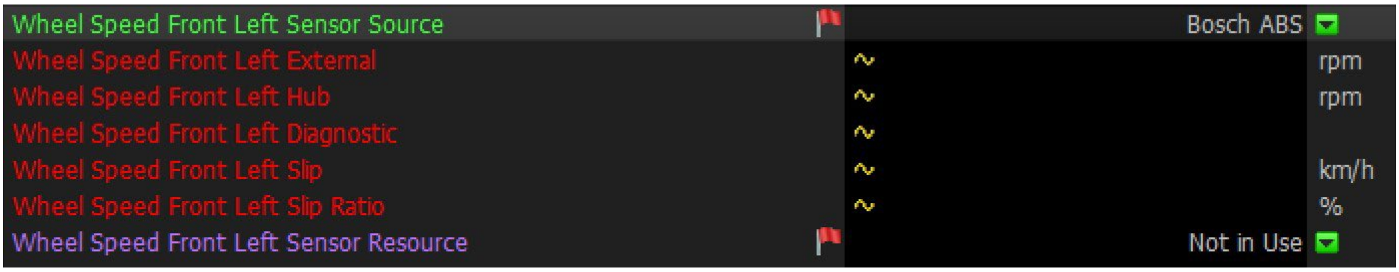

Figure 19. The correct setup when Bosch ABS sensors are utilised from CAN, with Source set to Bosch ABS and Resource Not In Use.

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 the Bosch ABS Front/Rear Circumference settings, before writing the rotational speed to the Wheel Speed Front/Rear Left/Right Hub channels. The hub speeds are converted back to the Wheel Speed Front/Rear Left Right speeds using the Wheel Speed Front/Rear Circumference settings.

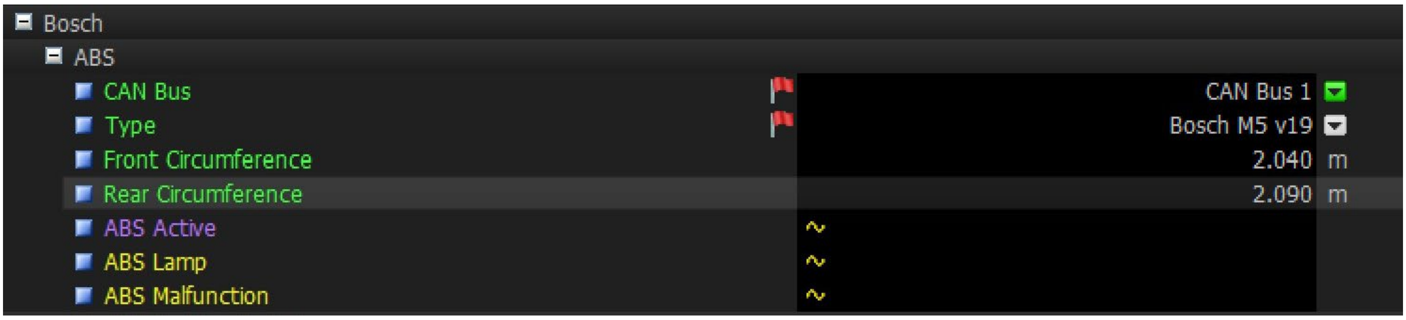

Figure 20. The Circumference settings that MUST be set to the values programmed into the Bosch Motorsport ABS unit for correct operation.

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.

The Wheel Speed Front/Rear Circumference settings should always match the tyres fitted, which can differ to the Bosch ABS circumference settings. For example, if wet tyres have a slightly different circumference to slicks, it may not be necessary to change the circumference setting in the ABS, but the ECU's wheel circumferences can be changed with a driver switch so the wheel speeds are corrected.

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 value after compensations for torque reduction (ignition timing) as well as fuel and ignition cut averages have been applied to the Torque Ideal.
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	Reduction on generated torque through the use of ignition timing retard, ignition cut or fuel cut. Torque Reduction % values are applied to the Torque Ideal Generated.
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	Current throttle based torque limit. 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 generated by combustion.
Inlet Mass Flow	Calculated inlet mass flow from the inlet plenum into the engine based on engine load, engine speed and number of cylinders. Modelled Inlet Mass Flow is used in conjunction with Throttle Mass Flow Modelled to calculate Inlet Manifold Pressure Modelled.
Throttle Mass Flow	Calculated throttle mass flow by measuring the pressure difference across the throttle body via inlet manifold pressure and boost/ambient pressure. Uses Throttle Area and Throttle Area Factor in calculation.
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	A throttle size factor used in modelling air flow through the throttle. Can be used for correction error in the Inlet Manifold Pressure Modelled for more accurate torque control, as well as adjusting an already tuned engine for a change in throttle diameter.

CONTACT US

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