Technical Brief

Prodrive Performance Packs

Subaru WRX – PPP Stage 2

Date: September 21, 2003

System: Prodrive Performance Pack – Stage 2 – Subaru WRX

Tests: Independent Third Party Dynamometer Tests

Prodrive Administered Acceleration Tests

(Preliminary Report)

neverstop >>

Disclaimer: Following is a technical report detailing test results for the Prodrive USA WRX equipped with a Stage 2 Prodrive Performance Pack. Test results in this report were achieved on a 2002-2003 WRX with a Stage 2 PPP. Results are believed to be typical but actual results may vary from vehicle to vehicle or from dynamometer to dynamometer. This report in no way acts as a guarantee or warranty of actual performance results for any individual's vehicle. Many factors can influence actual results.

Summary of Results:

Prodrive USA performed independent dynamometer (dyno) testing on a stock 2004 WRX and on a 2002-2003 WRX with 40,000 miles and equipped with a properly installed Stage Two Prodrive Performance Pack (PPP). The 2004 stock WRX has slightly greater horsepower than a stock 2002-2003 WRX. This slight horsepower advantage in a stock 2004 WRX puts the 2002-2003 WRX at a slight disadvantage before being equipped with the Stage 2 Performance Pack.

Below is a summary of test results from this report:

- Horsepower increased by 42.5 HP or a 25.1% increase by installing the Stage 2 PPP. Peak horsepower for the Stage 2 PPP WRX was slightly over 211 HP.
- "Useable" Horsepower increased across the entire RPM driving range (i.e. – where drivers need it) at some RPM rates by as much as 37% (i.e. – at 5000 RPM the horsepower increase was approximately 37%)
- Manifold Absolute Pressure (MAP), or "Boost Pressure," was not increased significantly which means the PPP Stage 2 achieved its performance gains without simply "winding up the boost."
- The Stage 2 Prodrive Performance Pack provided increased power and acceleration across the drivable power band
- Ambient conditions can affect both on street and dyno testing results significantly. These conditions are discussed in this report and recommendations for peak performance are provided.
- Variations in performance between PPP's tested in the US and the UK are discussed. Primary reasons for the differences between US and UK PPP results include: ECU calibration differences, differences in climates, dyno testing methodology differences, and fuel differences.
- Torque figures are not included in this series of tests. However Prodrive tunes vehicles to increase torque (for example, rally cars) in order to improve vehicle driving performance across the entire range of useable RPM.

Test Set-up

Prodrive retained XS Engineering in Huntington Beach, CA to perform the dynamometer tests described in this report. XS Engineering is a well respected, independent engineering and testing company and has provided dynamometer testing services for numerous magazine tests. The test results provided in this report were performed using XS Engineering's state of the art dynamometer and were conducted by XS Engineering's skilled staff.

Ambient temperature has a large effect on achieving desired test results, especially when a 2-liter turbo engine is being tested which tends to be susceptible to heat overload if proper cooling is not provided. This topic is discussed at length later in this report. For this reason one of the Prodrive dynamometer testing selection requirements was to use a dynamometer testing facility that could adequately control the inlet air temperature over the course of the test. Prodrive also required a properly calibrated dynamometer and a knowledgeable dynamometer operator. The dynamometer cooling fans that XS Engineering use are capable of producing air flow speeds of 80 MPH (2 fans in parallel). XS Engineering's cooling fans draw their air from near the building entrance thus ensuring that the engine and intercooler inlet temperatures are as close to ambient as possible.

During the dynamometer test, XS Engineering performed these tests with the hood in the up position as this simulated real world temperature conditions most accurately. XS Engineering also used a Load Dynamometer which is described below. Test conditions for the tests described in this report were as follows:

Test	Ambient Air Temperature
Stock WRX (Prodrive Tested)	81° F (27.2° C)
PPP Stage 2 WRX (USA)	81° F (27.2° C)
PPP Stage 2 WRX (UK)	53° F (12° C)

Figure 1: Ambient temperatures during various tests

Detailed Test Results:

Dynamometer Testing:

The following table is a summary of results from the dynamometer tests. Peak horsepower increased by 42.5 HP, or a 25.1% increase, by adding the Prodrive Stage 2 Performance Pack. Manifold Absolute Pressure (MAP), or "boost pressure", was increased slightly due to the addition of the Stage 2 PPP from 190.7 kPa to 191.9 kPa or a < 1% increase. As expected the Manifold Absolute Pressure stayed relatively constant over the desired power band for both the stock WRX and the Prodrive Stage 2 Performance Pack equipped WRX. This means Prodrive performance gains are not achieved by "cranking up the boost" but rather are achieved by tuning the engine control unit to optimize performance across the engine's useful RPM range.

	Peak Horsepower (in HP)	Peak Manifold Absolute Pressure (MAP) or "Boost Pressure" in kPA
2004 WRX - Stock	169.4 HP Produced at 5775 RPM	190.7 kPA Produced at 3385 RPM
2002-2003 WRX PPP Stage 2 Installed	211.9 HP Produced at 4724 RPM (42.5 HP Increase or 25.1% over stock '04 WRX)	191.9 KPA Produced at 4215 RPM (1.2 KPa increase or 0.63% over stock '04 WRX)

Figure 2: Comparison chart of HP and Manifold Absolute Pressure (MAP) for a stock WRX versus a WRX with a Stage 2 PPP

Following are the actual dynamometer tests for the two tests. Additional discussion of these tests appears after each chart.

Stock 2004 WRX

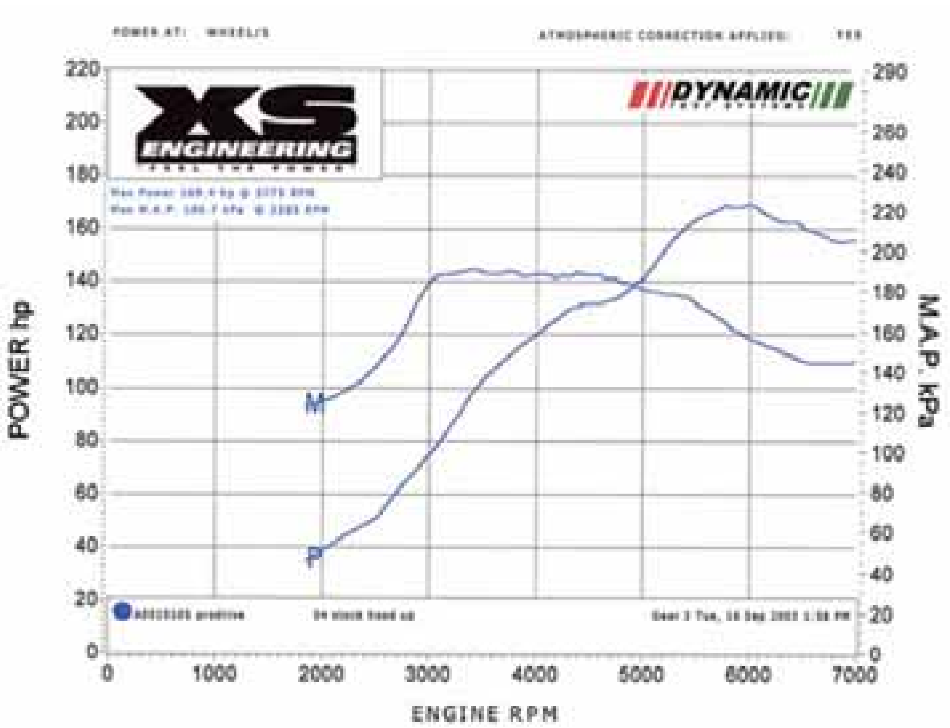


Figure 3: Graph of dynamometer results for the Stock 04 WRX. Horsepower (P) and Manifold Absolute Pressure (M), or "boost pressure") are plotted.

Horsepower:
The stock 2004 WRX reached a peak horsepower of 169.4 HP. Other points to note on this graph are as follows:

RPM	Horsepower (approx. as read from graph)
3000 RPM	75 HP
4000 RPM	120 HP
5000 RPM	142 HP
6000 RPM	168 HP

Figure 4: Horsepower versus RPM for stock 2004 WRX.

These additional Horsepower points will become important points to compare versus the Stage 2 PPP WRX horsepower output at varying RPM in the next section of this report.

| Prodrive Performance Pack Stage 2

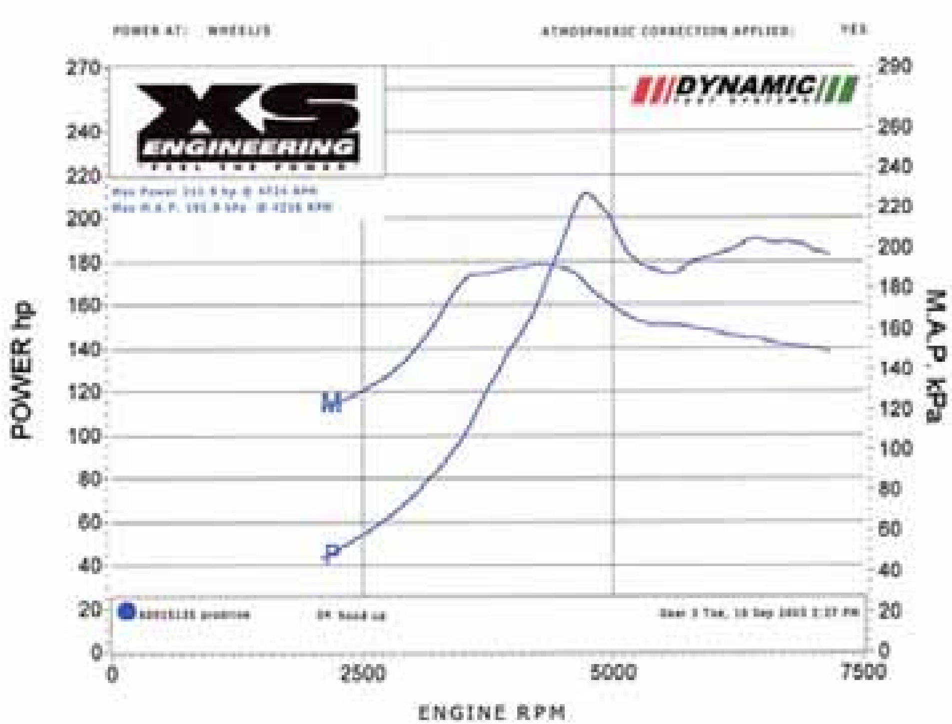


Figure 5: Dynamometer results for Stage 2 PPP. Horsepower (P) and Manifold Absolute Pressure (M), or "boost pressure", are plotted.

The above dyno test results for the Stage 2 Performance Pack shows not only a higher peak horsepower (25.1% higher or 42.5 additional HP) versus the stock 2004 WRX but also that the horsepower versus RPM curve is much steeper versus the stock WRX tests. What this means to the driver with the Stage 2 PPP installed is the power is available to them at much lower RPM – or in effect the power "comes quicker" to the street driver, increasing acceleration.

To illustrate the above point, note the following points on the Stage 2 PPP dyno graph:

RPM	Horsepower (Approx. as read from graph)
3000 RPM	75 HP
4000 RPM	145 HP
5000 RPM	195 HP
6000 RPM	183 HP

Figure 6: Horsepower versus RPM for Stage 2 PPP.

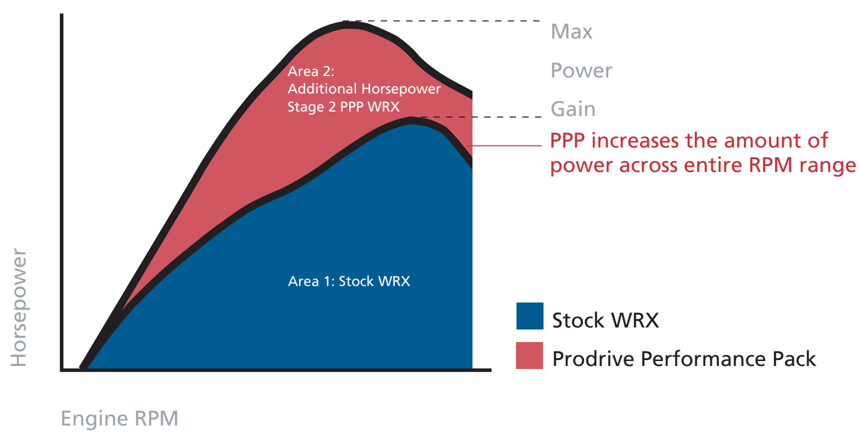
If we compare directly the horsepower generated at the chosen RPM points between the stock 2004 WRX and the Stage 2 PPP WRX we can see this shift in power more clearly:

RPM	Stock '04 WRX Horsepower (approx. as read from graph)	Stage 2 PPP WRX Horsepower (approx. as read from graph)	Percentage Increase
3000 RPM	75 HP	75 HP	0%
4000 RPM	120 HP	145 HP	21%
5000 RPM	142 HP	195 HP	37%
6000 RPM	168 HP	183 HP	9%

Figure 7: Increased Horsepower due to the Stage 2 PPP across the entire band of RPM.

Figure 7 shows that the installation of the Stage 2 PPP kept constant (at 3000 RPM only) or increased significantly (4000-6000 RPM) the amount of power available at every RPM. At 5000 RPM drivers will experience a 37% increase in available horsepower (~ 53 additional horsepower at 5000 RPM). Again the benefit to the driver is that more horsepower is available quicker thus aiding in acceleration across the entire drivable RPM range. This concept is referred to as increasing the "area under the curve". Increasing the "area under the curve" refers to generating additional power across the entire drivable RPM band and not just at one peak power point. This would increase the amount of area under a curve plotted on a graph representing horsepower versus RPM. The "area under the curve" concept is demonstrated on the following page in Figure 8.

Example Graph*



*Data is representative of trends only. Actual data not displayed here.

Figure 8: "Area under the curve" concept demonstrated. The PPP design increases "drivable power" at all RPM as well as "peak" power. The above graph is representative of actual data but is not an actual dynamometer plot.

Acceleration Testing:
Prodrive also performed acceleration tests with a stock WRX versus a PPP equipped WRX both in the US and the UK. The final results were that the installation of the PPP improved acceleration times as expected in the US and UK. However, the acceleration times achieved for both the stock and modified WRX in the US can not be compared to the stock versus modified WRX in the UK. This is primarily due to temperature testing differences. The effect of temperature on boost performance is discussed later in this report at length. For the following data the ambient test conditions were as follows:

Test	Ambient Air Temperature
USA tests – Stock and PPP	81° F (27.2° C)
UK tests – Stock and PPP	53° F (12° C)

Figure 9: Ambient Test Temperatures for USA and UK tests.

Since ambient temperature has a significant effect on boost temperature the acceleration times were much faster in the UK when the vehicle was tested during a significantly cooler day. Test results were as follows:

3rd Gear

MPH	Stock US	Stock UK	PPP2 US	PPP2 UK
50-70	4.3	3.5	4.0	2.9
60-80	5.2	3.8	4.9	3.2

Figure 10: Acceleration times in seconds in third gear

In third gear, the stock WRX went 50 to 70 MPH in 4.3 seconds and 60 to 80 MPH in 5.2 seconds. The Stage 2 PPP WRX went 50 to 70 MPH in 4.0 seconds, an improvement of 7.0%, and 60 to 80 MPH in 4.9 seconds, an improvement of 5.8%. The stock WRX in the UK went from 50 to 70 MPH in 3.5 seconds and from 60 to 80 MPH in 3.8 seconds. The PPP equipped WRX in the UK went 50 to 70 in 2.9 seconds, an improvement of 17.1%, and 60 to 80 MPH in 3.2 seconds, an improvement of 15.8%. The improvement between the US acceleration times and the UK acceleration times is attributed to the ambient temperature difference (i.e. – cooler during the UK tests) as well as greater boost available via the UK PPP. These two effects are discussed in further detail later in this report.

It is important to note that the stock US WRX and the stock UK WRX are almost identical vehicles yet their acceleration times are quite different. This again is due to the differences in ambient temperature during testing. The ambient temperature being supplied to the engine and intercooler has a large effect on performance of the stock WRX. The PPP improves the performance of the vehicle whether being tested in hot or cool weather.

The conclusion of this test is that the performance pack in the US improves acceleration times between ~ 6 to 7% for speeds of 50 to 70 MPH and 60 to 80 MPH and in the UK ~ 16-17% at the same speed ranges.

It is also important to note that the Prodrive UK PPP tested here is closer in performance to a Prodrive USA Stage 3 PPP (versus the Stage 2 PPP tested on the US car). Testing a Stage 3 PPP from Prodrive USA would result in quicker acceleration times and higher horsepower output.

4th Gear

MPH	Stock US	Stock UK	PPP2 US	PPP2 UK
50-70	6.3	5.3	5.8	4.1

Figure 11: Acceleration times in seconds in fourth gear

In fourth gear, the stock WRX went 50 to 70 MPH in 6.3 seconds. The Stage 2 PPP WRX went 50 to 70 MPH in 5.8 seconds, an improvement of 8.0%. The stock WRX in the UK went from 50 to 70 MPH in 5.3 seconds. The PPP equipped WRX in the UK went 50 to 70 in 4.1 seconds, an improvement of 22.6%. The conclusion of this test is that the performance pack improves acceleration times in the US ~ 8 % and ~22% in the UK at the stated speed range.

Dynamometer Overview

Dynamometer Operation
Different types of dynamometers exist. However, the two most common types are Inertia Dynamometers and Load Dynamometers.

- Inertia Dynamometers: Inertia dynamometers use a large drum or several drums combined. These drums are of a known mass. The vehicle is then balanced on top off these drums. A computer calculates how much power is required to accelerate the known mass of the drums between two given speeds.

- Load Dynamometers: Load dynamometers typically use electromagnets to control the speed of two or more rollers that the vehicle's wheels sit between. The electromagnets are connected to load sensors that tell a computer how much force is being applied to them. The computer is programmed to use these load measurements to calculate torque figures for the test.

Dynamometers need to be calibrated frequently in order to work properly and achieve the highest accuracy during testing. The basic calibration required allows the dynamometer to translate a given force input "x" at the roller into a known power output "y" in the computer. However, accurate calibration is only the first step in using a dynamometer accurately. Once the dynamometer is accurately calibrated, it must then be matched to a known standard (e.g. - ISO, SAE, DIN, etc) so the force measured can be displayed in internationally known and accepted units of measurement like Kilowatts or SAE hp. If this step is not performed dynamometer test data results have the potential to be inaccurate or useless.

In addition to proper calibration and standards matching, the dynamometer operator also has an influence on the power output results if proper procedures are not followed. The operator can apply correction measures for altitude and/or temperature. On some dynamometers the operator can control how the load is applied that the vehicle is working against, with a turbo car this can have a massive effect on boost produced. For example, if the operator applies a small load and the vehicle is in a low gear (like 3rd gear on a WRX) it will never make full boost, and therefore will give a low power reading. If the run (or pull) is made in 4th gear and against a higher load, you will get much better (more accurate) boost readings and a more recognizable power measurement. However, if the run is in 4th gear with a more representative boost (i.e. similar to on the road) but the dyno fans are not powerful enough to dissipate the excess heat generated from the high load, this excess heat can affect the vehicle performance enough to more than offset all of the potential gain a driver may have received from the performance pack boost. As discussed in the section of this report titled "Ambient Temperature Effects on Results", temperature has a large effect on the performance of a vehicle equipped with a performance pack both during dynamometer testing and during driving. An operator should be sure that proper cooling is supplied to the engine during dynamometer testing.

Dynamometer Testing

In addition to ensuring that the dynamometer is properly calibrated and the dynamometer operator is properly trained, the dynamometer operator should also consider the following:

1) Cooling Fans:

As discussed above, inlet air and intercooler cooling air temperature plays a large effect on achieving accurate test results for maximum power measurements. Large powerful fans are crucial to chassis dynamometer testing. Reduced power output can be experienced as a result of improperly calibrated, set-up, or operated dynamometers. Power losses equaling as much as 40 wheel horsepower have been measured that resulted solely due to the use of inadequate cooling systems on a dynamometer test. The fans that XS Engineering use are capable of producing air speeds of up to 80 MPH. It is also important to ensure that the dynamometer cooling fans are drawing air from a source that is providing cool ambient air to the engine. XS Engineering dynamometer cooling fans are positioned to draw air from near the entrance to their building, thus ensuring air temperature that is as close as possible to ambient temperature.

2) Hood Position:

Whether the vehicle achieves maximum power output results while tested with the hood up or down is very dependent on the efficiency of the dynamometer cooling fans. Hood up gives a more desirable inlet temperature but lacks ducted airflow to the intercooler. Therefore a strong cooling fan is highly recommended for hood up dynamometer testing. Hood down has the potential for better intercooler cooling efficiency but a significant increase in inlet temperature may occur. Under most circumstances a large cooling fan used with the vehicle hood up will generate maximum power results.

Ambient Temperature Effects on Results

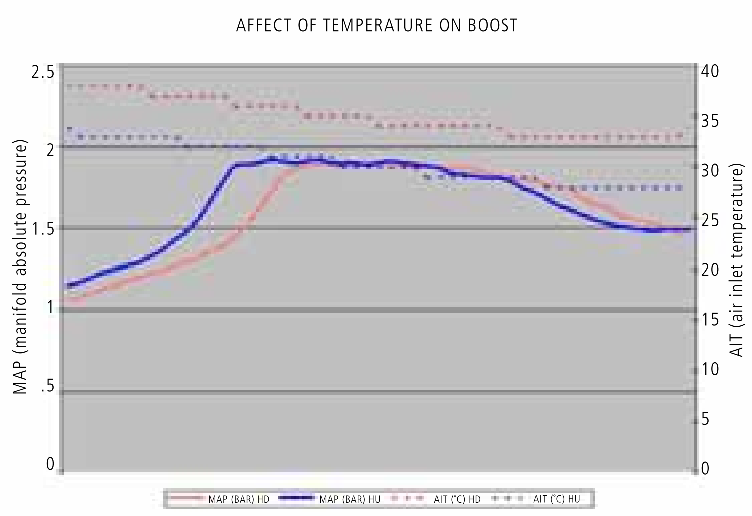


Figure 12: Temperature affect on Manifold Absolute Pressure, or "boost" pressure.

Figure 12 shows two separate tests. The first test, plotted in blue, was run at a cooler ambient temperature and the second test, plotted in red, was run at an elevated ambient temperature. The dashed lines represent the air inlet temperature (AIT) and the solid lines represent the Manifold Absolute Pressure or "boost pressure" during each test run. The curves are plotted versus a given RPM profile.

Note the increased manifold absolute pressure and the increased rate at which the MAP was built up when the ambient temperature was cooler (i.e. – the blue plot during the first, left-most part of the graph). The second (or red) plot did not build boost pressure as quickly. The ambient temperature difference between these two test runs was only about 4 to 5° C (7.2° to 9.0° F). However, the increased delivery of boost pressure is a direct result of having lowered air inlet temperature during the first (blue) test.

Testing on the road indicates it is possible to get intake temps of + 2° C (3.6° F) greater than ambient temperature. A series of dynamometer tests were performed by Prodrive in the UK during hotter than usual ambient temperatures. These tests were performed at Power Engineering, a respected UK tuner and dynamometer operation. The lowest intake temperatures came with the hood down but resting on the safety catch with an extra fan pointing at the intercooler intake. Being able to provide air to the inlet of the vehicle that is close to ambient in temperature is a requirement. If a dynamometer operator does not have the ability to measure the intake temperature and reduce it as required such that the air inlet temperature approaches ambient temperature, that testing facility should not be used and the results from those tests should not be considered accurate for comparison to other properly conducted dynamometer tests. Ideally, vehicles will be left running for 3 to 4 minutes on the dynamometer at slow speed to cycle air through intake systems prior to beginning a dynamometer test.

Ignition Map Compensation for Temperature:

Since temperature has a significant effect on boost produced, Subaru has designed into the WRX ECU a very advanced and clever mapping algorithm to deal with this fact. Two main maps for ignition exist and other maps that "influence" these two main maps exist as well. These maps control the ignition of fuel in the engine and continuously adjust themselves based on driving conditions and generally how the car is being "treated". The main ignition map and the ignition correction map are both 3D. These maps correct themselves based on driving conditions, in effect allowing the car to"learn" what setting it needs based on the environment it is driving in.

The values in the correction map are added to values in the main map depending on certain factors, but mainly how "happy" the car is and how much learning has taken place, this can literally be positive or negative learning and these factors are taken into account each engine revolution. There is a coarse adjustment called an Advance Multiplier that can read between 0 and 16 (0 meaning the car is "unhappy" and 16 meaning the car is "ecstatic"). This multiplier also controls some other areas, such as the switch-over from the low to high detonation fuel map, but its main purpose is to apportion ignition correction mainly depending on temperature and detonation. Generally, more multiplier means more ignition which means more power. This advanced temperature correction mapping allows the WRX to be driven in vastly different ambient temperatures while optimizing vehicle performance.

The temperature correction map in the ECU has control over the duty cycle of the wastgate solenoid. This is used to stop over-boost if the ambient air temperature falls too far and as a safety device to protect the engine if the intake temperature air gets too hot. This primary safety device kicks in above 40° C and lowers the boost pressure. This allows use of higher boost when conditions are optimal (i.e. below 40° C) and it also has a positive effect on the advance multiplier, which will drop if the car is detonating or running with very hot intake and getting close to detonating. When the multiplier drops it takes a reasonably long time for it to recover. So this safety feature has the ability to reduce a power figure produced on a dyno due to poor operator practice, poor cooling, or high ambient temperature causing the PPP ECU to reduce boost in order to protect the engine.

This is important to understand for two reasons: 1) WRX performance drivers should be aware that this temperature correction mapping is continuously occurring in their ECU for performance and safety reasons and 2) the hotter the vehicle driving conditions get the more "unhappy" the vehicle gets (i.e. – Advance Multiplier moves toward zero) and the less ignition and less power the vehicle will produce. Subaru has implemented this advanced temperature correction mapping algorithm for safety reasons for the driver and the vehicle engine. Prodrive supports and retains this safety feature when remapping the ECU. If a driver were to dyno test their vehicle in a hot environment the vehicle will correct its maps and the ECU would lower boost dramatically.

Overview of the Prodrive Performance Pack

Prodrive's primary concerns in developing the PPP were to increase throttle response and improve drivability. This required providing additional horsepower. However producing the largest and highest overall horsepower figure was not as great of a priority as providing improved acceleration coupled with higher peak power and improved drivability. This is what Prodrive USA refers to as 360° Performance™. 360° Performance™ refers to considering all the performance requirements of the vehicle and driver and optimizing the vehicle for maximum overall performance, not simply improving a certain area for a single test or a single parameter.

Prodrive Performance Packs are designed to provide increased power, be safe, and improve drivability. The PPP were designed realizing that drivers must drive their vehicle on the street so both power and drivability are important. While testing a vehicle on a dynamometer to measure results is important, Prodrive understands that performance drivers don't want just a peak power number on a dynamometer test, but rather want increased drivable power for the street in order to enjoy their performance vehicles. The majority of Prodrive's performance increases with our PPP Stage 1and Stage 2 are in the lower- to mid-range RPM. This increase in power in the lower to mid range RPMs versus a stock vehicle is referred to as the "Area Under The Curve". This "Area Under the Curve" concept is displayed in Figure 8 from earlier in this report.

One of the main reasons Prodrive concentrated on the lower- to mid-range RPMs with our PPP Stage 1 and Stage 2 is because Stage 1 and 2 designs required keeping the factory installed catalytic converters in place. The factory catalytic converters limit the amount of boost that can be safely added to the engine with out experiencing excessively high and dangerous temperatures. The Stage 3 PPP deals with this issue by eliminating all three of the factory catalytic converters and replacing them with Prodrive's single high flow catalytic converter. By doing this, Prodrive is able to increase boost pressure in the higher RPM ranges on Stage 3 vehicles, thus increasing power even further for Stage 3 vehicles. Stage 3 kits are able to increase boost pressure and further optimize ignition and fueling due to the addition of Prodrive's higher flow catalytic converter without experiencing overheating temperature problems.

Differences between the US and UK Prodrive Performance Packs

Prodrive has designed its Performance Packs to optimize performance of vehicles in its given surroundings. Due to different environments as well as regulatory requirements, the US and UK performance packs should not be compared because they are substantially different systems designed to operate in different environments. The main differences include:

1. Mechanical components are fundamentally similar, however ECU mapping is different in the US and UK.

2. Weather differences affect testing and driving.

3. Dyno testing methodologies are different

4. Fuels are different

ECU Mapping Differences:

Although the UK and US Stage 2 Performance Packs each are made up of a muffler, a 3rd cat replacement pipe, an intercooler pipe and a re-flashed ECU, there are significant differences in the tuning of the ECU that result from different driving conditions in each country. The UK PPP is able to use more boost than the US PPP, not because of engine differences but because of country differences. The temperature extremes experienced in the UK are typically much less than the temperature extremes in the US. Because temperature has such a significant effect on achievable boost, the UK ECU tuning can be much more aggressive since temperature extremes are typically milder. Since the US experiences much wider swings in temperature the ECU tuning must be less aggressive in order to perform safely and reliably throughout the United States. Even with a slightly less aggressive tuning of the ECU, the US Stage 2 PPP still achieved over 211 HP on the dynamometer test described earlier.

The UK PPP can be more aggressive compared to the US PPP. If the UK does experience extreme high temperatures, the ECU safety features can cope with these temperature extremes on a short term basis. However in the US, the Prodrive PPP cannot do this since long-term temperature extremes (i.e. – Death Valley versus the Rocky Mountains) need to be accommodated within the basic tune.

Weather Differences

Over England the mean annual temperature at low altitudes varies from about 8.5 °C (47.3 °F) to 11 °C (51.8 °F), with the highest values occurring around or near to the coasts of Cornwall. The mean annual temperature decreases by approximately 0.5 °C (0.9∞ F) for each 100 m increase in height so that, for example, Great Dun Fell in Cumbria (at 857 m) has an annual mean temperature of about 4 °C (39.2 °F). For additional UK weather information you can click on:

http://www.met-office.gov.uk/climate/uk/location/england/index.html#temperature

However, in the USA the situation is very different. The United States experiences sub zero to 115+ °F temperatures and humidity from 0 to 100%. Clearly there is a huge disparity between the two countries weather systems and this has to be taken into account with the PPP stage designs in order to prevent failures due to excessive heat. The lower ambient temperatures experienced in the UK allow for a more aggressive ECU tuning and thus UK test results are not comparable with US test results on the whole.

Dyno Testing Methodology Differences:

As mentioned earlier in this report, numerous parameters can effect the outcome of a given dyno test including proper calibration, proper set-up, operator use of the dyno and test temperatures. For this reason, dynamometer tests vary not only from country to country but even within a given country. Dynamometer tests originating in the UK versus the US should not be directly compared unless one can be confident that all of the test conditions were identical. This is usually not the case when looking at test data from two different facilities. As an example, any web research will show disparity between seemingly similar cars that have been chassis dyno tested in the UK and USA.

Fuel Differences:

The octane levels and, in particular, the additives used in fuels in the US and UK are substantially different. These changes between fuels will affect vehicle performance and dyno testing. In general, dynamometer testing from the United States and England should not be directly compared since numerous influences which are not held constant between the two countries will affect the test results.

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