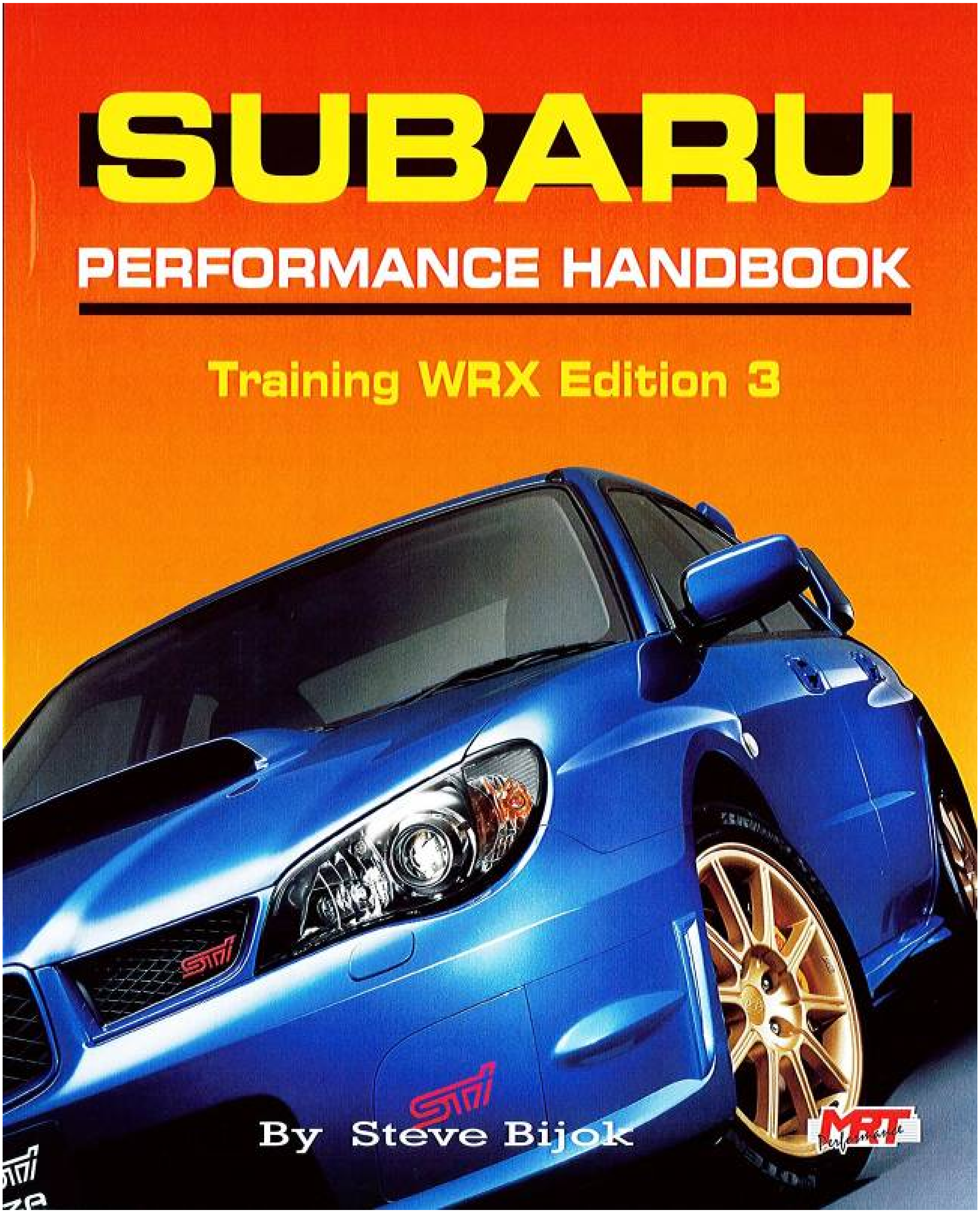
SUBARU
PERFORMANCE HANDBOOK
Training WRX Edition 3
By Steve Bijok

SUBARU

PERFORMANCE

HANDBOOK

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Written by Brett Middleton
and
Steve Bijok

Published by Brett Middleton

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Training WRX Edition 3

By Brett Middleton and Steve Bijok

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Electronic Version

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Chapter 1

Preface by Nick Warne

1 Preface by Nick Warne

The Subaru WRX Performance Handbook is in spirit the third edition of *Training WRX*. Observant readers will note it no longer has my name on the cover. The book was previously jointly owned and created by myself and Brett Middleton. Brett, Steve and the team at MRT Performance provided the facts and figures that I then took and wove into the first and second editions of Training WRX.

Back in 1999 and 2000 my share of the modest profits generated from the book was largely spent on putting my money where my mouth was, in the process transforming my humble MY99 into a serious (for the time) performance car that was never dull to drive. First on the list of upgrades for me was a suitable personalised number plate, more in keeping with what I was setting out to achieve, and in a blinding flash of inspiration I settled on URF00D. Other more orthodox modifications included:

- Group A Rampod induction kit
- Stainless steel 3" exhaust system
- VF23 Turbocharger (those were the days!)
- EBC and boost gauge
- Whiteline suspension kit including adjustable Koni struts
- Full Recaro interior
- Alpine amp, double DIN head unit, speakers and subwoofers
- Monster tune engine with forged internals (pre the advent of 2.2 or 2.5ltr conversions)
- Bar and plate FMIC
- Four point Momo racing harness
- Odds and sods like a brake support bracket, upgraded driving lights etc.

It was a great car and a good example of what could be done five years ago, and pre-EcuTek. I was very proud of it. Sadly, in 2000 I sold it to a friend, intending to move to Silicon Valley (a move that fizzled at the last minute – remember the "Tech Wreck"?). He still owns URF00D today.

Since the second edition was completed, I've sold my share of *Training WRX* to Brett. A large part of Brett's livelihood is tied up in the Subaru WRX, so he can devote more time to this thing than I. My career, for better or worse, is in corporate management. These days the only time I have for the book is my personal time. Since 2000, this has been largely taken up with motorbikes – an old passion of mine since my teens.

For those that care, I've owned a Ducati 996, an Aprilia Tuono, a Yamaha R1 and currently run a KTM Duke II. On four wheels I've had a Nissan 200SX S15 for the last three years, with a Holden Monaro CV8 6MT due in September 2005.

It was seven years ago – sometime in 1998 – that I first thought it might be a good idea to put together a book about tuning the Subaru Impreza WRX. Even then it was the affordable performance car to have, in Europe and Australasia. Of course, if you lived in North America back then you could but only dream of turbocharged Subaru's (an asthmatic turbo 2.2ltr non intercooled Legacy notwithstanding) as the WRX and STi versions were not exported to the 'Land of the Free' (or indeed Canada, the 'Land of the Freely Taxed' [ha-ha]).

To use a corny phrase, time does not stand still, so where did it go? The last seven years have seen many changes in WRX land. The first edition of *Training WRX* came out in 1999 in its little, spiral bound A5 notebook style. In 2001 it all started to happen: the new shape hit the market and Subaru started exporting mainstream Turbo models to North America (which had an impact on everyone). A second edition of *Training WRX* was needed to cover the new vehicle and all the changes it encompassed. That came out in 2002 in a hip new quarto-sized, conventionally bound product. It even had an ISBN making me feel like a real author! Rather more critically to the WRX phenomenon, EcuTek was also starting to make its impact on the market forging somewhat of an impressive reputation with its unique and revolutionary software products. In 2003, Subaru responded to the somewhat negative reception to the new shape car by revising the front end, which made the current WRX look less like an anthropomorphic illustration from a children's story.

Locally here in Australia, fuel quality has inexorably been on the increase, with 95 octane premium unleaded becoming the default standard, with a newer more potent 98 octane brew the choice for the owners of performance cars. This has had the effect of more or less bring us into line with other vehicle producing countries – with the exception of the US, where curiously enough octane ratings have fallen. After years of trying to make reliable power on low octane fuel you have my sympathy.

Enough of current developments. This new edition will cover them far more thoroughly than I can. I thought I'd try and share some ad hoc observations on what it means to be a petrol head in Australia and more specifically a WRX owner:

Bling versus Brawn
No, and yes. Think about it, you know this statement makes sense.
Sports
A bunch of friends start talking about football / cricket / baseball / choose-your-poison. When you mention something you witnessed in WRC or MotoGP, they look at you as if you'd just farted obnoxiously and carry on. I hate that.

Track Days
I used to think there was a practical limit to upgrading any road car for hard core performance work on the race track. While it was theoretically possible to upgrade a WRX to outperform a standard Porsche 911 at the track, in practice it would cost as much as just buying the damn Porsche in the first place. I suspect that is no longer true. There are many more performance components out there and the price has dropped on many of them (surely one of the benefits of enlarging the potential market by adding the huge buying power of North America). In essence the practical performance envelope within reach to the average enthusiast is growing all the time.

On the other hand, tyres remain a significant cost issue for any track racing junkie. While I can get three full track days and a couple thousand kilometres out of my motorbike tyres (OK, maybe not on the Yamaha R1), a full day at Sydney's Eastern Creek circuit will knock the stuffing out of your WRX's treads, and when replacement time comes around, you can kiss goodbye to A$1,000 or more for a set new donuts.

EcuTek
What EcuTek has done for WRX tuning is not dissimilar to what the Internet has done for global communications. For all those wishing to enhance their Subaru, be it a mild set of modifications or by going the whole nine yards should be factoring in EcuTek's product range.

I expect this third edition will be the end of my involvement in *Training WRX*. That's sad, but it is time for me to move on. I am very proud that my original idea is still going strong, seven years later.

I wish Brett, Steve and the team all the best for the future.

Nick Warne
Sydney
July 2005

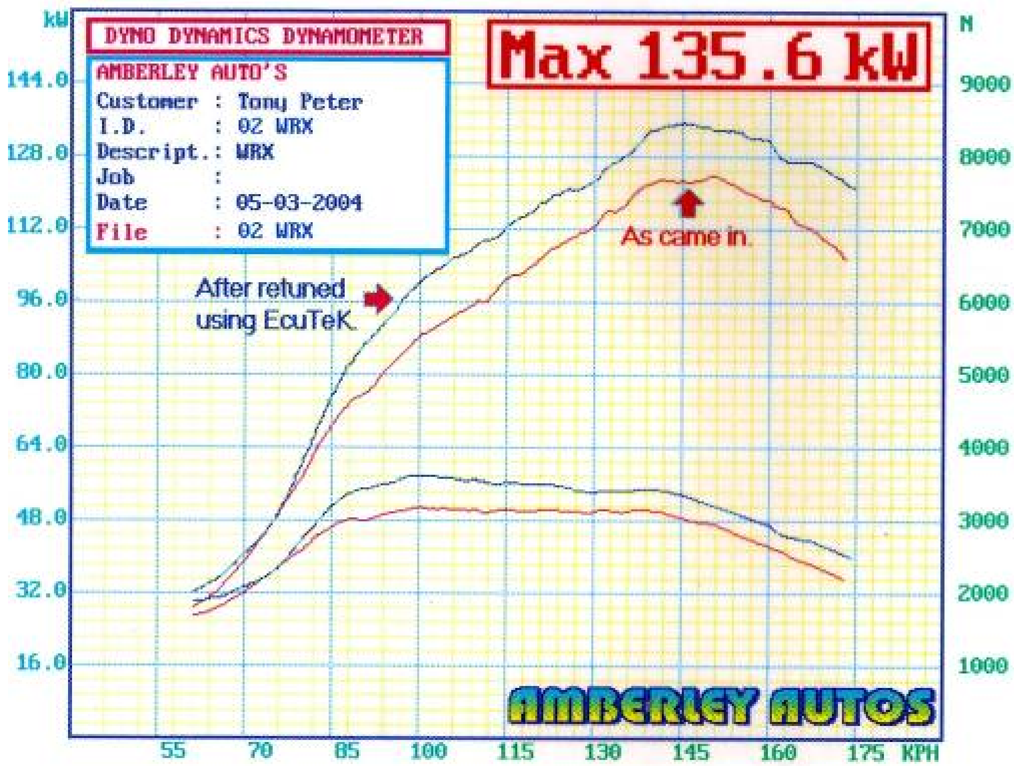
Chapter 2

"The hardest working STi in the world"

Foreword by Tony Peter

Foreword by Tony Peter

Ask anybody that knows me, and they will all say without hesitation that I am an enthusiast in everything I do. I love my software development business, and my WRX. Always a fancier of fast cars, and a one-time seller of several marques, including the big Ford V8s of the 1970s, I bought my first WRX in 2002, a Version VII. This car, which serves as my daily transport even to this day, some how managed to stay completely stock standard until March 2004 when I fitted an XA Power up kit supplied by MRT and fitted by the Horsepower Factory, one of MRT's re-sellers in Melbourne. What really caught my eye with the XA kit was the way it was marketed as complete performance package, with clearly documented information on what it will and won't do. They even guaranteed exactly how much extra power would be made after fitting the kit. MRT was true to their word, with power increasing at the wheels from a stock reading of 120kW up to 135kW.



Pic MRT XA Power up Kit Dyno Graph

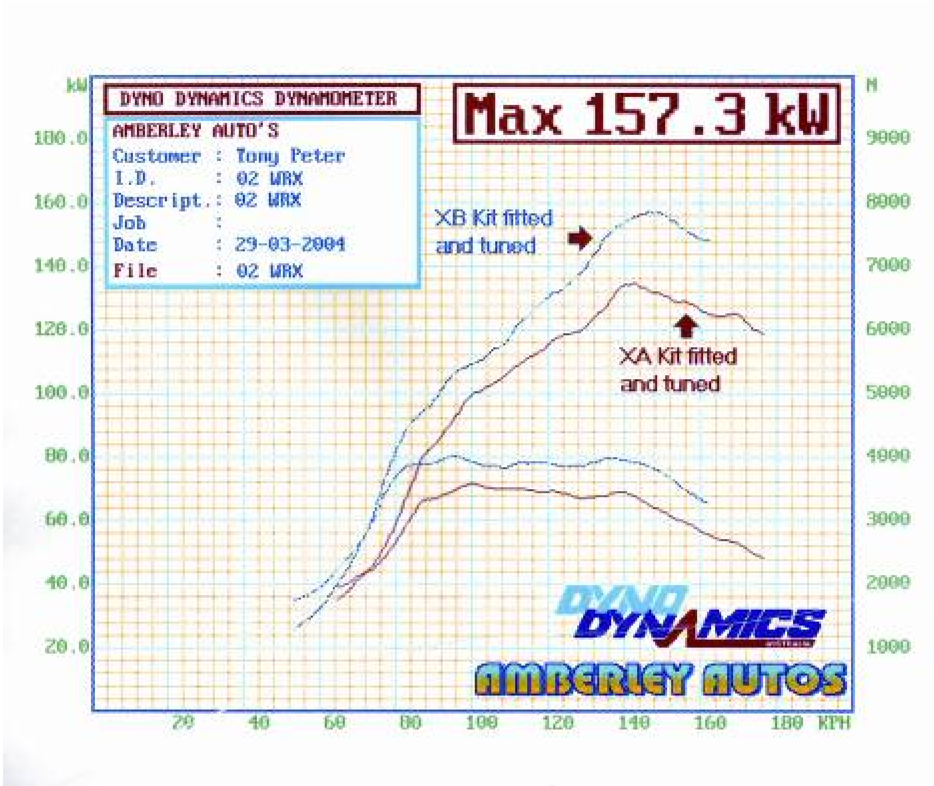
The Bug had Bitten

But let's re-wind a little. Like many WRX owners, to begin with I really didn't see any immediate reason for tinkering with arguably what is the best small four-door sports car in Australia. In my case, the decision to modify the trusty WRX came immediately after hitting the racetrack for the first time.

It all started with joining the Victorian branch of the WRX owners club, going downhill quickly thereafter. In somewhat of a blur, the next thing I knew, I was taking part in a WRX club driver training day at Winton raceway, just outside of Melbourne. All it took was for a few flying laps around the track for the racing bug to well and truly bite, and bite hard. I was hooked, and I spent the rest of the week with a grin plastered across my face. For anybody that was prepared to listen, I wasted no time mixing metaphors by informing them that it was the "Best fun I've had sitting down!"

Pic Heavy Weather

In addition to my instant addiction to the racetrack, a second craving developed, and that was the need for more speed! My WRX was quickly taken back to Melbourne for another round of modest but well chosen upgrades. Engine power was further augmented by upgrading to an XB power up kit. Once again the Horsepower Factory and MRT delivered, with power at the wheels climbing by a further 21kW. Total power at the wheels now sat at very healthy 157kW and like a kid with a new toy couldn't wait to hit the racetrack with all this newfound "grunt".



Pic MRT XB Power up kit dyno Graph

The WRX has great handling even ex factory but they do have a tendency to understeer. On the track this is somewhat of a liability and was the next item to receive some attention. Following the recommendations by a fellow WRX club member, the WRX was off to Trutrack suspension in Melbourne. New H&R coils changed the spring rates and lowered ride height by 35mm for a more track-friendly attitude. A host of Whiteline suspension components were also added to the shopping list, such as an anti-lift kit, front strut brace, camber kit and stronger front and rear sway bars. More aggressive negative camber was applied to the front and rear.

My WRX was now ready for its next track day, hopefully I was too! The combination of these modifications made the WRX a much better track car, with a whole lot more power that was far more tractable in its delivery. Grip on the racetrack improved significantly, not just in out right terms, but also in terms of predictability. In somewhat of an example of how much I was enjoying blasting around the track in my WRX, over the next three months I managed to squeeze in a further 10 track days.

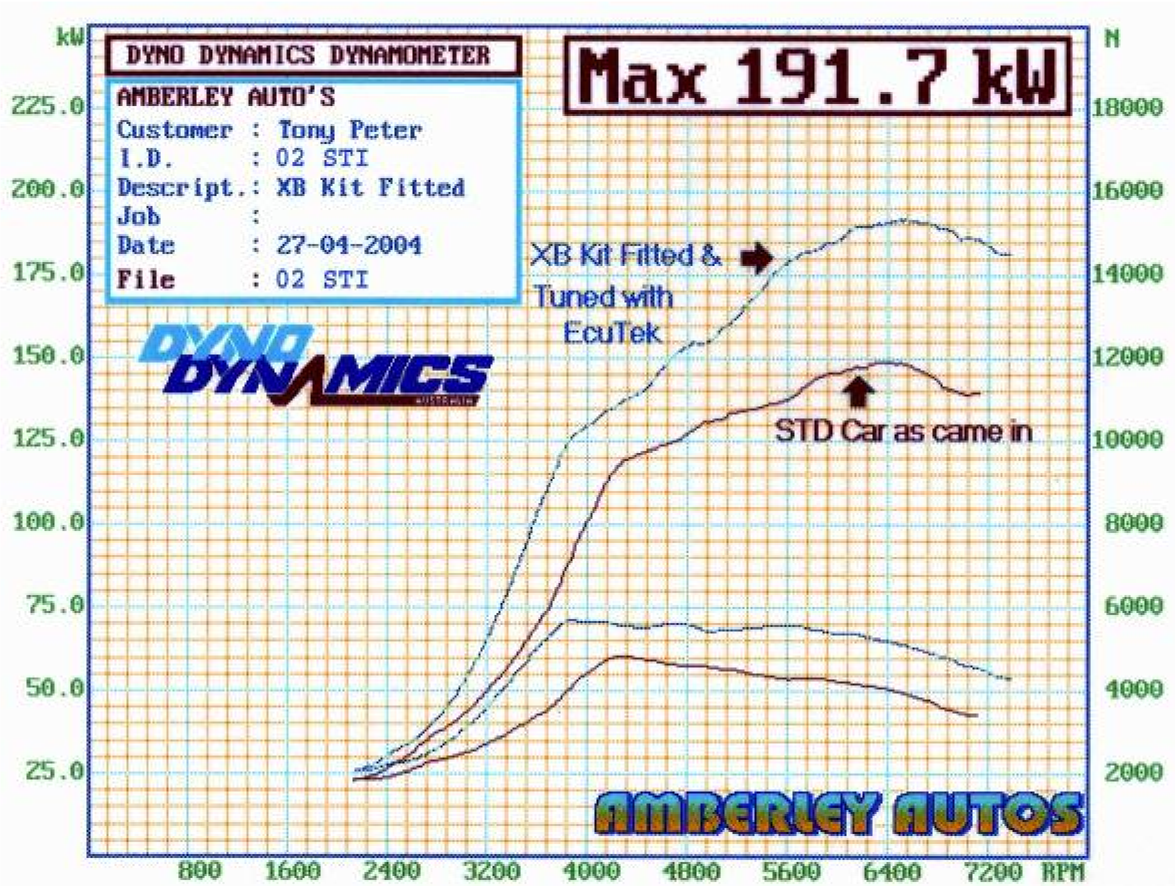
Problem was, the WRX had become, in effect, two cars. During most weekdays, it was daily transport for me, while I toiled away running a business developing and installing sophisticated home automation software and equipment. For much of the remaining time, which included the occasional mid-week event, the car was a regular fixture on racetracks such as Phillip Island, Calder Park, Sandown and Winton.

Arrival of the STI

Pic The STi

By May 2004, enough was enough, it became apparent to me that my near standard WRX required a lot more power in order to be a bit more competitive with some of the faster members of the club, and that meant a dedicated track car was the only real solution. Thus I acquired a black 2002 STi that had only been used on Sundays (or so the last owner said). And it was with this that the real fun began. As with most hard driving Rex drivers, factory kilowatts, handling and braking was never going to be enough, and certainly not when your motivation is to go up against far more expensive and powerful exotica in a humble Subaru.

What followed next was a full no-nonsense program of both engine and suspension modifications. Using the healthy power gains achieved on the WRX, my new baby was off to the Horse Power Factory for MRT's STi XB power up kit and EcuTeK reflash. I decided to customise the exhaust by fitting a Cannon N1 muffler with an angle mounted 4" tip. This moved peak power a little higher up in the RPM range as it has a lot less restriction. Of course it was a lot louder than the normal muffler MRT supplies with their power-up kits, but as this was a track car only, this was of little concern to me. Results speak for themselves, with power at the wheels climbing from a stock reading of 155kW to 191kW, an increase of almost 40kW! Given that a standard STI has 195 kW at the flywheel on the track the gains were substantial.



Pic STi XB Power Up Kit Dyno Graph

Suspension was treated to the same package of mods as the WRX, sticking with H&R springs and Whiteline suspension components. It didn't take much time to catch onto the benefit of sticky rubber, culminating in digging deeper still into my pockets with the purchase of some R-spec Dunlop Direzza 02G tyres.

STI Engine Safety Enhancements

Track days create levels of stress (for both the driver and car) that are never reached in a road environment. As I steadily increased the number of track days, in the back of my mind I started to become concerned with a few areas on the STi. My focus shifted from chasing more engine power, to making sure that it would continue to do so reliably for the foreseeable future! A surge tank complete with a Bosch 044 motor sport pump was fitted to guard against any possibility of fuel surge during high speed cornering. An MRT alloy fuel rail kit with dual regulators was also installed to prevent fuel starvation at high RPM and load.

The next major modification for me was done for increased reliability, but as a bonus a few more neddies were liberated from under the bonnet. In order to cool the intake charge more effectively, a Hyperflow FMIC was fitted in place of the OE top mount and made another substantial improvement to power and torque. The Version VII STi comes standard with a manually triggered manual water spray system, which in practice is totally useless on the track, so an MRT Electronic water spray control kit was fitted. This saves me from trying to grope around under the dash attempting to trigger the waterspray while pushing 10/10ths around a corner.

Next to go was the OE plastic turbo intake pipe, replaced with a larger diameter silicone intake hose, for noticeably improved throttle response, and a little more power. By now, all the additional engine power over stock, along with the FMIC (which tends to block some of the air that normally flows through the radiator) started to push engine temperatures a little bit too high for my liking. The OE radiator was given the flick and an aftermarket all-alloy unit installed in its place. This radiator weighs in at just over four kilograms (dry weight) and has 50 per cent more capacity over stock. It is also 32mm thick (compared to 22mm stock). Much to my satisfaction, maximum engine operating temperature was reduced by approximately 10 degrees C.

Pic Hyperflow Intercooler and Other Parts

More Suspension Mods

An incident at Phillip Island late in 2004 at turn 10 going onto the main straight proved that the car now had a lot more power than what the suspension was capable of using efficiently. Much to my displeasure, I found out that at 170 km/h the STi decided it would not fully obey my commands to turn, resulting in a trip out over the grass and into the kitty litter for a quick bit of off-roading. Thankfully, there was no permanent damage, save for scooping out some of the gravel the car had picked up in the front spoiler. Not needing any more encouragement I wasted no time sending the STi off to Trutrack for some more intensive suspension tuning.

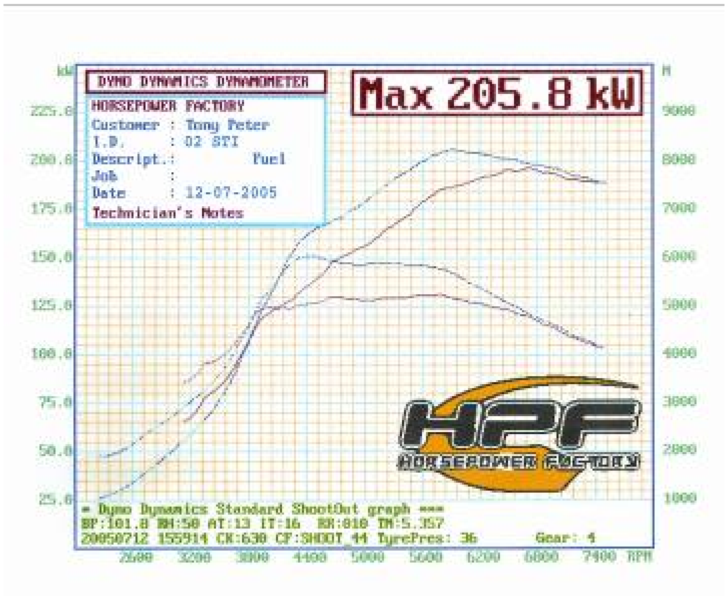
After discussions between Whiteline and Trutrack it was decided that the Whiteline Group 4 coil-overs and Eibach springs would go a long way towards fixing the problem. Fully adjustable rear control arms gave greater was also fitted for more accurate rear wheel alignment settings courtesy of their turnbuckle adjusters and polyurethane suspension bushes. Finally, a set of camber adjusters allowed more aggressive adjustment of the camber, with the front set at 3.5 degrees negative and the rear set to 2.5 degrees negative, resulting in one of the flattest cornering STi's on the racetrack.

Weight Reduction, Aerodynamics & Safety

In the quest for weight reduction, about the only factory interior component left in the STi is the dashboard! Seating is now courtesy a tight hugging Cobra Evolution race seat. It is safer and a heck of a lot lighter than the STi factory seat. Very early on in the piece, I had fitted a basic half-roll cage, but with the speeds that car was now capable of, I was no longer confident that in the event of the unthinkable this would be strong enough. The half cage was taken out and replaced with an FIA certified chrome-moly six point roll cage, custom designed by Malvern Motorsport, and was worth the extra expense for a whole lot more piece of mind.

Aerodynamics was next. At the rear the standard STi wing was replaced with an adjustable carbon fibre GTC-200 APR performance wing. At the front end of the car Australian fibreglass products supplied a custom made front splitter. Always one to be a bit cynical of these sorts of things, I was surprised by the amount of down force this achieved, translating into measurable improvements in track times.

Now that the suspension was finally working as it should, and what with the gains in down force from the newly installed aero parts, I felt that it was time to chase a few more ponies. The OE VF 35 turbo was swapped out for a roller bearing VF34 for more power and improved throttle response. I also made the decision to stop using pump fuel, switching to Martini Racing 102 octane fuel. It was then back to the Horsepower Factor to have the ECU remapped to suit both the new turbocharger and fuel. By now, the STi was making upwards of 240kW at the wheels!



Pic Race Fuel Dyno Power Graph

While not trying to sound like I am big-noting myself, it is no understatement when I say that racing is a real passion of mine. So much so, I decided to apply for, and was successful in gaining a CAMS C3 provisional circuit racing licence, something that allows me to step up into more serious forms of track racing if I should chose to. During the period Feb to Dec. 2004, I competed in an exhausting programme of 35 track day competitions, with the majority of those spent at my favourite racetrack Phillip Island. It truly is a fantastic track; most of it is done at high speed, providing a real test of a driver's ability to control their race car at high speeds. My next favourite track is Sandown with lots of apex hopping and kerb jumping. I never miss an opportunity to do a bit of two wheeling in my STi.

A new race series

Literally as I write this, I am busy working with a group of other like-minded enthusiasts to begin a new race series we are to call the WRX / EVO Lancer Challenge. The need for this type of new race category arose because there really is not a suitable series for these popular cult cars. It has been a long held opinion of mine that the current racing classes place far too many restrictions on turbocharged four-wheel drive cars. Therefore, I got together with a group of others and are in the process of approaching the Victorian Motor racing Championship event organisers, with the view to establishing a proper WRX versus EVO Lancer challenge format. I look forward to this being a good old fashioned stoush of epic proportions!

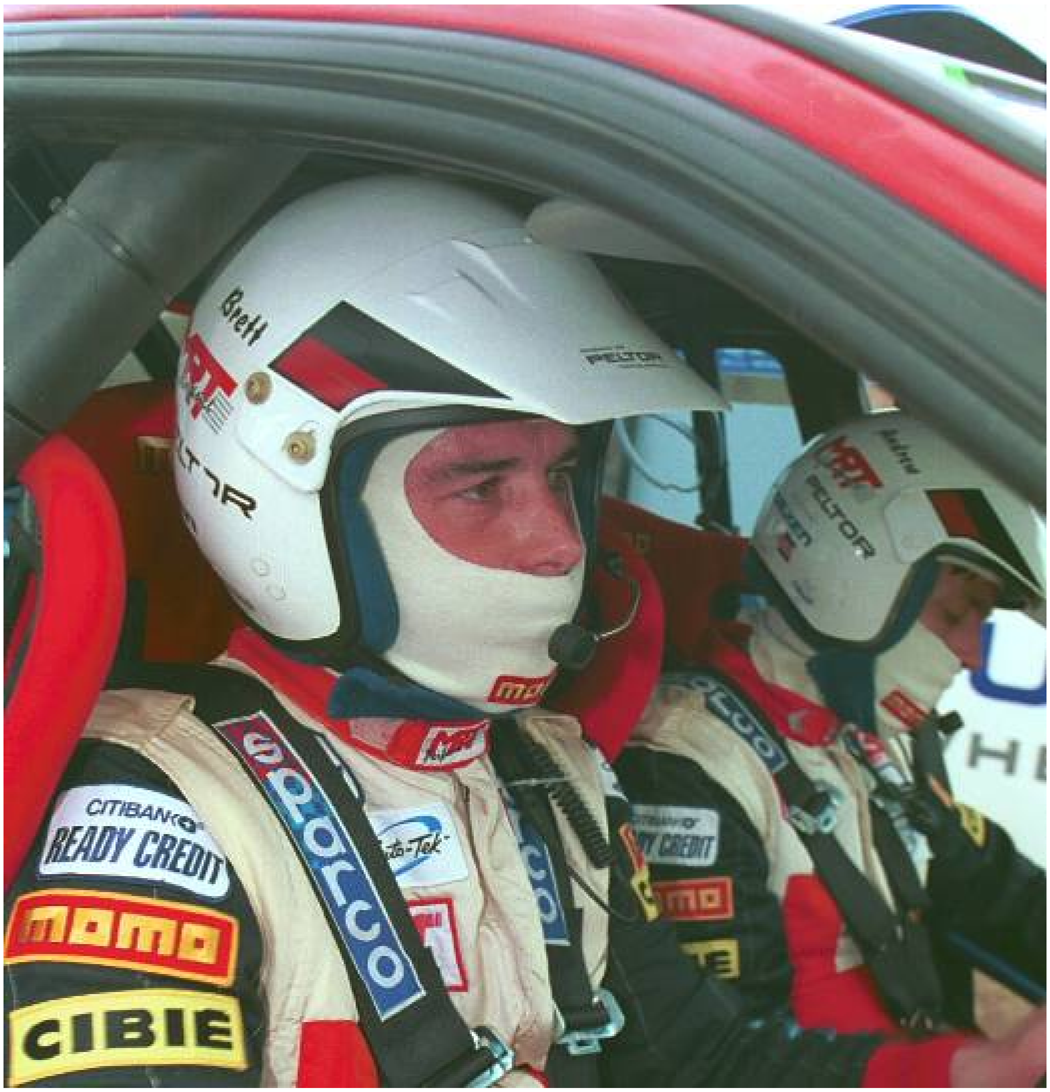
Mine's bigger and better 'an yours!

And just a friendly heads-up for the other several thousand owners of modified WRXs – most of who believe they are in possession of the quickest WRX or STi in Australia. I am proud to *up the ante* just a tad and modestly claim ownership of "the quickest STi - ***in the world!***" However, look out for my tongue firmly planted in cheek when I talks about cars and their respective performances. Instead of boastful claims, I like to let my STi do the talking for me, and then only on the track. Irrespective of speed, simply going by the amount of track days my STi has done, it surely must hold the title of the "worlds *hardest* working STi"

Have fun with your Subaru, and stay safe out on the roads!

Tony Peters.
June 2005

Chapter 3



Brett and Andrew at work

Introduction By Brett Middleton

Introduction By Brett Middleton

Pic Brett Middleton, (1st turbo car) Datsun P510./ Left at Amaroo Park Rallysprint, Right at home washing off the mud!

Pic My brother Scott (left) , me and my dad Ross

Since the first Training WRX was released way back in 1999, followed by edition two late in 2001, the Subaru tuning performance industry has seen both sides of the boom and bust cycle of business. I have seen many companies move into the Subaru Performance attempting to tap into a market that continues to grow, as more and more Subaru owners realise how much fun their cars are to modify and enhance. Only to disappear just as quickly as they didn't fully come to grips with how hard it really is as a workshop to provide customers today with the kind of results they are seeking. I genuinely hope the new and improved 3rd edition of Training WRX, assists you and makes your involvement with Subaru as enjoyable as mine has been over the last 11 years of Subaru performance enhancement.

As the owner of a high profile Australian rally team and an active tuning business, my philosophy is simple: if its not fun then don't do it! It is true that this can sometimes be stretched to the limit, especially when the development of new performance products does not go as planned, or the expensive international rally in which we were competing in, ends in failure cancelling out the huge amount of time, effort and money spent in preparation due to a ten cent part!

Nevertheless, I believe myself privileged to be given many enviable opportunities. These have included an involvement with Prodrive at the Australian World Rally Championship event, back when Colin McRae drove for them; attending a secret WRC car test session; being closely involved with three car manufacturers and their products, as well as those stressful trips overseas to compete in rallies and develop our tuning business.

Most satisfying has been the people I have been fortunate enough to meet and be involved with, and they include our loyal base of re-sellers world wide, our enthusiastic and motivated staff, and most importantly, you Subaru owners!

Pic Brett with Colin McRae at Rally Oz (Perth) Brett with his best mate and Co driver Andrew Benefield

My involvement in motorsport began early in life. My father was heavily into rally navigation in the 1960s and I can remember attending many events at an early age. Obviously something must have rubbed off. One day, when I was seventeen, on a trip back from a car club meeting, I remember telling my Dad I wanted to make a career in motorsport. He told me he thought I wasn't committed enough. Well, that was like showing a red rag to a bull! These days I remind him of that and he tells me I am *too* committed.

Pic Bretts Children, Oscar Hayley and Zac with his mum and dad (2005)

My Motorsport history started off with a Datsun 1600 (P510) 1968 model (the most popular rally car ever in Australia). The typical set up was to fit Weber carburettors and a 2 litre engine. We bucked that trend and installed a turbo instead. This was hard work as no one had got it right in the past. We continued with this car with reasonable success, fitting many new body shells and other parts. In much the same way as grandpa's axe, change the head or change the handle its still always grandpa's axe.
Eventually, with Australia pushing for a domestic round of the World Rally Championship (WRC), it was time to change to an FIA approved car, as the essentially home-built back-yard specials that had dominated the forests of Australia in the past were not eligible to compete in international sanctioned events.

After calls to many local car importers we accepted an offer of a 1300cc 1989 Daihatsu Charade. What a change, less than 25% of the power of the Turbocharged Datsun, and front wheel drive to boot. I had to re-learn how to drive fast without the easy power of the Turbo. In fact, this was very good for my driving skills and something I encourage any new driver to master before making the move to "big grunt".

Pic Somewhere in NSW

The second Charade built by MRT

Campaigning the little Daihatsu led to the formation of a National Daihatsu Dealer team, and in 1994 to a contract with the Japanese Daihatsu factory to build (and homologate) the new G200 1600cc "De Tomaso" styled 2 door Charade. This in turn required a load more space, and forcing us out of our old workshop and into our home of almost 11 years in Ryde, a suburb of Sydney. The MRT Performance workshop was born. I never would have thought back then, that involvement with such a small car company as Daihatsu could spawn the rapid rise of MRT Performance to become a strong force in the Subaru performance aftermarket industry.

Initial testing of the car at Wisemans Ferry forest and World Debut of the new G200 by Brett
World Debut of the new G200 by Brett
Australian Rally Championship, Adelaide, South Australia.

We continued with the Charades for some time, winning two National Formula 2 rally championships, until Daihatsu had a change of marketing strategy and withdrew from the sport. This was disappointing at the time, but in retrospect it allowed me to focus on the rapidly growing MRT Performance workshop without the distraction of fielding (and financing) a full time national rally championship programme.

Pic Yes it does snow in Australia. ARC Rally in Tasmania

Given that my Motorsport habit is somewhat of a permanent monkey on my back, we could only stay away from the Australian Rally Championship for a year. In 1996 Honda gave us a chance I was looking for, handing us the responsibility of building the very first Civic VTiR Formula 2 rally car in the world, with the (then) new chassis. In our debut season the following year (1997), we won the Australian Formula 2 Rally Championship again, making history as the only team to win it three times!

Winning F2 Again In 1997 VTiR Honda Civic

In 1998 and 1999 we developed and pushed the car to the limit, but were outpaced and out-budgeted by rule changes that allowed the mega-dollar WRC F2 "kit" cars to compete in our national Championship. Reluctantly we pensioned off the Honda. At this time the Daihatsu component of MRT's business had slowed, but we were now busy with the relatively new Subaru WRX, and had little competition in the market outside Japan. A year later the WRX tuning market took off explosively and immediately everybody was a Subaru specialist! By then, MRT Performance had extensive experience and at least two years head start on the rest of the pack.

With this success came the obvious conclusion; it was time to rally a WRX! But which one? My business and family were growing rapidly. With the season fast approaching, we had insufficient time to build a car from scratch. With some kind help (from Subaru Australia and Nick Senior) and some fortunate luck, we received an offer to acquire Subaru Australia's Group N 1998 championship-winning car, as campaigned by Cody Crocker and Greg Foletta. It was a very special car, having been prepared originally for Toshi Arai by the STi competitions department in Japan. It has proved to be a rocket and we were very lucky to get it.

Pic The WRX STi Version 4 Group A at Rally Canberra

The team converted the car from Group N to Group A spec because I wanted to drive a car that had heap more grunt. A Group N car is fast but requires a lot of maintenance, especially if you wish to mix it with the big boys at the pointy end of the sport. Equally important, Group A allows us to use more modified parts, many of which we make ourselves, with the dual advantage of allowing us to test in competition what we sell, and give us another avenue to promote our parts, whereas group N rules dictate that mostly factory parts can only be used. The expense and complexity involved in the Group N to A conversion made it a slow and sometimes frustrating process. At the same time I also had to learn how to drive the car. To be frank, I found it harder than expected switching from front drive VTEC Honda power and into the Four Wheel Drive Turbo Subaru.

Changes to the Australian Rally Championship rules for 2000 started MRT Performance on the development of our special gearbox internals, a.k.a the "Dogbox". Brakes were another area to benefit from renewed development. Our already close relationship with Sydney brake manufacturer DBA grew further as we tested, re-tested and tested again newly manufactured replacement parts on our rally WRX. Now we are all lucky to benefit from the fruits of that relationship and without hesitation I can unequivocally state that the Disc rotors supplied by DBA are by far the best in the world.

Recent motorsport highlights for me would have to include packing up our newly acquired WRX in 2000 for the long journey to Jamaica, so as to compete in an international Rally. Not just a long way from home, but also a whole world away in culture. The support received and the enthusiasm on the part of the locals made a difficult trip worthwhile.

Pic Jamaican Rally

2001 also saw us take part in the New Zealand Round of the World Rally Championship. (WRC) My experiences as a competitor of the NZ WRC had me hooked on New Zealand's famous gravel rally stages and building on the experience gained on our first outing, we returned for the 2002 Rally New Zealand.

Rally New Zealand

The teams plans are to continue run the car, as "We Rally and You Win" is not just a fancy advertising gimmick, but one of MRT's most strongly held philosophies. Motorsport improves the breed, to quote an old saying. Evidence of this is reflected by the large number of products contained within our Performance Parts Catalogue, which are a direct flow-on from our Motorsport programme.

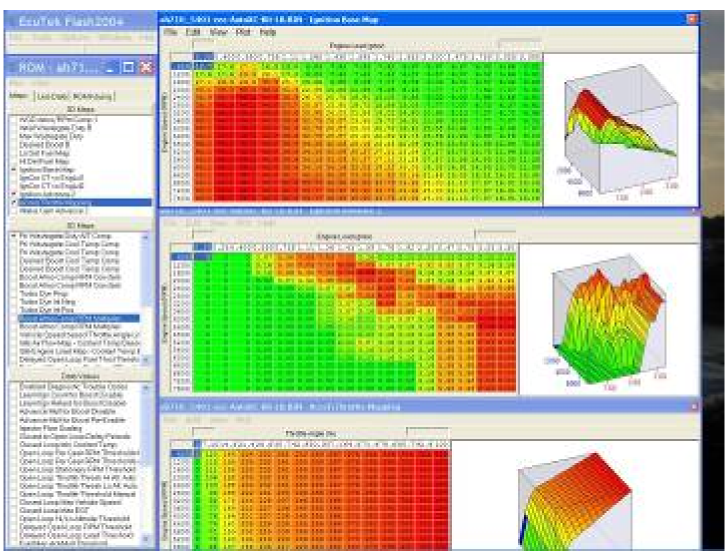
However we are no longer committed to the whole Australian Rally Championship. Family commitments for both myself and my co-driver take up an ever increasing amount of time, which means we are re-assessing our focus. Deciding instead to pick and choose those events that are our personal favourites. Tarmac rallies are especially interesting for me, and maybe could be a sign that I am either growing older, or I just don't like getting mud in my tool-box and driving suit anymore.

In 2004 we competed in the inaugural Mt Buller Sprint. A closed special stage rally on a public tarmac road. The climb to the summit of Buller takes in 16 Kilometres of tight and twisty tarmac. A popular Ski Resort in the alpine area of Victoria in Australia during the southern Hemisphere winter months, the event is held in January, so its mostly all sunny and fine and is simply stunning to drive.

Mt Buller Rallysprint

Yippee, the mineshaft stage, rally Canberra

On the business side of MRT Performance, growth has been rapid over the last few years. The development of EcuTeK (For which MRT is the Australasian distributor) is a major revolution in the Subaru aftermarket tuning industry. I cannot stress how much the ability to re-program the mapping information contained with the Factory Subaru computer has changed forever, the face of performance tuning for the Subaru. (More information on the modern miracle of re-tuning your factory computer will be covered in the *Engine Management* chapter)



Pic EcuTeK Screen Shot

Introduction of the new (for 2002) GD series WRX or Bugeye Impreza was widely criticised for its large gain in weight, and the negative impact this had on its performance. This handed us a dual challenge, firstly being to develop a new range of parts to claw back the losses, but also to cater for the introduction of this car in North America.

Our success in the North American market, and the popularity of our parts has seen us quite "stretched" with the task of servicing a new market, with new distributors and agents, without neglecting our existing Australian and worldwide agents. However, this is a good "problem" to have! More recently has seen things get a bit tougher on the business front with the slide in the value of the US dollar against most major currencies. This has effectively forced up the landed costs of all (imported) and Australian supplied parts. Never one to shy from a challenge, we just have to work harder in order to compete, and also at the same time grow into other countries. Something I am pleased to say we are doing well and are always building new partnerships and friends.

Pic MRT Overseas Distributor

I count myself lucky to travel as often as I do, visiting MRT resellers and clients all over the world. It is an invaluable opportunity to learn from the ideas of others, get a feel of the local market and its needs and expectations, something often overlooked by some of our competitors! Our strength is to supply what people want. If the part works, we offer it. If parts are out there that don't work, we always try where we can to help consumers learn the "easy way" instead of doing it the "hard way" The future for our industry looks strong, Subaru moves from strength to strength, with the introduction of each new model, from the very latest 05/06 Impreza's, to the constantly improving Forrester, GT liberty/Legacy and even the H6 model Outback.

Liberty GT

2005 has also seen us make the big move out of our old Workshop in Belmore Street Ryde to our new and much larger facility in Averill Street Rhodes. (Just 2 minutes away) The process of moving was exhausting, frustrating and extremely costly, but now I can say that MRT Performance finally has the premises I have always wanted. The extra space means we have one of Australia's best dyno performance test cell, dedicated engine and transmission building clean rooms, a fabrication area and finally a workshop that allows us to quickly and efficiently service large numbers of cars. Featuring a spacious showroom, office, storage space and ample car parking has improving conditions for not just myself, but staff and clients!

New Premises

Dyno Test Cell

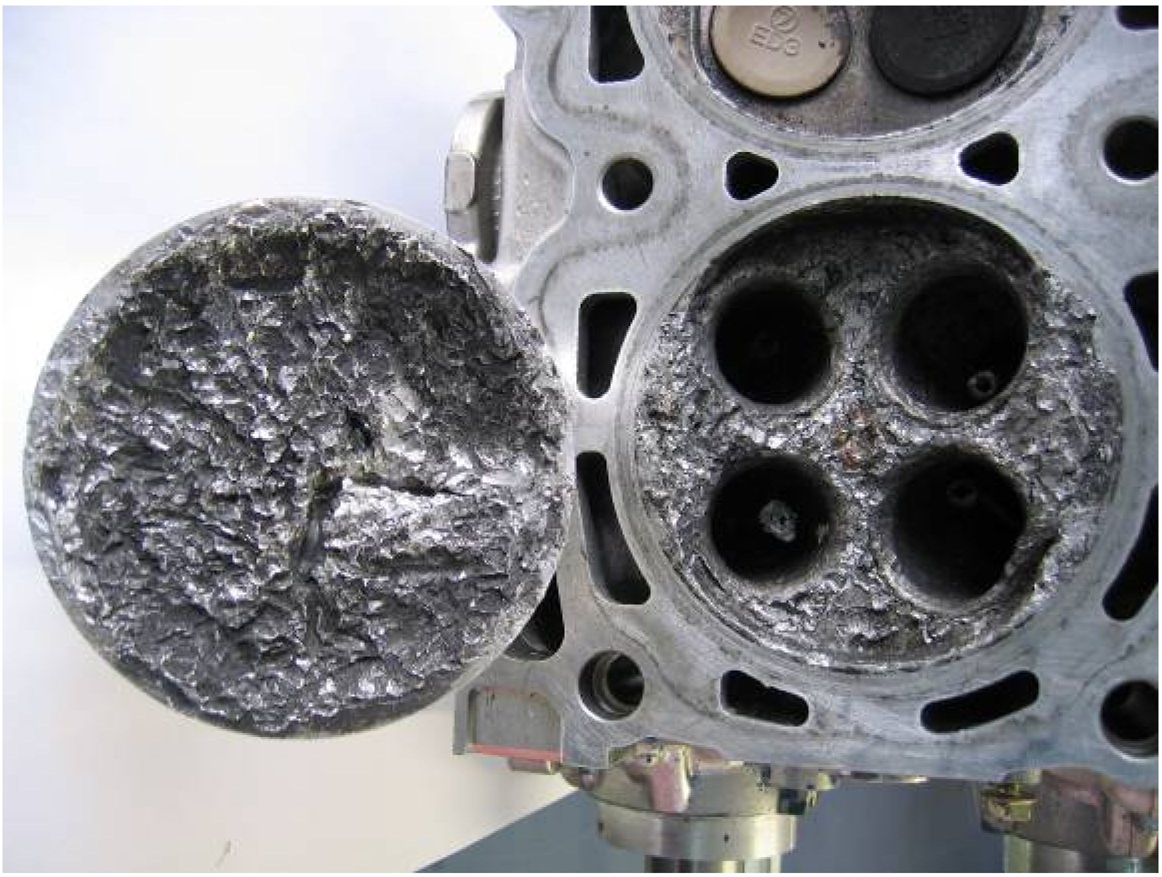
I hope the effort that we put into running MRT Performance and the workshop, can now be shared with you by means of this book. We also hope that it will help assist you in your decisions on how and where to improve you're Subaru, while saving you from some of the agonising mistakes we've seen and made ourselves! Take it from someone who knows, this book is an excellent source of performance related information for the Subaru owner!

Pic Long time clients and good friends the team at S&J Automotive, (Sean and Joanne Day)

My Brother Scott, (left) who was instrumental in many events in preparation of our early cars

Brett Middleton
Owner, MRT performance
Driver, *MRT*

Chapter 4



Oops!

Disclaimer

Work In Progress

We're not going to beat around the bush. Modifying your car is not without risk. Such risks include:

- Loss of your factory warranty;
- Making your vehicle illegal by the laws of your land;
- Serious Injury or Death, not only for you, but also your passengers and anyone else unlucky enough to be in your path.

Your car, the safety of yourself and others, and the legality of your actions are YOUR OWN RESPONSIBILITY. This book is not to be used as a substitute for qualified professional advice on any matter. ALL MATERIAL IS FOR INFORMATION ONLY.

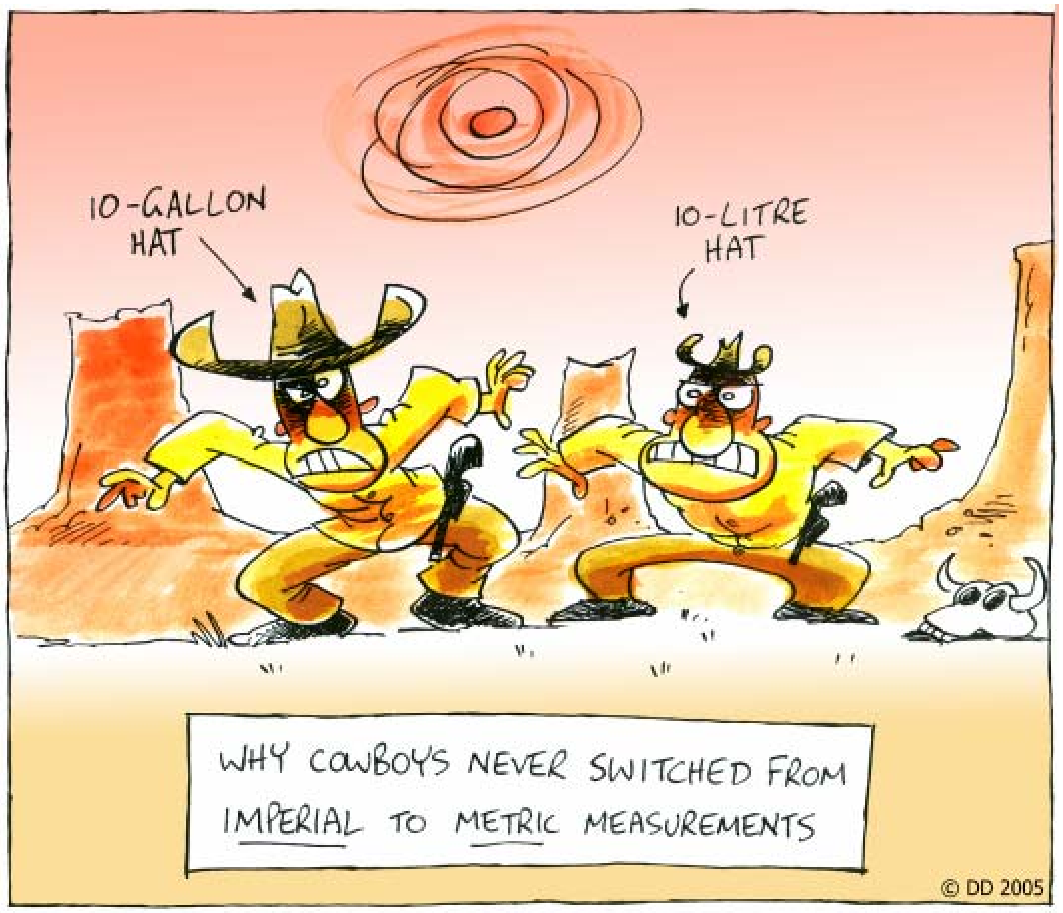
Making even small modifications will DRAMATICALLY change the way your car behaves, and could be completely different to drive than before. Understand this explicitly before exploring your cars new found potential.

Pic Brett makes a (very public!) error in the 2004 rally of Canberra!

This book is intended for sale internationally. MRT Performance and all its associates do not accept any responsibility for the legality of the modifications in any country.

Be a grown-up. Read this book, find a responsible and reputable performance workshop and take control of your own life.

Chapter 5



Measurements and Price Conversions

Measurements and Price Conversions

5.1 Fuel Rating

Fuel's resistance to detonation, or *knock* is vitally important to forced-induction engines, and is therefore a subject with which every turbo Subaru owner should be familiar with. There are two key methods of grading fuel quality: RON (Research Octane Number) and MON (Motor Octane Number). Japan, Australia and Europe all use the RON rating for petrol/gasoline.

Fuelling the Beast

North America chooses to use the average of the RON and MON rating or (R+M) ÷ 2 as it is known by pointy headed petroleum chemists. What this ends up with is a rating known as AKI or *Anti Knock Index,* and is the number used to identify all gasoline sold in North America. This book uses RON numbers exclusively, but it is easy enough to convert. As a general rule of thumb, AKI + 5 equals its RON rating. Thus, 98 RON is the same as 94 AKI

5.2 Measures

After the British conquered half the world and made an empire, one technique they used to ensure that the colonies would be forever dependent on 'Perfidious Albion', as it was affectionately known, by inculcating a system of measurements that baffled anyone not educated in a British public school. This stratagem has left the world a legacy of Babel-like proportions. Even in a country such as Australia that has been metricated for the best part of 3 decades, an ugly combination of metric/imperial units still exists. Thankfully, as time marches on, the disease of imperial measurement is slowly being eradicated, but as written and published even in 2005, this book contains a mish-mash of imperial and metric measures, guaranteed to annoy someone, somewhere.

Of course, you Americans are the worst offenders, stubbornly clinging to imperial measurements hundreds of years after you kicked out the imperialists themselves!

There is no simple answer to this, as one person's kilowatt is another's horsepower. The relationship between the imperial and metric measurements used in this book is left as an exercise for the reader. Just remember that:

1 Kilowatt (kW) = 1.340 Horsepower (Electric)
1 Horsepower (Electric) = 0.746 Kilowatts.

Just to further confuse the issue, there is the small issue of rating engine power in PS. This unit of measurement is used almost exclusively by the Japanese and Europeans, who have their own interpretation of how much work Nellie the nag can perform.

1 PS = 0.735 Kilowatts
1 Kilowatt = 1.359 PS

(Metricated Euro/Japanese Horsepower? Electric Horsepower? Where will it all stop??!!)

1bar = 14.7psi (Pounds per square Inch)

1 Kilogram (kg) = 2.20264lbs

If anyone is using *pints* and *quarts*, well you have our sympathy. Hopefully your owner's manual will have appropriate conversion rates.

5.3 Prices

It is expected that most readers of this book will have some form of a budgetary restriction to work with. With the exception of millionaire Subaru enthusiasts, the majority of Subaru owners would gladly own a Porsche, Ferrari or some other exotic performance car, if money suddenly became no option. It is the WRX's killer bang-for-your-buck ratio is its stand out star quality. Accordingly, we felt it was important to provide some sort of price guide to the various modifications discussed in this book. To this end all prices mentioned throughout the book are in Australian dollars (A$)

The problem with this is that prices vary from country to country, from time to time and from technology to technology. In other words, this year's mega-dollar super-duper EBC could be next year's bargain basement sell-out special. A huge swing in the international value of the Yen will change the prices of Japanese components, but will have a lesser or zero effect on others. Or a new tax in whatever passes for a free country where you live, could hike certain components into the stratosphere. Well, you get the picture.

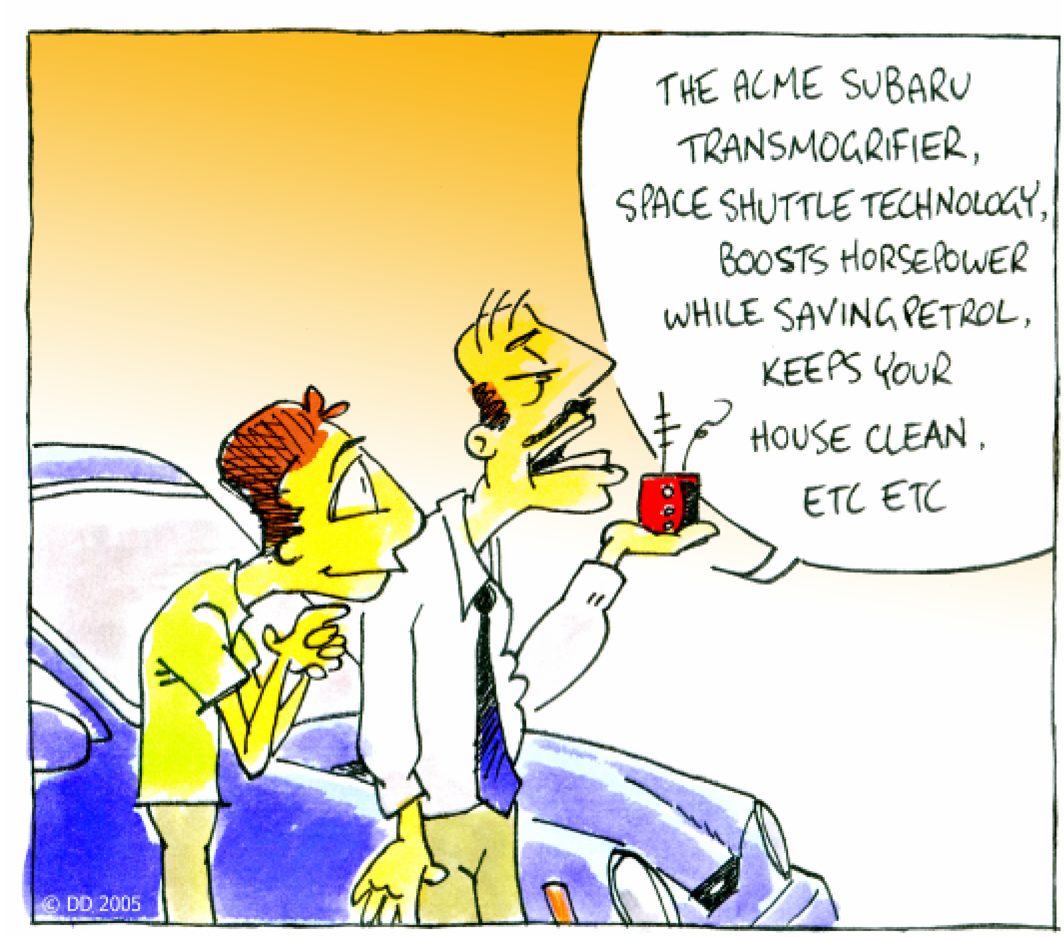
Therefore, when you read this book, please keep these points in mind:

- All prices are relative to each other. If one product costs twice as much as another in this book, this pricing ratio may exist elsewhere;
- Prices have been researched from a number of sources, but are not a guarantee of exact pricing from any particular vendor, particularly MRT, although we have tried to provide an honest guide to costs at time of publication;
- Prices do not include labour for fitting, unless specified;
- Prices do not include tax, such as GST, VAT, sales tax etc if applicable;
- Prices do not include freight, duties or handling charges for mail order sales;
- Use currency converters. MRT uses and recommends www.xe.com. Perhaps purchasing that new VF34 Turbo is more cost effective in Shekels rather than Yen.

Despite the above, we hope you will find the pricing provided throughout this book of some use. After all, there is not much point seriously considering spending A$1250 on a set of high flow 800cc fuel injectors, if you don't have the A$18,000 Minimum to spend building the ultimate engine, ECU and turbo package (A.K.A the monster tune) to fully take advantage of them.

Pic So Much to Spend On

Chapter 6



Why This Book Was Written

Why This Book Was Written

The Subaru WRX Performance Handbook intends to be a reference resource for anyone who owns, or intends to own a Subaru Impreza WRX (a.k.a the Impreza Turbo GT in some markets) manufactured between 1994 and 2005 (Version I-VIII), including the re-bodied Version VII and VIII. The Version VII WRX was the first turbo Impreza to be offered for sale in North America in late 2001, going from strength to strength since then. This book provides a wealth of information about the design, strengths and weaknesses of the car, together with a comprehensive guide to improving the car according to one's own requirements. The book is primarily aimed at the enthusiast planning to modify his or her own car in some way for use on the street and the occasional blast around the racetrack. Although some information maybe pertinent towards vehicle preparation for serious motorsport competition and maintenance, that is not the intended purpose of the book.

Pic Forged Pistons and Conrods

Subaru and its WRX have spearheaded the modern phenomenon that is the Japanese aftermarket performance industry. Although many people will disagree, for us here in Australia, in the period we like to call BS (before Subaru) the performance industry would be unrecognisable by today's standards.

WRX and Other Subaru Models

While not intending to be an exhaustive guide to improving the entire Subaru range, there is information within this book that is easily transferable and applicable not just to the Impreza WRX. The Forester GT shares the same floor-pan as the Impreza, as does much of its running gear. Likewise with the Liberty / Legacy GT. Although it is based on a totally different body shell with major differences in suspension and construction, engines and transmissions are fairly similar, with few exceptions. Needless to say much of the process and principles involved in correctly modifying a Liberty / Legacy GT and Forester are the same as the WRX.

During those deep dark days, performance workshops were loosely grouped into three different categories, the first being the carburettor, cam, head and dizzy specialists that catered for the V8 heavy metal brigade. Second were the mad professors, serving the market for exotic and not so exotic European machines, although most self-respecting mechanic would lift the bonnet on one of these cars, only to shudder, slam it shut and walk off muttering incoherently.

Lastly were those bravely attempting to make living modifying Japanese cars. Life was not easy, most of the common replacement computers were adjusted using nothing more than a screw driver and the principles behind turbocharging and fuel systems were poorly understood at best. Even Garrett had yet to release its GT series of Ball bearing turbos and accessories. Very little off-the-shelf products were available, and what little was, often set new standards on the cheap and nasty scale. Ignorance is bliss as they say.

This all changed in an almighty hurry with the advent of the Impreza WRX here in Australia. Almost overnight, tuning parts no longer were the domain of the official performance departments such as STi for Subaru, Nismo for Nissan and Honda's Mugen. In addition to existing Japanese brands like HKS, Apexi, Cusco, Blitz to name a few. Top quality parts quickly began to be produced by Australian and European suppliers. Much the same parallels can be drawn with the accelerated growth of the US performance industry and the speed at which local suppliers has embraced the new wave that is the sport compact scene in that country. Its just like Playstation's *Gran Turismo* but for real!

Replacement Fuel Injectors

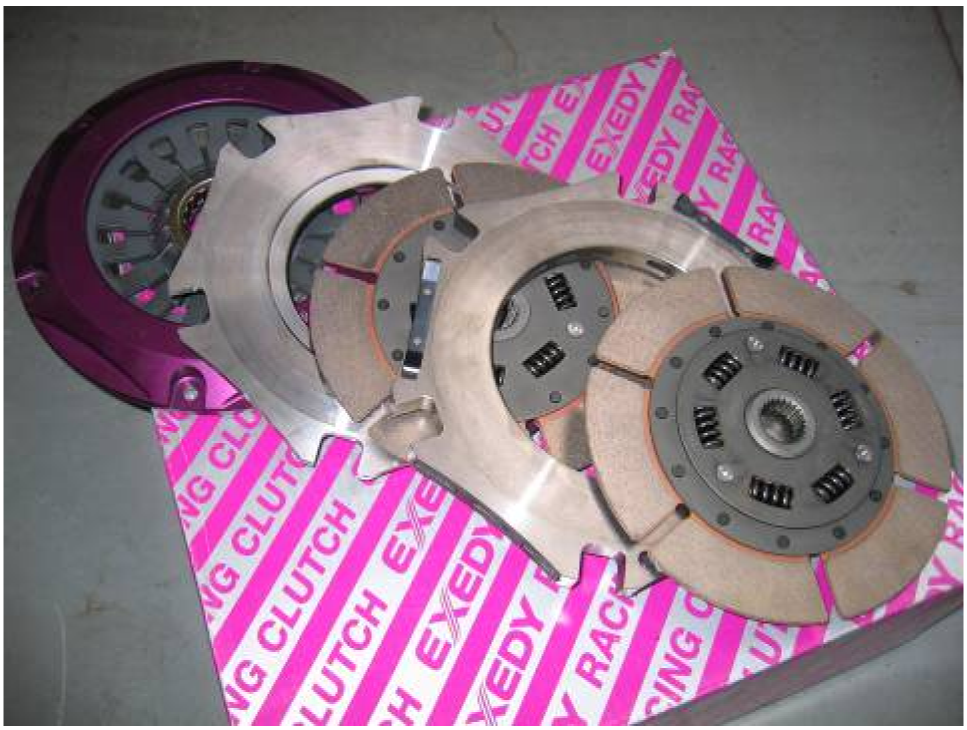
Improving the Breed

Subaru copped a lot of flak with the introduction of the VII. Many felt that the car had got fat and stupid compared to the outgoing GC8 series, much of the blame for this lay with a large increase in weight due to an extensive redesign of the body shell to improve structural strength, compared with the outgoing model. Crash safety was improved, but barring the unthinkable, what most drivers instantly noticed was how much better these cars felt from a NVH point of view. After driving as many creaky old GC8 WRXs as we have, you will agree that the newer cars are far better.

The VIII WRX here in Australia has seen the addition of variable valve timing, deletion of a power robbing catalytic converter in the turbocharger up-pipe, boosting performance. Extra power, better refinement and a re-style that is definitely easier on the eye, finally makes the current Impreza significantly better in all areas when compared to the old GC8.

Extracting more power from a turbocharged engine is generally relatively easy to extract. Regardless of the progress made by the aftermarket industry and general levels of skill and knowledge, the process is still complex. Likewise it is still possible to blow up your engine, get your collar felt by Mr Plod, (arrested) for a noisy exhaust or some sort of other infringement, and more importantly, create a car that is dangerous to yourself and other road users.

So what do you need in order to avoid these pitfalls you ask? First and foremost a healthy serve of common sense is essential. Performance tuning has been a controversial subject almost since the dawn of the infernal combustion engine. Nothing has changed in that respect. If you have ever tried to find out even the simplest of information regarding the enhancement of your WRX (or any car for that matter) suddenly everybody is an expert and has an opinion. These opinions are usually contradictory to your planned course of action, often purely self-serving to the interests of those dispensing advice, and therefore at best useless hearsay, or potentially damaging at worst. Let's consider some of the common sources of information.



Dual Plate Clutch Kit

1. Lots of people are trying to part you with your hard earned dollars. This tends to make them sing the praises of their own products, while harshly criticising those of the competition. Often those who blatantly rubbish their competitors do so to mask misgivings about their own products and services.
2. Some people feel the need to offer advice on a wide range of subjects – not just performance tuning, even when they are not qualified or experienced to do so. Let's not speculate at what motivates such people to do so in the first place.

3. Another version of the same tune is the guy that has just spent up big time on an expensive gizmo for his/her car, and now needs to justify the expenditure in his/her own mind, and of course yours!
4. Other people just plain enjoy talking, either down at the pub, at back yard BBQ's, or in front of the TV during commercial breaks, and hey, why let the truth get in the way of a good story!
5. Showroom standard class road/rally racing, or really any sort of racing formula that works to a strict set of rules. Modifications that are done on such cars often have no relevance off the racetrack or special stage. What he must do, you need not.
6. Internet Chat lines and other enthusiast web sites. Both of which can be invaluable sources of information, but take only with a pinch of salt, as they are often dominated or run by people that fall into the above categories. Unfortunately, it is normally the ones that flame the hardest that are seen as the expert. Finally, just because it is in print and on the internet, don't automatically assume that it is gospel!
7. Then there are the people that have good information and real advice, except that his/her needs (and/or budget) are completely different to yours.
8. Finally there is the gold to be had. Someone with good, relevant and most importantly realistic information for you and your car. Now for the $64 dollar question. How to spot them from the rest of the crowd?

6.1The Approach

Most modifications fall into three very broad categories. There are a few useful cheap 'n cheerful mods that are both inexpensive and quick to install. Some of these can even be done at home by you, given a small amount of mechanical aptitude and a few common tools.

Then there are modifications that really need to be installed professionally, by reputable operators that have a proven track record. Even though most of these parts still can be classified as "bolt-ons" specialist attention is required to ensure everything is assembled and tuned to work in harmony. Be very wary though, of outfits that claim to "specialise" in everything from Formula One engines to fitting tow bars.

Finally there are the hard core performance modifications, a.k.a the "monster tune". This category contains the biggest, brightest and most expensive mods you can do to your Subaru. Such enhancements consume both money and time in equally frightening proportions.

This book covers all of these categories in at least some detail, and, while not professing to be the last word in Subaru tuning, is an excellent base to get you started, providing you with the ammunition required to start asking questions that are applicable to your intended level of modifications. The great thing about the WRX modification journey is that as long as you don't go down a blind alley, you can start out with the smallest and least expensive of mods, and then build up as you get more intrigued, better paid or simply just obsessed! Pick your own excuse.

Pic Replacement ECU

Reality Check

All new cars must comply with the relevant legal requirements of the country that they wish to sell in. Within the framework of these regulations, the manufacturer will then engineer and equip the vehicle to best suit the target market they wish to sell cars to. Such a market is generally very price conscious, so after legalities, price becomes the defining limitation on what the manufacturer offers up for sale.

Membership of your local WRX club, or even a few hours spent on a few Subaru chat lines will show you the rich diversity of humankind that makes up such a market! In order to sell the maximum amount of cars, the manufacturer has to make their product appeal to as many of us as possible, while offending as few as it can, and at the right price. How hard can that be?

As an example, the intercooler fitted to the WRX is relatively small and inexpensive (especially on the early models) A better unit/front mounted unit would produce more power with less thermal load on the engine than the OE unit, but at a cost. Such a unit would drive up the base car's price, with little benefit for the average punter. Or take the case of vehicle handling, its widely accepted that understeer at the limit, is the safest characteristic for a car to exhibit. Rather than risk being labelled as having a reputation for "deadly handling" in the tabloids, Subaru have tuned the WRX's suspension to understeer when pushed hard. While not the most sporting, nor enjoyable way to negotiate a corner, it's the safest in unqualified/unskilled hands.

Bearing in mind that with all of these constraints Subaru works with, in order to sell the maximum number of cars, it is then very easy to appreciate improvements can be made to certain aspects of your WRX to suit you, and not the great unwashed masses. Inevitably, additional cost over and above the purchase price of the original car is always a downside, although there are some pleasant exceptions. In all cases though, the legality and integrity of the vehicle should always be maintained.

6.2 Understanding Dynamometers

Subaru on Dyno

Dyna-what?
In case you were wondering, a Dynamometer is a machine used to measure Power and Torque output of an engine.

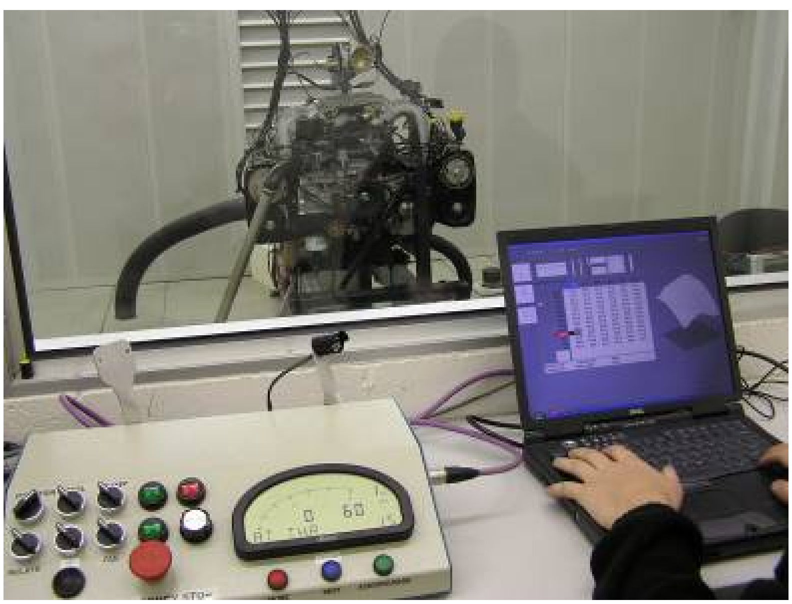
For both tuners and consumers, dynamometers (dynos) are now an integral part of the aftermarket performance industry. Increasingly complex engine management and turbosystems are all but impossible to tune on anything other than a dyno, while giving consumers an easy way of quantifying improvements in engine performance for a given set of modifications. If your tuner does not have a dyno, or easy access to one, then we strongly recommend you only buy tried and tested parts that do not require such set up. Dynos fall into two main categories. Engine and chassis dynos.

6.2.1 Engine Dynos

Engine Dyno Test Rig

Who Else Uses Engine Dynos?
Manufacturers and race teams love engine dynos. None of the drivetrain hardware is connected to the engine being tested, so all results are supremely repeatable. Some race teams even have automated dynos that will run an engine to replicate exactly actual racetrack conditions, all without even leaving the comfort of the workshop! Probably the most extreme use of an engine dyno is when manufacturers use them to endurance test new engines. It is not uncommon for a manufacturer to check durability by running engines at WOT and max RPMs for days on end. Something that normally would have cooling systems, transmissions and tyres expiring in short order on a chassis dyno.

Using an engine dyno is complicated and time consuming, as the engine first has to be completely removed from the car *before* it can be attached to the dyno. Back in the olden days when carburettors and distributors were king, it wasn't much of a job to unbolt an engine, set it up and begin power testing. These days it is a totally different proposition, what with cars having multiple electronic control units on computer networks, and ignition keys with computer chip transponders and unique Immobiliser Identity codes. It literally can be an impossible task to try and run a modern engine with the factory computer outside of the car.



Engine Dyno Console

Sheer economics makes an engine dyno impractical for all but the most serious enthusiasts. Where an engine dyno cannot be beat, are for those mega projects where ultimate power takes precedent over cost. Having the engine out of the car makes the task of swapping out cams, turbos and other engine components a snack compared to when it is installed in an engine bay. Engine dyno power and torque numbers are calculated directly off the engines crankshaft.

Wheel Vs Flywheel Power

Flywheel power and at the wheel power are two figures that are used throughout the industry and is sometimes cause for confusion. One thing is for sure, only an engine dyno can give a 100% accurate reading of true engine output, as it does not have to deal with driveline losses due to friction. Flywheel power numbers generated by chassis dynos are only the dyno manufactures best estimate. Therefore it is best to stick to numbers at the wheels, after all this is where it really counts!

6.2.2 Chassis Dynos

MRT Dyno Test Cell.

Chassis dynos are broken down into three further sub-categories, braked and un-braked inertia roller dynos and bolt-on type hub dynos. All essentially achieve the same goal of measuring engine performance without having to totally disassemble the car, but have subtle differences that are important to understand.

Inertia style dynos are popular due to their low cost and simple construction. An inertia dyno consists of a very heavy set of rollers that the car is driven onto. The dyno computer monitors how fast the engine can accelerate the heavy rollers, calculating power and torque from the results. Disadvantages of this type of dyno is that it is impossible to hold an engine at a certain RPM point, making it very difficult to zero in on specific engine operating zones for tuning and testing purposes.

Dyno Dynamics Roller Dyno

Comparing Power Numbers

As a general rule, a braked roller dyno will give the lowest indicated power number, with inertia chassis dynos and the same car generating a slightly higher number. The same car tested again on a hub style dyno will give a slightly higher reading again. Who is right and why can't dynos produce similar numbers? Don't know. Perhaps when the entire world learns to spell aluminium the correct way, these any many more mysteries will be solved.

Dyno-Test the Easy Way

Most WRX car clubs organise on a regular basis dyno days, where a nominated workshop will open their doors to club members to use the dyno at a discounted price. There's no such thing as a free lunch, as normally the nominated workshop will have staff on hand suggesting ways to improve your car. This aside, it is an invaluable chance to see how other cars respond to certain modifications, without so much as laying a spanner on your car. You can play virtual tuner from the comfort of the second row, simply by keeping tabs on results versus modifications. The pen is mightier than the sword!

Braked roller dynos also measure power and torque, but more importantly have the flexibility of being able to test at different loads and RPMs, making it far easier to simulate real world conditions.

Both types of roller dyno require the car to be securely strapped down so that the tyres will grip the rollers adequately and also so that the car doesn't leap up and away at an ill-opportune time!

Lastly are the newer hub dynos, which are very different to the roller type. The vehicle to be tested has its drive wheels removed, and then are connected directly to individual pods, by means of special hub adaptors. Hub dynos will do everything that a braked roller dyno will, with the advantage of being quieter, kinder to your tyres and without the troubles associated with stopping a monster tune car from trying to launch itself out of dyno rollers. Another advantage is a big reduction in rotating inertia, making it more accurate and sensitive to power loss caused by detonation among other things.

Pic Dynapack Hub Assembly

Pic DynaJet Inertia Dyno Hub Assembly *Pic under the floor*

6.2.3 Pre-Dyno Preparation

It is mostly common sense and centres around making sure your car is in a good state of repair. Dyno testing / tuning an engine that already has one foot in the grave is a sure fire way of making you take the bus home. A few checks of engine oil, coolant, transmission fluid and drive belts along with a quick peek underneath looking for leaks is all that is required. If you are using a roller dyno, make sure your tyres are in good condition and are not low on air pressure.

One last point, if your car is to be run on the rollers for a long period of time, or has rally/competition tyres, talk to with your dyno operator beforehand. Roller dynos love high powered cars with soft and sticky tyres, gobbling them up at an alarming rate. A swap with cheaper rubber is often prudent. Those using hub type dynos don't need to worry about damaging tyres, but it is the wrong time to discover seized or missing wheel-nuts.

Cars get very hot on all types of chassis dynos. You must get adequate airflow to the radiator and intercooler. Its *imperative* that the car does not overheat and that transmissions and differentials are given enough time to cool during extended testing. Finally, don't waste time on unnecessary tests or risky modifications.

Dynos are an extreme environment for your car, treat them with care.

Dyno Fans

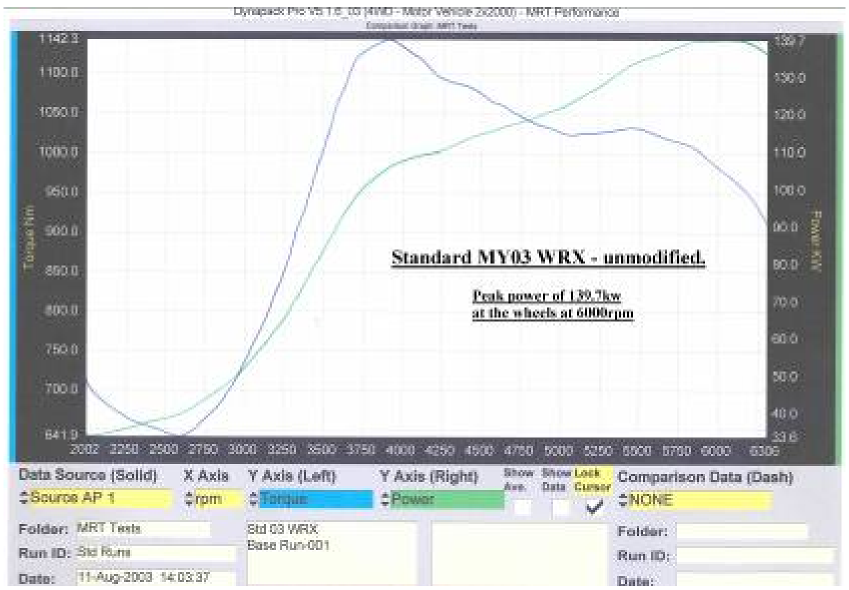
6.2.4 Interpreting Dyno Results

Once dyno testing is complete and you have the computer print-out in your hand, there are still a few more points to consider:

- The same car will measure differently on another brand of dyno.
- The same car can measure differently on same brand of dyno at a different workshop.
- The same car can measure differently on the same dyno on a different day.
- Unscrupulous dyno operators can make any car perform very well or very badly, rigging the test by manipulating results.
- Turbo engines are more susceptible to power robbing heat soak than naturally aspirated engines, particularly if the intercooler is not fed sufficient air. Pay attention to where air temperature is measured, as probe placement will have a big effect on power numbers generated, as software within the dyno controller adjusts power numbers based on this measurement.
- Power at the wheels of a standard WRX on a braked roller dyno is approx 35-40% of its rated flywheel power, due to drivetrain losses and tyre friction. These losses are not linear. A WRX with more power loses a smaller overall percentage.
- Testing a car in different gears will give different power and torque figures (eg 3rd vs 4th)
- Get as much information as possible. Most modern dynos can data log turbo boost pressure, air-fuel ratio, inlet air temperature all against engine RPM, printable in graph form. If your dyno operator cannot provide this information find out why!

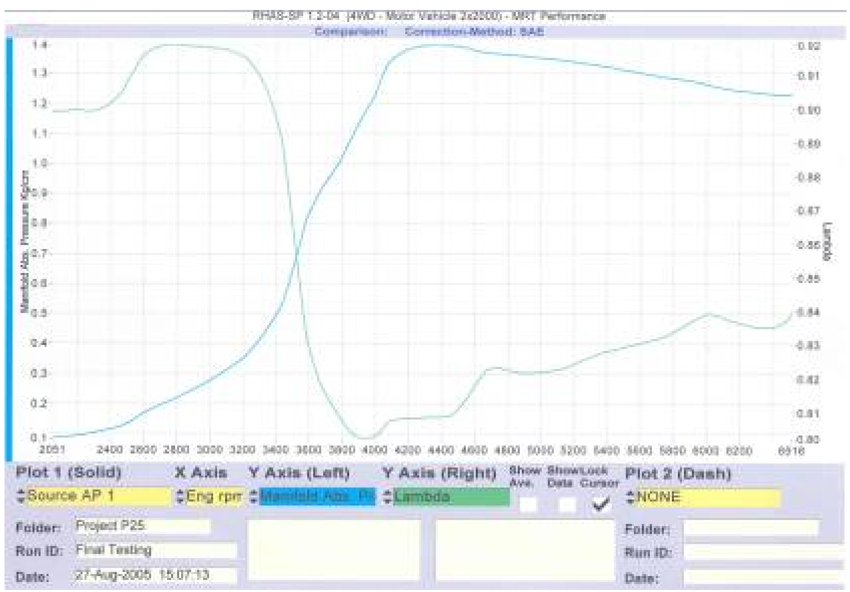
What a Great Figure
For those of you who have been through the sometimes painful process of building a real "monster tune" get your dyno graph laminated, or even framed. Now there's real car park cred! *Blimey sunshine, would you have a look at the legs on that!*

These points make the answers available from the dyno rather harder to evaluate. You need to use the same dyno for before and after modification readings. If at all possible these should be done on the same day, with the same fuel and dyno settings and calibrations. Make sure that your tuner adequately explains the finer details of the information contained in dyno printouts. Above all you need to trust your dyno operator. Ah, life is difficult.



Dyno Power+Torque Graphs

Dyno Units of Measurement
Power is usually expressed as either kilowatts or horsepower (metric or imperial) while torque is a bit more complicated with newtons, Newton metres, metre kilograms, pounds and foot pounds all to describe the same thing. What units are best to use? Easy, the ones that you are most comfortable or familiar with. In the end it is six of one and half dozen of another. Additionally, comparing dyno numbers from other regions of the world will always require an abacus and conversion tables.



Boost+Air-fuel ratio graphs

6.2.5 Reading Dyno Power Graphs

Printed data from your dyno session is a lot more than just squiggly lines drawn on paper. Dyno graphs are the visual record of how your WRX is performing, showing not just peak readings, but more importantly your engines power and torque characteristics across its RPM operating range. A single dyno printout on its own is interesting, but when multiple graphs are overlaid in the form of before and after tests, they can be fascinating!

Dyno Fans

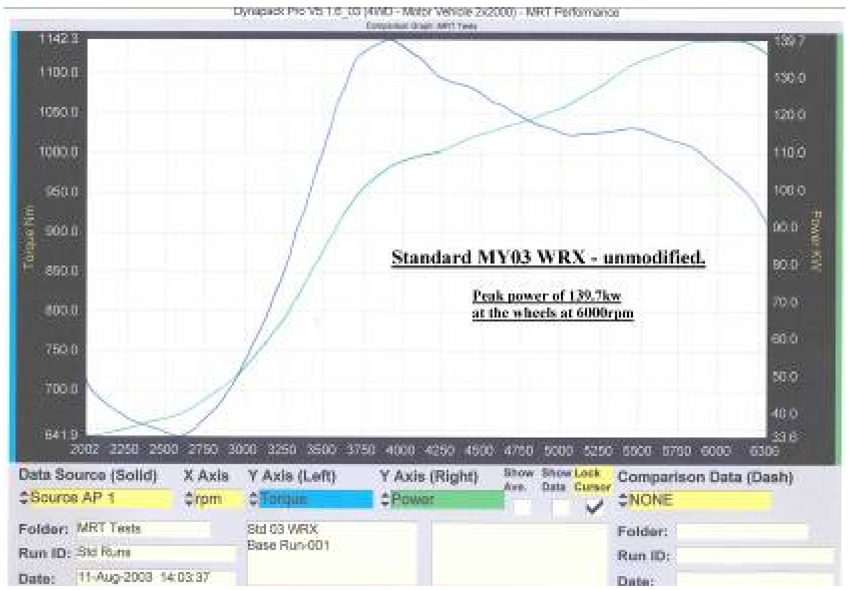
6.2.4 Interpreting Dyno Results

Once dyno testing is complete and you have the computer print-out in your hand, there are still a few more points to consider:

- The same car will measure differently on another brand of dyno.
- The same car can measure differently on same brand of dyno at a different workshop.
- The same car can measure differently on the same dyno on a different day.
- Unscrupulous dyno operators can make any car perform very well or very badly, rigging the test by manipulating results.
- Turbo engines are more susceptible to power robbing heat soak than naturally aspirated engines, particularly if the intercooler is not fed sufficient air. Pay attention to where air temperature is measured, as probe placement will have a big effect on power numbers generated, as software within the dyno controller adjusts power numbers based on this measurement.
- Power at the wheels of a standard WRX on a braked roller dyno is approx 35-40% of its rated flywheel power, due to drivetrain losses and tyre friction. These losses are not linear. A WRX with more power loses a smaller overall percentage.
- Testing a car in different gears will give different power and torque figures (eg 3rd vs 4th)
- Get as much information as possible. Most modern dynos can data log turbo boost pressure, air-fuel ratio, inlet air temperature all against engine RPM, printable in graph form. If your dyno operator cannot provide this information find out why!

What a Great Figure
For those of you who have been through the sometimes painful process of building a real "monster tune" get your dyno graph laminated, or even framed. Now there's real car park cred! *Blimey sunshine, would you have a look at the legs on that!*

These points make the answers available from the dyno rather harder to evaluate. You need to use the same dyno for before and after modification readings. If at all possible these should be done on the same day, with the same fuel and dyno settings and calibrations. Make sure that your tuner adequately explains the finer details of the information contained in dyno printouts. Above all you need to trust your dyno operator. Ah, life is difficult.



Dyno Power+Torque Graphs

Dyno Units of Measurement
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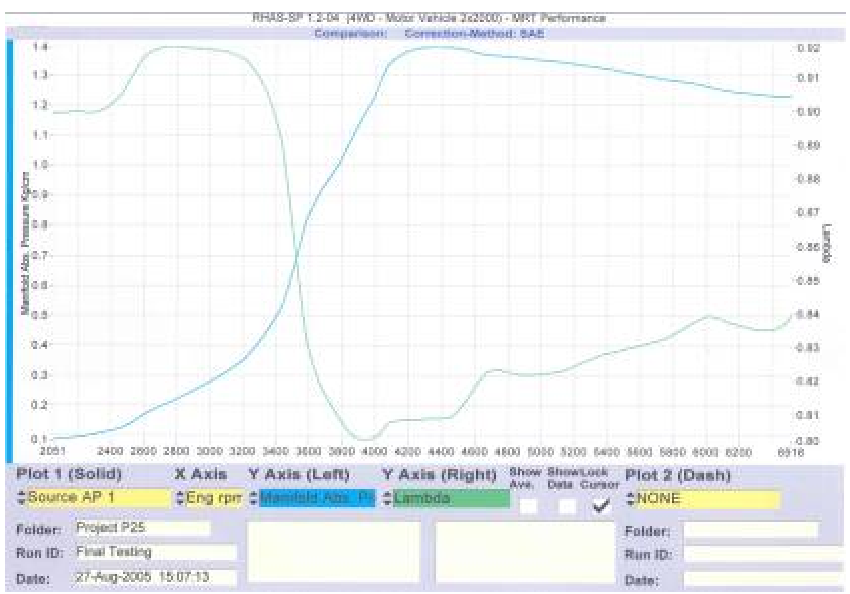

Boost+Air-fuel ratio graphs

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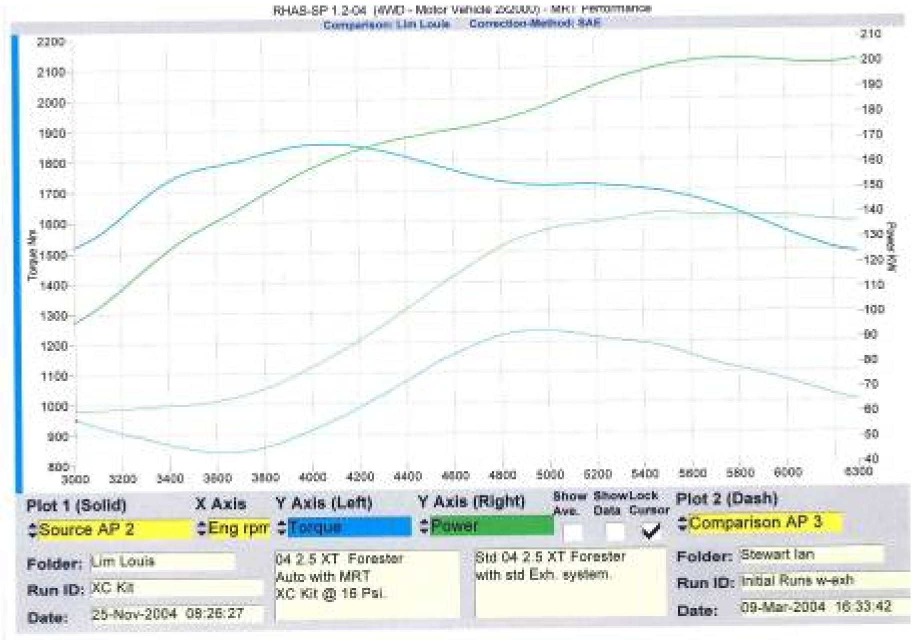
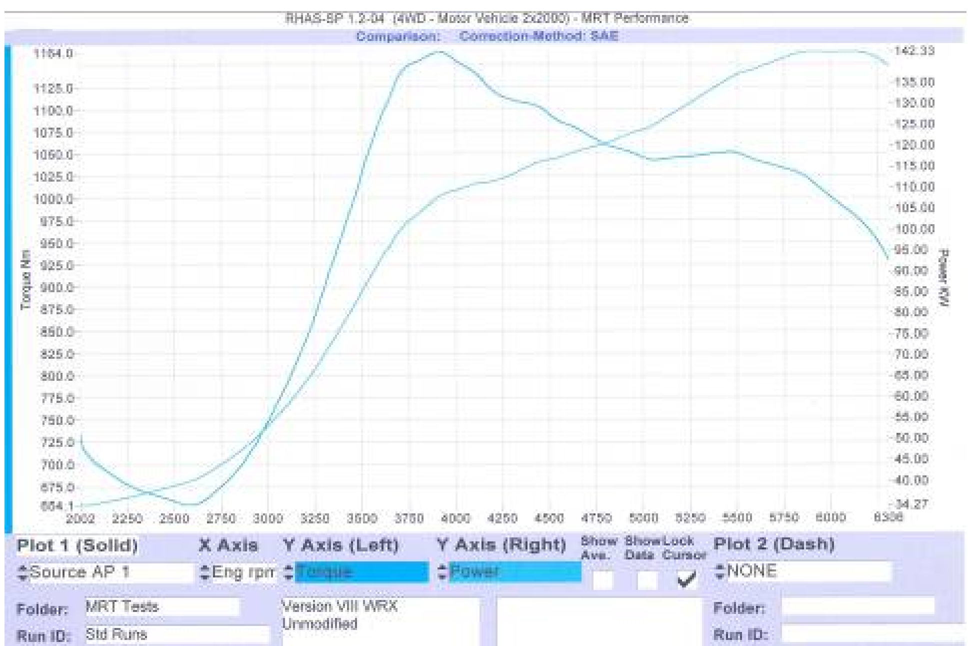


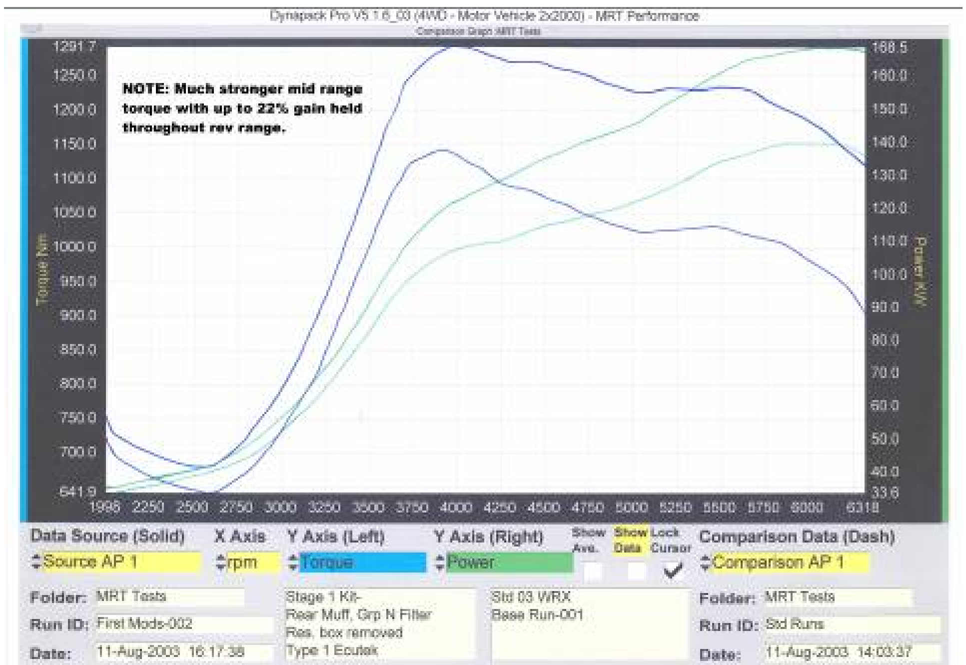
Dyno Graph Before and After

Most dyno printouts will have the test results graphed against three main parameters, engine RPM (or road speed), tractive effort (torque applied to the wheels) and actual power at the wheels. As touched on before, any type of chassis dyno that rates power and torque as flywheel is only estimating actual engine power figures, so we will only look at what is being delivered to the roadway.



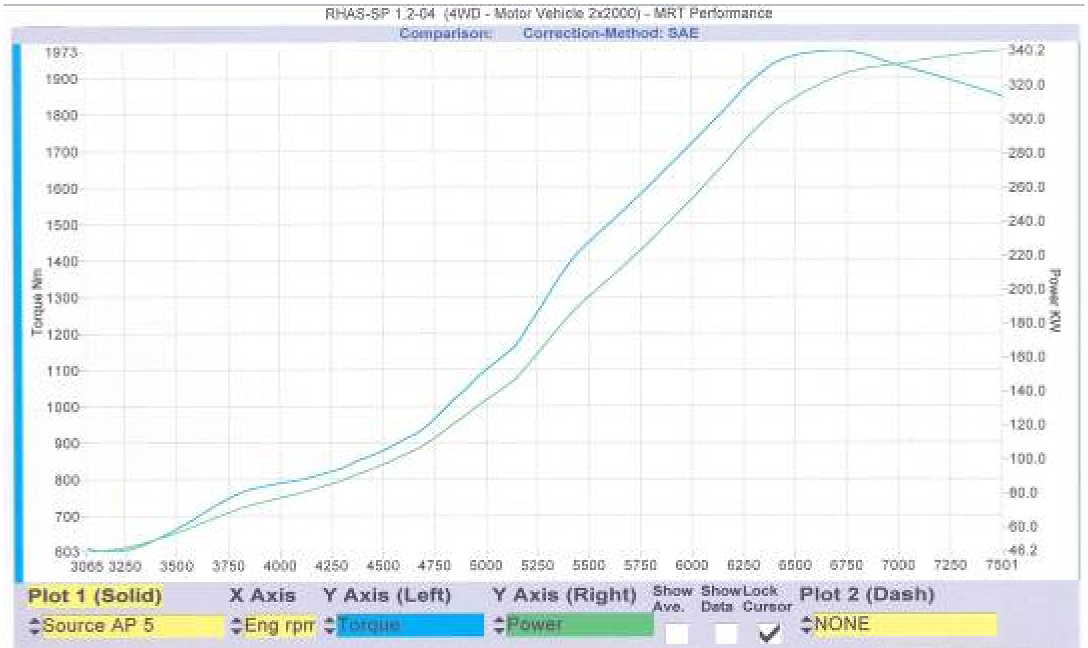
Version VIII WRX Unmodified

A standard un-modified car is a good starting point when analysing dyno curves, and are a direct product of all the cost vs performance constraints facing the manufacturer. It is never going to set the world on fire, but it is pleasant and un-offensive to drive, and more than likely will still be running in 10 years time given the right servicing. Key features of the standard car is the way power and torque build quickly, with maximum torque around 3,600 RPM with a nice spread right up until 5,600 RPM, at which point it starts to drop away. Power builds nicely all the way till about 6,000 RPM, where it gets a bit breathless and beginning to taper away close to the redline.



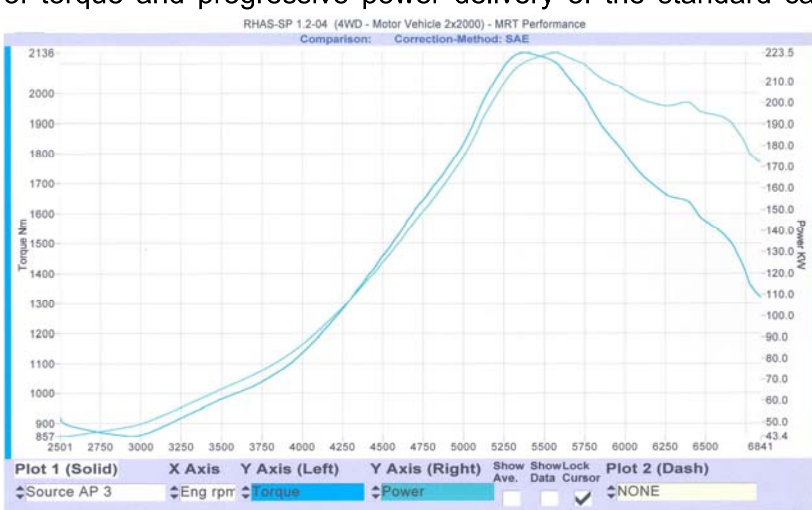
Version VIII WRX Std vs Modified

Looking at the same cars dyno graph after a few simple mods the differences may not be immediately noticeable in its shape, except that it has got a lot more power and torque everywhere, especially at the top end where power does not drop off as significantly. On the road this car will feel a much better device to drive, that is quicker and most importantly more fun, without compromising any of the standard cars driveability.



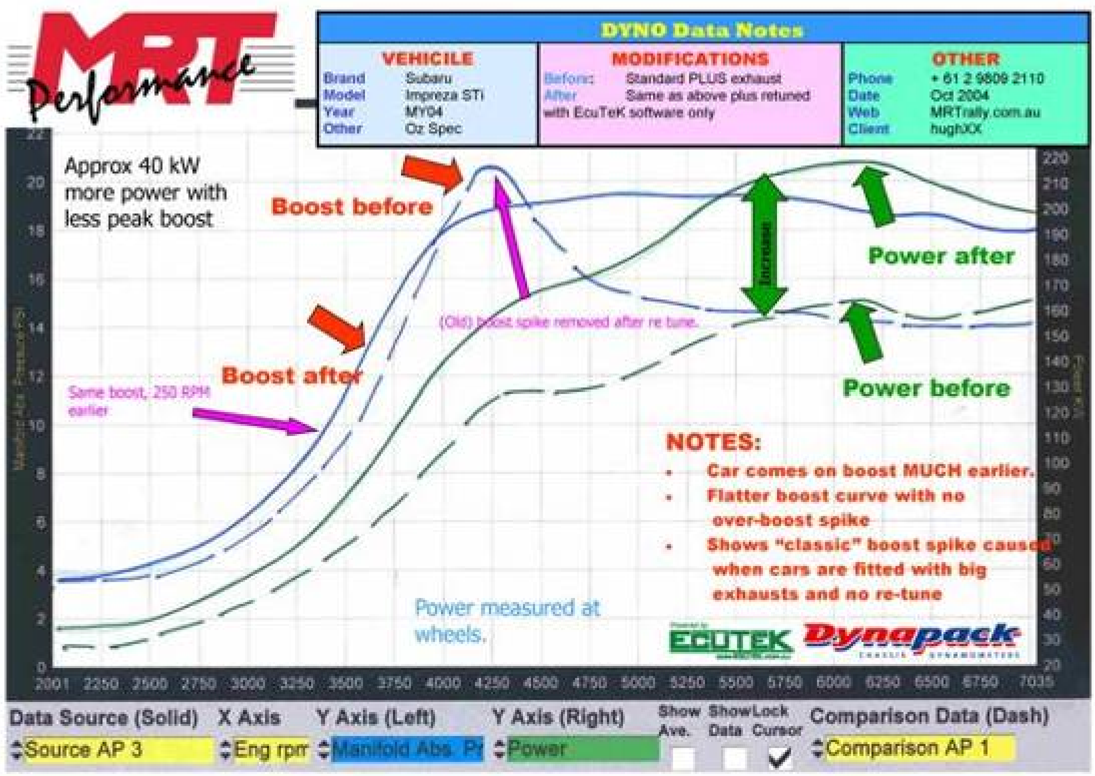
Low Compression Engine Big Turbo Top-End Screamer

Next is a dyno curve that demonstrates when no compromises are made when it comes to the goal of achieving maximum power, a no holds barred effort, featuring a specially built low compression 2.0ltr engine, big cams, ported head, large throttle bodies, intake manifold plenum and a massive turbocharger. The engine makes enormous amounts of power, but completely gone is the nice spread of torque and progressive power delivery of the standard car. Between 5,200 RPM and 6,200 RPM engine power jumps massively from 145kW to 300kW, that's 200Hp in the old numbers! Peak torque is achieved at 6,500 RPM and as long as engine RPMs are kept between 6,200 and 7,500 (its rev limit) the car is devastatingly quick to drive, if you are brave enough to keep the throttle nailed to the floorboards. Totally impractical for day to day driving and you certainly wouldn't lend it to Granny for drive down to the shops for a litre of milk!



Turbo Too Small For Engine Configuration

Then there is the case where good work has been let down through a miss-match of parts. Right up until 5,900 RPM both power and torque are increasing smoothly and strongly, at which point due to poorly selected turbocharger combination, the engine hits a brick wall and runs right out of breath. Torque drops off steeply heading south at a rapid rate, as does power, dropping by a massive 40kW towards the redline. Being too small, the turbocharger simply cannot flow enough air to maintain power and torque high in the RPM band. Out on the road the car is seriously quick, until 6,000 RPM, where it really starts to struggle alarmingly for the last 1,000 RPM before the rev limiter kicks in. Not a nice feeling!



STi Boost Spike Cause by 3 inch Exhaust System

The last dyno graph illustrates the pitfalls of modifications without matching engine management modifications. This Version VII STi had almost every bolt-on known to man fitted up, but with all the extra airflow potential generated by a 3" exhaust system, the factory computer could no longer control boost properly, going into a self-protection mode, causing the terrible lumps and bumps in the power and torque curves. Out on the road the car drove as bad as it looks on paper.

Dynapack Dyno On-Site

Dyno Scaling

Does your "monster tune" WRX dyno graph look like a couple of sickly worms all on their own in the middle of the page? Don't despair; it could just be a case of the scales needing adjusting on the X, Y and Z axis of the printout.
Even a 300kW stove hot Subaru power curve will look anaemic, if it is lost in the middle of a power scale that goes from 0 to 1,000kW, the same goes for poorly selected torque and RPM scaling. Check with your dyno operator if unsure.

Dyno graphs are an excellent source of information, and any serious tuner will have dyno graphs that clearly show power and torque curves both before and after modifications are carried out, clearly indicating what the gains are, and how that translates out on the road. Vague assertions that an exhaust will do this, or part X is guaranteed to double power no longer holds weight without supporting documentation to back up such claims.

Poorly Scaled Dyno Graph

Chapter 7

Model History

Model History

7 Origins of Subaru

It may come as a surprise to learn that Subaru and parent company Fuji Heavy Industries, can trace its roots back to the obscurely named “Aircraft Research Laboratory” founded by Chikuhei Nakijima in 1917. Previous to this, while enrolled at the Japanese naval academy, and at age 19, Nakijima became captivated by the notion of human flight, and the romance associated with taking to the skies on hearing of the Wright brother’s first successful powered flight. This quickly led to Nakijima working on the production of aircraft for the Japanese navy. Ultimately less than satisfied with simply building aircraft, Nakijima became more and more absorbed in the development aspects of aircraft, culminating in leaving the Naval academy to found the aforementioned Aircraft Research Laboratory.

Very quickly this new company was renamed as the Nakijima Aircraft Co. Ltd., rapidly becoming one of Japan’s leading aircraft design and manufacturing companies in the ensuing years leading up to, and including the period during World War II. Following the defeat of Japan in 1945, and the total collapse of the domestic aircraft industry, Nakijima Aircraft was renamed Fuji Sangyo Co. Ltd., and began the task of adapting design and production techniques learned from aircraft production into the manufacture of motor scooters and bus body building.

7.1 Fuji Rabbit

Pic Fuji Rabbit

Reacting to the demand for cheap personal transport, in June 1946 Fuji Sangyo, after studying for six months a Powell Streamliner scooter (as used by American service personnel of the time) produced their own interpretation of this existing design. Called the Fuji Rabbit, it proved to be an instant success with the local population who appreciated its step-through design, low centre of gravity and satisfactory performance. Propulsion was by a 1.5kW 135cc air-cooled engine and made use of surplus wartime tail-wheels from military aircraft! It is also interesting to note that the Rabbit made it to the market a full six months prior to the very first Vespa scooter.

7.2 The Formation of Fuji Heavy Industries

Changes to prevailing corporate law in 1950 forced Fuji Sangyo to separate into a further twelve autonomous companies. In 1953 Fuji Heavy Industries (FHI) was formed as an aircraft manufacturing, maintenance and sales company through the combined investment of five of the original companies formed from the break-up of Fuji Sangyo. Two years later these five investors merged with the newly created FHI, beginning the modern era of FHI's business activities as we know today.

Greek Mythology and Subaru

The constellation of stars that forms the corporate logo of Subaru comes from the cluster of stars known as Pleiades, named after the seven daughters of Greek mythology and their parents Atlas and Pleione. The Pleiades group of stars contains literally hundreds of stars; the vast majority of which are invisible without the use of a telescope or binoculars. Only nine stars have actually been named. Of these nine stars, only six of Atlas' seven daughters are visible to the naked eye.

7.3 The Subaru Name

Early in 1954 the prototype of FHI's very first passenger car was produced, known creatively as the P-1. Then president of FHI Kenji Kita, made it a priority to come up with a dedicated name for the fledgling car making division of FHI, by conducting an inter-company poll. Ultimately unsatisfied with the suggestions made, Kita chose instead to use a name dear to his own heart, and that of the Japanese people. For both the Chinese and Japanese, the cluster of six visible stars known as Pleiades in the west, is known by the name Subaru. For the Japanese, literally translated, Subaru means "to gather together or to govern" and is sometimes translated as meaning "unity". It is interesting to note that FHI was created out of the merger of six different companies, demonstrating what an evocative name Subaru is for the Japanese.

Pic Subaru Corporate Logo

The P-1 became the Subaru 1500, which ultimately failed to be a sales success for FHI for a variety of reasons, but in 1958 Subaru hit on the right mini-car formula for the masses with the Subaru 360. The 360 was a small four-seat car and went on to sell successfully for eleven years.

The rest, is as they say, history!

7.4 WRX Model History

For specific details, ratios, specifications and more on all the Impreza models refer to the spreadsheet in Appendix "XX"
Historically, the WRX cognoscenti in Australia and the UK have taken to referring to the car in terms of model years; MY00, MY02 etc, and as such will be used from time to time throughout this book. However, it is useful to know that Fuji Heavy Industries or FHI, the massive industrial conglomerate that owns the Subaru brand, refer to WRX in terms of *versions*. This nomenclature has be used in publicity material for the series of factory hot-rodded STi models, which are commonly referred to as STi Version I, II, III, IV, V, VI, VII and VIII.

First of the First

BAT555 shares the distinction of being pretty much the first WRX to be modified and featured in a performance car magazine in Australia, in this case long standing small car hotrod mag Fast Fours. Modifications were limited to a complete 3" exhaust, pod type air intake, TMIC, boost controller and a fuel cut lifter. Although simple mods by today's standards, it was heady stuff back in 1994 which was very much the early days of WRX tuning. Still owned to this day by the same enthusiast, it has evolved constantly, and now sports a 2.5ltr stroker motor with forged internals, hybrid Garrett ball bearing turbo, FMIC, Link Plus engine management, baffled alloy engine sump, DBA brakes and Whiteline group 4 suspension. This car is no show pony, working hard for its living, taking part regularly in club level motorsport events through out Sydney and surrounding districts.

BAT555 on the Dyno

As mentioned before, the Bug-eyed WRX is known as the MY01 model in Australia and Europe, and as the MY02 car in the USA. To avoid confusion on a global scale, we will endeavour where possible, to use FHI model identifications in this book, and as such the bugeyed WRX is know as the *Version VII*.

In this section we will refer to the models by their correct version names, with a cross-reference to model year. Every effort has been made to ensure the veracity of the data for the Australian market. Equipment levels and mechanical specifications do vary from market to market. Please consider this section more of a guide than bible. *See appendix II on chassis numbers nomenclature*

7.4.1 Version I-MY93 — Nov 92 Sep 93

Bonnet vent, intercooler scoop and front view

This little known car was only sold in Japan and not exported, and was simply named the Impreza GT. It introduced the "shark gill" bonnet vents and the horizontal "slatted" grille assembly. The GT was known to suffer with electrical problems and excessively soft, poorly controlled suspension compared to latter incarnations of the Impreza. Air to air intercooling was adopted for this car replacing the air to water unit fitted to the outgoing Legacy RS. Cooling air was fed to a heavily slanted small top mounted intercooler via a bonnet scoop, which also supplied air to a cooling "chimney" built into the turbocharger heat shield.

Limited Edition Specials

In November 95 Subaru Australia released the first in a series of special editions, the WRX Rallye, cashing in on the success of the WRC team and its exploits. Only small numbers were available, and featured a Prodrive blue paintjob, colour coding of door handles and door mirrors. Wheels were gold 16" rims fitted to the STi version that was unavailable in Australia at the time. Seats were trimmed in Alcantara (fake suede) and were of the same design as the seats fitted to WRX's as standard equipment for the following model year.

"Bling" aside, the Rallye edition was mechanically identical to the standard car, but this didn't stop them from selling out in short order.

7.4.2 Version II – MY94-96 Oct 93 Aug 96



Wagon Rear


Under side of bonnet


Airfilter assembly


Intercooler


Engine power steer & radiator header tank

This was the first turbo Impreza to wear the WRX nameplate. Engine management, vehicle electrics were all heavily revised to fix shortcomings prevalent in the previous model, as were a major overhaul of shock and spring rates. Understeer still dominated handling characteristics, but the overall package was much more in keeping with the sporty image Subaru was promoting. Central to the big step forward in refinement lay with technical input by UK based motorsport firm Prodrive. Prevailing Group A rally regulations of the day dictated that the race-car must retain in essence certain components carried over from the road vehicle. Consequently, items such as intercooler size and position, turbocharger spec, exhaust, intake manifolds and goodies like a weight saving alloy bonnet made the Version II highly desirable at the time. Another classic example of the practice is Mitsubishi's series of Evolution Lancers, produced specifically with the intention of going rallying in both Group N and Group A categories.

Front brakes

Rear brakes

Rear suspension

Front suspension

7.4.3 Version III- MY97 Sep 96 Aug 97

Major revisions to engine mechanical spec dominated the Version III. World rallying changed dramatically with the introduction of World Rally Car (WRC) rules, intended to make competition in the WRC more attractive and economical for manufactures, as it no longer required the huge expense of producing a minimum number of 5000 units of a particular road going model in order to go rallying. Instead manufactures could under strict guidelines convert a basic economy car (such as a 2wd Corolla) into a 4wd 2.0ltr turbocharged formula one of the forest rally car.

As a consequence manufacturers no longer had to equip the road going model with oversized turbochargers and other parts that increased production costs and detracted from the overall driving experience Subaru was trying to promote on the humble road going models.

Version III Bonnet Vents and Scoop

Version III Headlights and Grille

Limited Edition Specials

Early in 1998 Subaru Australia introduced the silver anniversary edition WRX to celebrate (25 years) in Australia, sporting a black paint scheme, full leather interior and gold wheels. Club spec Evo 2 came out mid 98, sporting a new shade of blue that was different from the previously used Prodrive blue. Other goodies included gold wheels, alcantara seat panelling and racy decals. Mechanically the Evo 2 was identical to its lesser brethren.

Significantly, the adoption of a smaller turbocharger improved low RPM performance (at the expense of high RPM) and with a lot less turbo lag. Higher turbocharger pressure ratios necessitated a larger capacity twin entry top mounted intercooler and revised intercooler entry ducting. A new design intake manifold with longer but smaller diameter runners further boosted low to mid RPM torque, along with a new plastic turbocharger air intake pipe that feeds air directly from under the intake manifold, replacing the restrictive 90 Degree bend from the old model. A revised larger capacity blow-off valve rounded out changes to the induction system. Mechanically, new pistons, headgaskets and shim-adjustable solid tappets replaced the sometimes troublesome hydraulic valve lifters fitted to the Version I and II. Further improvements to vehicle electrics were made with a new ECU, ignition coil and boost control system. Despite a smaller turbocharger, engine power actually increased significantly by 10 kW to 155 kW over the Version II.

Underside of bonnet scoop

Standard engine bay, note revised inlet under inlet manifold

Transmission operation and durability improved with a dual cone synchro ring for 3rd gear, a weakness found in even moderately driven Version II's, while a different design shorter throw gear leaver enhanced transmission shift feel and precision.

Cosmetics were changed with a new bonnet with revised intercooler scoop and vents, re-styled headlights and front grille, 16 inch wheels, while the interior was transformed with the adoption of greatly improved front and rear seats.

Pic Interior

7.4.4 Version IV – MY98 Sep 97 Sep 98

Major changes to cosmetics centred on a new re-styled dashboard and centre console incorporating white faced dials on the instrument facia. Airbag equipped Momo steering wheels were fitted as standard. Mechanically the engine package remained essentially the same, with only small changes to engine electronics and turbocharger spec.

Further modifications were made to the transmission with a re-designed shift lever, while brakes were revised slightly and suspension set-up was improved.

Late in 1998 Subaru Australia imported five out of a production run of 425 22B-STi models. Somewhat of an automotive legend, this very special 2 door WRX was created to celebrate Colin McRae's winning form in the WRC. They were very expensive at A$125,000 each, and didn't include compliance to enable it to be road registered here in Australia. Only at a later stage did Subaru Australia assist owners with registering the cars for road use in this country. Hand built by STi in Japan, 2.0ltr engines were enlarged to 2.2 litres by boring the cylinders (hence the 22B nameplate) fitting them out with forged pistons and specially matched cylinder heads and cam profiles. A VF23 Turbo was fitted standard, but could be specified with a bad boy VF22 as a no cost option. A unique twin-plate clutch fed power to a revised transmission sporting a newly developed primitive form of in-cabin driver adjustable centre differential.

The rare beast. 22b

Most striking of all was the 22B's coupe body shape, complete with pumped-out flared front and rear guards, aggressive front spoiler and rear wing. Styling cues were taken directly from the championship winning World Rally Car version, giving the 22B a much more muscular appearance than the sveltely styled GC two door cooking model. Wheels were specially made BBS 17x8.5" wheels with Z rated Tyres.

Under bonnet

Unique vents

No fog lights here!

Clear tail lights and pumped guards

Alloy arms with huge offset wheels

Rear brake calliper

Front brake calliper

Rear suspension

Unique badge

Titanium fender badge

KYB struts

7.4.5 Version V – MY99 Oct 98 – Oct 99

Out of the Dark Ages
With the advent of the Version V WRX came the ability to flash tune the factory ECU, or directly access the factory calibration data and make changes. Added to this was also the ability to monitor and log all supported data parameters from the factory ECU, such things like RPM, boost, temperature, fuel duty, wastegate duty, O2 sensor and knock correction. See *Engine Management* chapter for more information.

The Version V's powertrain received its first major makeover since 1993 with major changes to the engine, consisting of new pistons, (Now with Teflon coated skirts and ceramic coated crowns) redesigned cylinder head and camshafts. Further adjustments were made to intake manifold runner length and plenum size. A newer and more sophisticated engine management system was fitted, with a new ignition coil, air mass meter, idle speed controller and boost control system. Engine power increased from 155 to 160 kW. Japanese domestic models (sometimes exported to markets such as Singapore) featured cast alloy front lower control arms, larger IHI roller bearing turbocharger and red silicone intercooler hoses.

Transmissions came in for some detailed attention, with a new stronger and stiffer transmission casing, with eight bell housing to engine mounting bolts instead of four in previous models. Minor changes were made to reverse gear and synchro hubs. Externally the transfer case was redesigned, containing detailed improvements to selector mechanism, case bearings, and a completely new centre differential assembly. For the first time in Australia a four-speed automatic transmission option could be specified as an extra cost option.

Limited Edition Specials

Despite releasing for sale 400 Coupe STi's, Subaru Australia continued on with its programme of cosmetic only limited edition cars. In March 1999 the WRX classic was introduced. Only 150 examples were offered for sale, and featured beige leather interior, wood capped gear knob and matching wood rimmed air-bagged Momo steering wheel, and the same irritating security system first fitted to the Version V STi. June saw the release of Clubspec Evo 3, with alcantara trimmed interior and blue fabric seat inserts, revised decals and a different dashboard finish.

Version V 4 door STi

Brakes were upgraded to four piston fixed callipers replacing the old sliding two piston units, along with larger diameter discs. Rear brakes received two piston fixed callipers and ventilated discs.

A new re-styled front bumper was immediately apparent, which had remained un-changed since 1992. The rear wing from the Version IV STi was adopted for the WRX, along with a re-styled grille rounded out cosmetics. Dual airbags were fitted as standard equipment for the first time.

Big news for Australia was the arrival of the two-door coupe STi in early 1999. Only 400 were imported making it highly sort-after, with its popularity remaining undiminished even to this day. Available in white or blue, these had the full Japanese domestic spec 206 kW engine, readily identified by its red intake manifold, complete with roller bearing turbo, revised cams and comparatively high boost pressures. Other Version V STi goodies included close ratio transmission, aluminium bonnet, rear screen wiper and the biggest rear wing this side of a 22B. Oddly enough, Australian delivered models had the old Version IV suspension, and not the inverted strut type fitted on the Japanese delivered Version V. Aussie STi's had "semi" automatic climate control, and a special in car security package offering anti-hijack protection.


Sti engine   STi interior

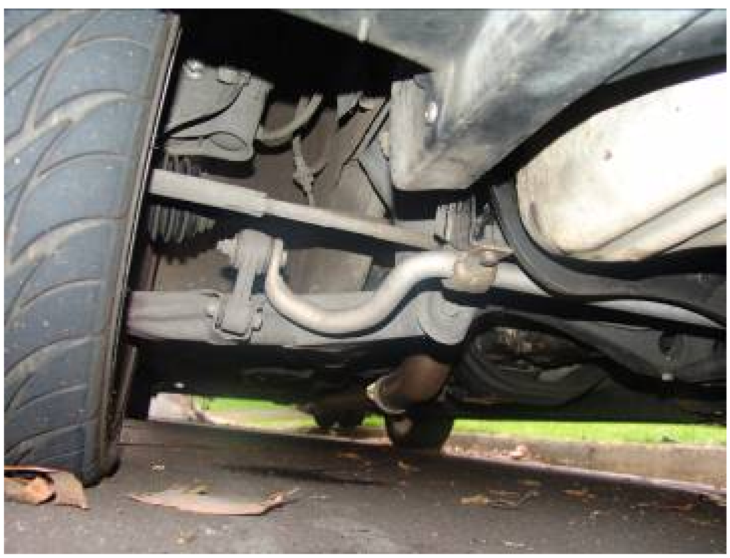
Leave it standard or modify?

This car proved to be an instant hit with both customers and the motoring press, who praised the car for its impressive performance and handling, as did customers who voted with their cheque books, ensuring that the entire shipment of 400 cars sold out in double quick time. It was not all good news for Subaru as a certain number of cars fell foul to mysterious piston failures, possibly due to a mismatch between Japanese domestic engine calibration and Australian 95 Ron octane fuel. One can only guess if this is the reason why that all STi variants imported into Australia from the Version VII onwards now have factory fitted forged pistons as original equipment.


Limited edition STI type RA *Roof scoop*


Australian delivered alarm module *WRX seats*

Rear WRX suspension



Front WRX suspension

Factory switchs for waterspray, "Auto" and "Manual"

Big Weakness.

Most notable for the MY99/00 model was the Air Flow Meter, or AFM. Until the release of EcuteK Delta Dash (see separate notes) this componant went unknown in its hidden problems. These days we know it's the culprit for over %50 of all engine failures. This includes std and modified cars. Prone to damage the sensor measures mass airflow and via a voltage signal sends data to the ECU. This data is critical in several areas namely fuel mixture. As the sensor deteriorates with age (mostly due oil contamination from OEM and aftermarket filters, dust and other contaminants) the Ecu is unaware of this, and so is the owner. Often a sensitive owner may note his car is going harder than a friends, most commonly this is due to the impendining disaster, of lean fuel mixtures. Never showing up as a CEL fault and hard to log or see on most scan tools and even the Subaru select monitor, the obvious signs are low injector duty cycle in high load situations. (checking voltage is not an accurate method).

Basically if you own a MY99 / 00 model and have never replaced the AFM sensor, in the last 6 mths or 30,000 Kms, a new one would be a wise investment.

Pic the troublesome sensor

7.4.6 Version VI – MY00 Nov 99 – Nov00

Limited Edition Specials
Clubspec Evo 4 was the last special edition for the old GC8 body shape, offered for sale in March 2000. Sporting a "look at me" post-it-note yellow paint scheme, and yellow alcantara trimmed interior, the Evo 4 also had gloss-black painted 16" wheels.

Essentially identical to the Version V, 16" wheels with a slightly different pattern were fitted, and for Australia colour coded door handles and mirrors for the first time. Although a small point, finally windscreen wipers with a variable speed delay were specified.

Not so well received was the news that Subaru was to bring in another shipment of 400 STi variants, this time in the four-door body shape. Owners of two door models were annoyed as they felt it would affect the resale value of their cars. These concerns proved to be short lived, with the four door rocket ships selling out just as quickly as the previous year's batch of 400 coupes. Mechanically identical to the Version V (some minor engine management calibration tweaks accepted), they differed marginally in the form of new and improved inverted strut suspension, full automatic climate control and a new slightly re-styled front spoiler.

Rear suspension

descreet change to rear wing

interior

Version VI STi Seats

7.4.7 Version VII – MY01 (MY02 in USA) Nov00 – Nov 01

The body of the Version VII was completely new and had considerably improved torsional stiffness and much greater resistance to bending, compared to the old GC series body shells. Crash safety also benefited with the addition of a large "U" shaped reinforcing brace bolted to the underside of the front chassis rails. Smoothness, feel and NVH all improve directly as a result of greatly increased torsional rigidity of the new body shell. This comes at the price of an approximate weight gain of 100kg over the outgoing GC WRX, despite the re-appearance of an aluminium bonnet. Engine power remained essentially the same as before causing performance to suffer noticeably.

Limited Edition Specials
In line with the Version VII new model shape, Subaru Australia released the Evo 5 limited edition Clubspec WRX. The post-it-note yellow paint scheme found on the last of the GC series Evo 4 was toned down to a slightly less eye-catching hue for the 5. Gone too were the gloss black wheels, replaced instead with more low-key looking set of standard finish factory alloys.

Prodrive UK300 *Japanese mods to rear OEM wing* *Std interior*

Limited Edition Specials

After an almost 14 month gap, following on from the bugeye Evo 5 was the release of the restyled Clubspec Evo 6, featuring full Version VIII specifications including the high compression AVCS equipped engine and larger intercooler bonnet scoop. Upgraded Interior appointments consisted of factory leather seat trimmed seats featuring side airbags, factory sunroof and dual front airbags.

Available paint colours were graphite black mica, WR blue and premium silver metallic paint. Wheels featured a titanium finish. And not forgetting the ever present Clubspec decals.

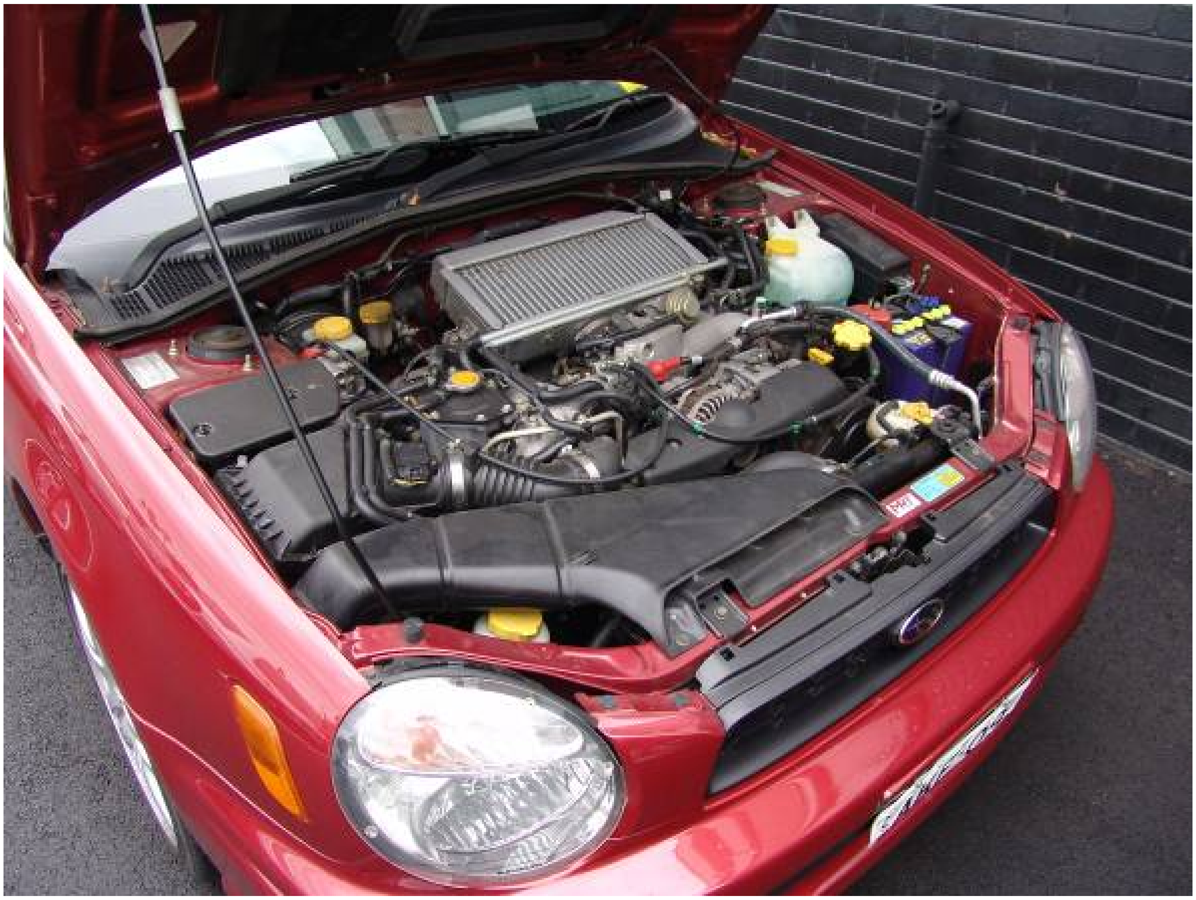
More detail changes were made to the engine specification, with revisions to cylinder head combustion chambers, a new intake manifold with revised plenum and intake runners incorporating tumbler valves that work at idle to boost intake turbulence. Engine electronics were upgraded with a newer generation electronic control unit, direct ignition by individual coil on plug (not seen since the Version II) and detail changes to boost and idle speed control. WRX's also gained a small pre-catalytic converter in the turbocharger up-pipe. Designed to meet cold start emissions (this proved to be troublesome, and for the aftermarket a common mod was to replace it with a "catless" pipe). It was deleted in later [MY03] models). Transmissions were essentially carried over unchanged from the Version VI.
Insert pic "up pipe
17inch wheels were fitted as standard equipment across the range, replacing the 16 inch items fitted since the Version III. Suspension geometry was improved all round, with a wider track than the old model and adjustments to rear roll centre. Curiously, the wagon variant carried over the same track dimensions as the outgoing model.

Cosmetically the new model was radically different to the outgoing model, with *those* round headlights, flared front and rear guards, re-styled intercooler bonnet scoop minus the small bonnet vents present on all turbo Impreza's since the Version I, new dashboard and instrument facia, centre console, front and rear seats and interior trim. Rear end styling treatment is far less controversial and more conventional. Gone was the large rear wing, replaced with a more subtle flat lid type spoiler.

Brakes remain the same as the Version VI, except for the US market, where Subaru chose to sell the car with old spec (Version IV) two piston sliding callipers at the front and non-ventilated rear discs.

WRX Wagon Front suspension

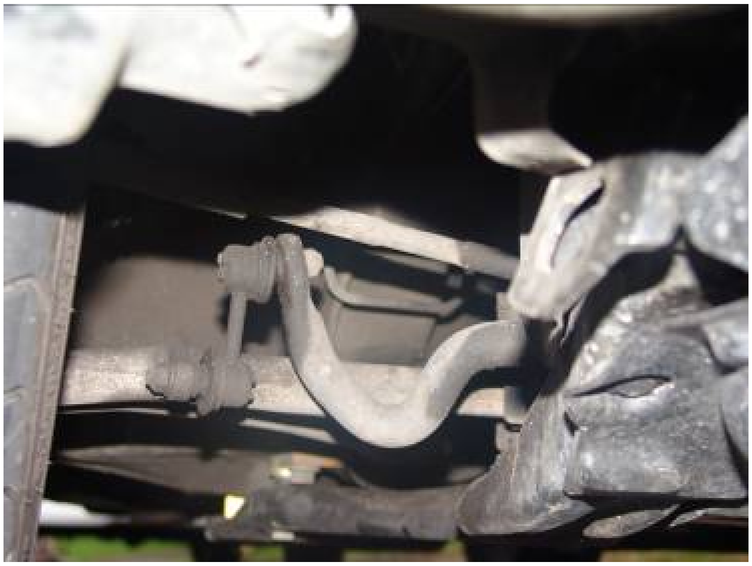
Rear suspension



WRX Wagon engine

Front Brakes were same for sedan and wagon *Rear*

WRX Wagon



Sedan front suspension, note alloy arm and solid drop link

Exhaust up pipe to turbo, note bulge for "pre" cat in OEM part. Factory clock in dash on both sti and WRX

Revised door controls for MY01

7.4.8 Version VII – MY02 (MY03 In USA) Nov01 – Oct02

Detail changes only with the MY02 WRX. Absent from the original release of the bugeye WRX in Australia was automatic transmission as an option, (Its assumed to meet demand all MY01 Auto models were being sopld in the USA) which was reintroduced as an extra cost option for the 02 Model Year. Manual transmissions received a new final drive ratio, increased from 3.9 to 4.4 to 1 in order to improve acceleration and offset some of the lost performance caused by the previously mentioned weight gain.

Limited Edition Specials

In quick succession, following on from the Evo 6 was the, you guessed it, Clubspec Evo 7. In keeping with a successful formula, Subaru Australia limited numbers to 300 only, and like the 6 it featured factory leather airbag equipped seats, factory sunroof, dual front airbags and racy decals. An automatic transmission option helped widen its driver appeal. Exterior colours remained the same as the 6 as was its sedan only body style.

Biggest news for 02 was the much anticipated Version VII STi, as it picked up variable intake valve timing, a new turbocharger and a completely new six-speed transmission. The up-pipe catalytic converter found in the WRX is deleted, along with the intake manifold tumble valves. For Australia only, our STi engines have forged pistons as standard. a trend that thankfully continued until the release of the MY06. An upgraded Brembo front and rear brake package was available as an extra cost option for the STi only. Cosmetically, apart from detail changes to intercooler bonnet scoop, foglight covers and badges, the Ver VII STi has different headlights to the WRX.
In Japan the 01 on model came in a variety of options, some with AVCS as well as Tumble valves.

STi interior

STi dash

A STi Variant of the Bugeye was never offered for sale in the US.

The Japanese spec STi

Australian STI with 2 litre engine



6 Speed transmission *huge front brakes* *rear brakes were different to WRX*


Australian STi water spray tank is in the boot. Controls were simple, with no auto function


STi Spec C and S202 had huge water spray tank *S202 had optional factory oil cooler*

MY01 S202. The first Subaru to win Targa Tasmania, beaking a 6 year Porsche record, by Tony Sullens.

S202 rear factory wing

S202 roof scoop

Genuine badge

Raising the Bar – "Special" Limited Edition

With the advent of the STi variant of the Impreza WRX becoming a permanent fixture in the Australian model line-up, Subaru was left in a quandary on what to offer prospective customers that wanted something different, but didn't want to spend STi money. Up to this point, enthusiasts were left with few options, (apart from resorting to the aftermarket) and that was limited to purchasing one of the Club-Spec Evo series of WRX's released for sale from time to time. Trouble was, cosmetics aside, these cars were mechanically identical to the WRX they were based on.

In somewhat of a "can't beat 'em, join 'em" type move, for the '05 model year Subaru Australia released 200 locally developed WRP10 WRX specials. A bit of a mouthful to say, the name commemorates 10 years of WRX involvement in World Rally (WR) running on Pirelli tyres (P). Crystal grey metallic is the only exterior body colour available, while in addition to fancy badges and interior trimmings is a very special modification; namely more underbonnet gristle. A recalibrated engine control unit and freer flowing exhaust is responsible for lifting power from a claimed 168 kW to a more muscular 175 kW. Other performance modifications include a 15mm lower ride height and a carbon fibre strut brace contributing to improved handling and a more aggressive on-road stance. (Interrogation by EcuTeK tuners found comparing the WRP10 ECU "map" to the WRX "map" to be very conservative)

On the whole, the WRP10 was not that well received by the motoring press, however Subaru should be applauded for what is on paper a rather brave marketing move. At the very least it should give the cardigan wearers at Mitsubishi Australia something to chew on.

7.4.9 Version VIII – MY03, 04, 05 (MY04 In USA) Nov02 – Sep05

Subaru gave the WRX significant facelift for the Version VIII. Gone are the round headlights, replaced with a less controversial and far more conventional set of rectangular units, new front grille, re-touched bumper bar and lightly re-styled rear lights. Big news mechanically for the WRX is that adoption of variable inlet cam control (AVCS), a boost in compression ratio and the deletion of the tumble valves and cat-converter in the turbocharger up-pipe. This boosts power and torque over the previous car, up from 165 to 168 kW

Limited Edition Specials

The most recent incarnation of the Clubspec theme is the Evo 8, coinciding with the minor interior upgrade that all WRX and STi variants received for the 05 model year. Available as a sedan only, but in either automatic or manual transmission, interior trimmings are exactly the same as the previous Evo 7 (Leather seats, airbags and sunroof), with the exception of the new centre console and HVAC controls. One major change was a new selection of exterior colour options, including Champagne and Crystal Grey. Have I mentioned the decals?

The Version VIII STi, apart from styling changes shared with the WRX, the most obvious difference is a new high-rise apartment block style bonnet scoop for the intercooler. Mechanically the 195 kW engine (forged pistons included) and turbocharger remains unchanged from the Version VII.

MY03 WRX front calliper, later models and limited editions were painted red

MY03 rear caliper

WRX engine

MY03 Wagon still had steel front suspension arms

MY03 Sedan had alloy arms

MY03 rear suspension

Pic WRX interior

The USDM STi differed by being offered with a 2.5ltr variant of Subaru's long standing EJ engine series. The extra cubic capacity of the STi was seen as the best way of increasing engine power and performance over the WRX without having to resort to risking high levels of turbo boost on relatively low octane US spec fuel.

In Aug 04, small improvements were made to both STi and WRX interior trim specification, including new HVAC controls and centre console assembly. Big news for the '05 model year was that STi models in Australia picked up Driver Controlled Centre Differential (DCCD), stronger wheel hubs and a change to wheel hub PCD. (See *Drivetrain* chapter for more information)

Limited edition

leather seats

painted brakes

STi wing MY03,4,5,6 were the same

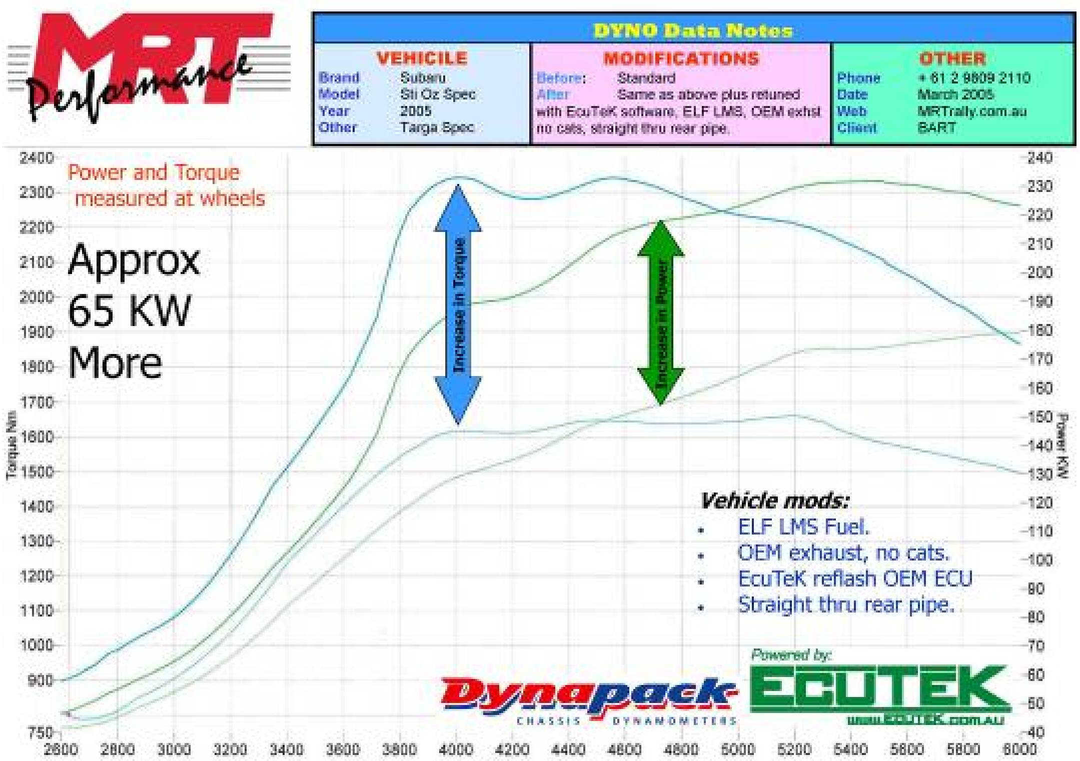
STi bonnet scoop was massive and higher than the WRX. No fog lights!
MY03, 4 and 5 were the same

STi MY05 interior

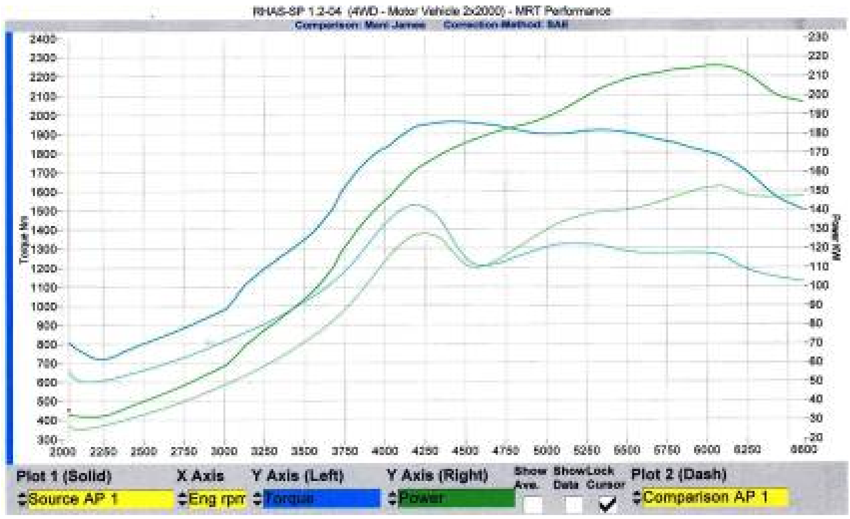
STi MY05 model

STi MY05

STi MY05 changed to new larger wheel brgs (front) with increased PCD for wheel nuts



Standard Vs modified STi MY05



STi MY05 ECU retune to fix over boost spike

7.4.9b Version IX – MY06, 07, 05 (MY07 / 8 In USA) Nov05 – Sep07

MY06 STi

Just about all but those legally blind will wholeheartedly agree that the standout feature of the Version IX Impreza is that controversial new front grille. One can only speculate that given the huge popularity and almost universal appeal of the turbo variants releasing a new model is always going to be a hard act to follow. Perhaps this is the reason why stylists feel compelled to push the envelope on what is considered the norm, in the quest to generate some emotions, be positive or negative from within the car buying demographic. As we all know Subaru has had a somewhat torrid time of late with this sort of aggressive styling, as was demonstrated by the way that the Version VII bugeyed Impreza was received.

With this model also came the worldwide release of the 2500 cc engine. No longer would the US market have exclusive access to the “big block” engine. Ironically even though all Impreza models are still produced Japan the “local” market has no 2500 cc option. Instead they get the 2000 cc “twin scroll engine”. We can only assume that strategically this is for two reasons. One is the engine capacity effects (horrendous) registration costs, (in japan) and Two, that the production of the 2 litre block will suffice for time being to meet FIA rules of homologation of models to meet World wide rally car requirements. Already we have seen the release of the limited “Spec C” Sti for the 2006 rally season.

Air injection pump was new to this model

Under side of scoop with air splitter

MY06 STi Interior

The world effectively got the MY06 in late 2005, with only the UK market dragging the chain so to speak due to excessive stock of “old” MY05 models to clear before the MY06 was eventually released in February (2006).

Rear suspension note sensor for HID lights

Front suspension

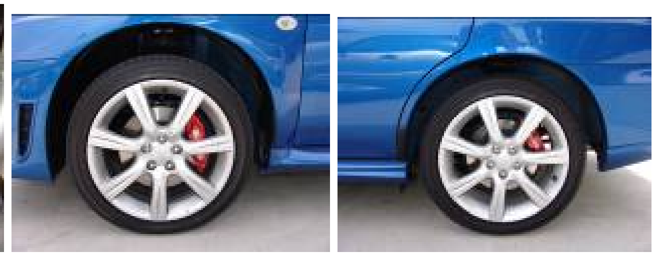
MY06 WRX

First WRX with single tip muffler.

Smaller scoop

Rear WRX suspension

HID level sensor



painted brakes

WRX Interior

MY06 Model variations.
"Impreza WRX TR"
All around the world markets fine tune their impreza's to meet "local" needs. For example, in the US, at the 2005 SEMA show, the VP for Subaru USA released a Impreza WRX "TR", basically a cut down version of the WRX, without all the showy bits. Aimed at the tuner who does not care for color coded mirrors, or a fancy stereo. Especially knowing it will be replaced by something ten times better from the aftermarket. This was a bold move, one that other markets will be sure to follow, as it shows that importers are starting to treat the "aftermarket" more seriousiously.
"Impreza Sti Spec D"
Released in the UK with the new model, this car is aimed squared at the up market. Basically a STi without the "look at me" options. Add to this a high tech stereo, low spec (WRX) wing, leather and more. ("D" stands for Descreet)

"Impreza Sti ESX"
Another test by the US market was the limited release, "Semi factory" of the locally tuned and modified model by hard core drag team ESX. Only available in red ot white with contrasting "GTO style" centre bonnet stripe, this model came with a feast of non factory fitted options. Larger intercooler, 3 inch exhaust, EcuTeK tuned factory ECU, and more.

Pic ESX models at SEMA 2005

The un-common element of all the WRX's and the Sti's around the world is the drivetrain and brakes. Effectively the WRX is now a detuned Sti, without the cream!

"WRX basic specs:"
Very similar to MY05, 5 speed, "small brakes" less fancy options,

"STI basic specs:"
6 speed, "big" Brembo brakes, VVT centre differential, better equipped interior.

The engine and more:
Both cars now come with DBW throttle,
, auxiliary air pump to meet new "step 3" Euro emissions rules "sti MY06-9",

Gone is the radial hook nose bonnet scoop that was larger on the STI

Washers for HID lights

The ECU is the latest spec, effectively the “same spec” as the CAN bus system of the GT Liberty/Legacy. Software to re flash (tune) this ECU by UK developer, EcuTeK is known as Flash 04”, when previous models back to the bug eye was “Flash 02”.

The ecu has total control over the throttle, with no mechanical connection whatsoever between the accelerator peddle and the throttle body. Subaru (and the aftermarket tuners) now have the ability to tune the right foot "feeling" of the engine response. In some cases 100% "foot" can not be 100% "throttle" and vice versa!

Pic WRX MY06

Pic WRX intercooler

With the 2500 cc engine so comes the Hypereutectic piston design that was common in the 2 litre twin scroll turbo's. Earlier we commented that Oz tuners thankfully did not have to deal with them until now, the reason being they are not as "tough" when specifically relating to engine knock. Even the smallest amount of knock can cause total failure of the piston. Notable engine bay pictures show a huge variation in the Intercoolers, with the WRX receiving the similar design plastic "tanked" unit that has been fitted to the 2500 cc turbo Forester since its release in 2003. Sti models also come with intercooler intake splitter and water spray. The STi has the similar design to the earlier MY05. Internally many parts are similar, just as many are varied. Refer Appendices for more data on this.

Body
The WRX came with the same low mounted rear wing as the MY05, whilst the STi came with the mandatory in your face big wing, ad to this a rear diffuser under the rear bar, and a mid wing mounted to the rear of the roof and you have a very different looking Impreza.

STi rear diffuser

STi rear "roof wing"

7.5 Subaru and Motorsport

Subaru maintains to this day a strong interest and participation in a number of different motorsport categories. Although best known for its rally championship exploits, Subaru also participates in touring car and endurance racing.

Rally Cars

Subaru Track Racing

The Origins of STi

Just about every Subaru enthusiast knows that STi stands for *Subaru Technica International*. But where do they actually fit into the corporate structure of Subaru and its parent company Fuji Heavy Industries? Well read on! STi was established in April 1988, and is 100% wholly owned by Fuji Heavy Industries, taking on the following responsibilities:

- Management of Subaru motorsport activities in the FIA World Rally Championship and Production Car World Rally Championship (Group N)
- Support of Subaru motorsport teams such as the Australian Rally Championship, Japanese GT championship, SCCA Pro Rally and Super Endurance Racing Series.
- Planning and development of STi variants of standard Subaru road going models.
- Planning and development of specialised STi limited edition competition homologation models.
- Development and manufacturing of performance and competition parts and accessories for Subaru model cars
- Manufacturing and marketing of official STi merchandise
- Co-ordination of PR activities, fan clubs and the promotion of motorsport program results, for the distribution through the Subaru dealer network and official magazine

Highlights of STi's achievements include:

- World record holder first to achieve 100,000km driven consecutively at an average speed of 223.34km/h in a Subaru Legacy.
- Group N category winner of the 1990 Safari rally, holding the title of the first Group N specification car to complete the entire distance of this gruelling rally!
- First victory in the WRC for Subaru in the 1993 Rally of New Zealand in a Legacy GT.
- 1995 FIA World Rally Championship for manufacturers and Drivers
- 1996 and 1997 FIA World Rally Championship for manufacturers
- 2001 and 2003 FIA World Rally Championship for Drivers
- 2003 and 2004 PCWRC Drivers Championship
- Unforgivable overuse of the colour known as "Barbie Pink"

Group N Homologation Specials

With the change from Group A rallying to the WRC formula, it can be argued that Subaru dropped the ball when it came to the basic road going WRX and STi. Suddenly freed from the requirement of making 5,000 homologation specials with different turbochargers, intercoolers, suspension parts and body panels in order to go rallying, they got a bit lazy with its road going cars. The Version IV, V and VI STi were a little on the under-whelming side, especially when compared to Mitsubishi's EVO IV, V and VI, who incidentally were the only manufacturer that decided to continue building cars to orthodox Group A rally regulations. As a direct result dominance was handed on a plate to the EVO in both road going and Group N Rally trim.

Pic Group N Rally Car

This has all changed now, with Subaru seemingly moving up a gear and getting serious with Group N homologation road going specials. This started with the release of the limited edition hot-rod S202 Version VII JDM STi, and more recently Spec C derivatives of the Version VIII STi. Continuing with this trend the Version IX Spec C is available in two different models; one with 17" alloy wheels and the other with 16" steel wheels (known as gravel spec). The latter is a stripped down homologation model specifically for Group N rallying, and features the following key differences from the outgoing Version VIII:

Weight Reduction – 70kg has been trimmed from previous models in the following areas;

- Aluminium roof skin and boot lid
- Smaller battery
- Deletion of rear window wiper and washer
- Lightweight front, rear and side window glass
- No passenger sun visor, drivers foot rest, internal grab handles and remote boot release
- Lightweight floor carpet, no transmission tunnel insulation, no fibre spare wheel cover, reduced underbody sealer and removal of the ISO rear child anchorage mountings
- Smaller 50 litre fuel tank

16" Wheel Model – saves an additional 40kg through;

- 16" Steel wheels with smaller diameter brake discs and smaller 4-piston front and 2-piston rear callipers and deletion of ABS brakes
- No air-conditioning
- Revised rear cockpit trim and no central locking

Body Stiffness – torsional stiffness of the bodywork has been improved with the addition of a titanium front strut tower bar, cargo area brace, additional steel plating of the front strut towers and revised bracing of the engine bay inner guard to "A" pillar.

Spec C WRX STi

Improved Specification – modified fluid-filled engine mountings, revised waterspray tank reservoir. Changes to engine management calibration and boost pressure have raised peak torque to 422Nm on 17" wheel models, and is now matched to revised gear ratios. The 17" model features a front mounted engine oil cooler in order to cope with the increased cooling load on the engine. DCCD operation (See *Drivetrain* Chapter) has been further refined with the addition of yaw and steering angle inputs.

Sounds good? You bet, but before rushing off to your local Subaru dealer to place an order, keep in mind that unfortunately these super-special models are available to Japanese domestic customers and race teams alike.

7.6 New Age Subaru Performance Tuning

For what seems like an eternity, the Subaru go-fast market has mostly focused on very narrow aspects of performance tuning, without much effort being put into designing and developing enhancements that seamlessly integrate together, across the whole spectrum of performance tuning. This has been somewhat of a complaint of Subaru owners and enthusiasts alike. Often in the quest for more performance, the aftermarket will carve up in piecemeal fashion, hard-won design integrity and engineering that characterises the stock car. Obviously some performance workshops have done a far better job in this respect than others, but by and large there has been nothing that could be described as a revolution in Subaru performance tuning, until now.

Litchfield Type 25

Pic Litchfield Imports Type 25

Late in 2003 UK based performance vehicle re-seller, Litchfield Imports bucked the trend and went against current tuning philosophy by developing a serious package of performance upgrades with priority given to total integration with the car as a whole. Finally it was realised that a modified car should be better than just the sum total of its parts. Admittedly Litchfield had a marketing imperative, in that they planned to sell the JDM Spec C derivative of the Version VIII in the UK. But this car in standard trim is a bit basic, lacking electric windows and air conditioning. Instead of simply fitting fast glass and aircond, Litchfield to their credit decided to do something unique with the engine and chassis package, releasing their Type 25 concept as a complete car.

Engine

Even the JDM Spec C with it's high-tech twin scroll turbocharger, and titanium alloy turbine wheel is a bit of a slug down low in the RPM range. The Type 25 gets around this issue by using a brand new 2.5 litre short block from Subaru normally found in the USDM STi. The fragile OE hypereutectic pistons and OE conrods are replaced with heavy duty forged pistons and conrods, in addition to a blueprint and check of the cylinder block and crankshaft.

A big advantage of using the Spec C as a donor car for this type of conversion is its superior cylinder heads. These parts are significantly different from the normal European/US/Australian model parts, featuring more aggressive camshaft profiles and bigger intake and exhaust porting, with a much greater power potential. Once "tweaked", completed cylinder heads are fitted to the newly prepared engine block for reassembly of the engine.

Increased engine capacity, in addition to detail changes to the cylinder heads contribute to a big increase in the airflow potential of the engine. So much so, the OE VF36 twin scroll turbocharger is simply not big enough to support the required airflow rates, so Litchfield replace the IHI core with a larger turbine and compressor wheel combination, with the desired aim of increasing the useable RPM range, without hurting low end power delivery.

Sophisticated engine management rounds out the mechanical package. Litchfield called on the expertise of EcuTeK to assist with developing a custom factory ECU re-calibration optimised for the bigger engine, turbocharger and more efficient cylinder heads. Results are healthy, with Litchfield claiming 261kW @ 6,900 RPM and 428 Nm @ 3,650 RPM at the flywheel.

Chassis

Another of Litchfield's design ambitions was to create a suspension setup specifically for UK roads and the very different set of roadholding characteristics required to achieve this. Dutch shock absorber company AST, drawing heavily on an existing Subaru development project with Whiteline and their range of Group 4 performance shocks, developed a set of replacement shock absorbers and matching spring rates with this in mind. Other suspension improvements include Whiteline front and rear sway bars and front anti-lift kit. Braided brake hoses replace the OE rubber items for improved brake pedal feel.

What does this add up to? If the road-test articles are to be believed, a very special Impreza! Respected UK motoring magazine Autocar quoted the Type 25 as "*The best Impreza on planet earth*", while Japanese Performance magazine summed it up "*redefines driving excitement for this class of car*". High praise indeed, resulting in Litchfield raising the bar in Subaru performance tuning. Until now that is;

For more information on the Type 25, see www.type-25.co.uk

MRT Performance / Whiteline Automotive P25

Early in 2004, in a meeting between Brett Middleton of MRT Performance and Jim Gurieff of Whiteline, discussed the idea of creating an Australian interpretation of the Subaru total performance package concept, as a logical extension of their respective businesses. Both MRT and Whiteline have had a long held commitment towards focusing on the total design, rather than a group of individual parts. All that was left to decide was to either take the easy option and make something equivalent to the Type 25 for the same price or cheaper; or bite the bullet and develop a package of upgrades that costs a bit more, but comprehensively out-muscles the Type 25, setting a new benchmark in the process. Never one to miss an opportunity for a bit of good-natured rivalry, especially between Australia and England, the latter upgrade path (and the harder of the two) was chosen, and thus the P25 concept was born.

Pic The P25

Right from the very beginning, goals were set to produce a car that would set new standards for handling and performance that is refined, comfortable and easy to drive, and above all reliable enough to be a genuine every day driver. The aim was to take a DCCD equipped Australian spec Version VIII STi, and increase power by a minimum of 100kW over standard, along with a complete set of matching suspension modifications. If this was not enough of a challenge, MRT also set out to ensure that the car would be competitive, both on and off the track with the likes of a Porsche GT3, BMW CSL and other exotica.

How hard can this be? Take a stock STi, pull it to pieces, swap out all the flaky bits the factory skimped on to save a buck, bolt it all together, run it on the dyno and hey presto! It actually turned out to be a significantly harder job than first anticipated. Think about the task to hand; 100kW more than stock (that's 55% more power!), but with the following considerations:

- The finished car must be capable of being legally road registered and insured.
- 98 Octane pump fuel with no additives.
- An exhaust that conforms to 92dB noise regulations, has a catalytic converter and is emissions compliant.

- Standard looking engine bay, maintaining an engine bay mounted intercooler and OE airfilter assembly.
- Exhibit standard idle quality, driveability and greatly improved low-end torque, in addition to significantly more top end power.
- Fully compliant with all Subaru engine management diagnosis equipment, requiring only scheduled maintenance as specified by Subaru to suit extreme operating conditions, as outlined in the owners manual.
- Suspension system that is more compliant that stock, but capable of delivering significantly more grip.

Getting a WRX to make 100kW more power or handle better is not too difficult when take in isolation. But trying to achieve this in a complete turn-key package that does not significantly compromise stock levels of NVH and driveability, while meeting if not exceeding the expectations of a new car buyer is no mean feat.

The transplant

Engine

As with the Type 25, MRT use the EJ25 semi-closed deck block as the basis for the P-25 power-up package. Forged pistons and connecting rods replace the OE items, and it is interesting to note that MRT tested over four different sets of pistons, finally settling on a combination for the minimum amount of engine noise and oil consumption. The crankshaft is checked for bend and balanced. Engine bearing clearances are set to motorsport specification clearances. Modifications to the OE oil pump and cooling system round out cylinder block modifications.

Pic Heart of the P25

Getting the cylinder head combination right was the single biggest challenge faced by MRT's development team and caused easily the most amount of aggravation. Stock (non Spec C) STi cylinder heads to put it plainly suck, and severely limit peak airflow capability. No fewer than four different evolutions of cylinder head modifications, matching camshaft profiles and compression ratios were tested before finally coming up with exactly the right combination that interfaces completely with the OE AVCS system. Metal multi-layer headgaskets and high tensile head studs accurately attach the cylinder heads to the engine block. This is only but a few of the modifications carried out on the STi's engine as MRT are tight lipped on the content of the entire package.

Pic Test Turbochargers

Final turbocharger specification was another area that caused a large amount of grief for the P-25 development team with seven different combinations of bolt-on turbos tested. But this was more to do with the abysmal performance of the cylinder heads more than anything. Here is an extract taken from a development log recording one particular session of turbocharger testing:

"The P-25 was well and truly wired for sound inside the dyno test cell set-up on the Dynapack dyno, with probes recording exhaust back pressure pre-turbo, turbo manifold pressure, turbo intake restriction, turbo compressor outlet temperature and intercooler outlet temperature. Time to test turbo No6, as the previous five combinations had proved to be deficient in one way or another. The latest turbo uses a Garrett GT ball bearing core, and features turbine and compressor wheels a good 25% bigger in raw airflow terms, compared to the last unit, which in itself was no weakling.

Initial run-ups with the new turbo produced an immediate improvement, with both power and torque heading north over the previous best. Trouble is, although the engine had taken a step forward, it was by no means as large as expected.

Exhaust back-pressure testing showed no major problems, with the 3" turbo back exhaust system recording a tiny peak reading of 0.1 bar. Back-pressure before the turbocharger showed some interesting results, peaking at 2.4 bar, which considering that the engine was running in excess of 1.4 bar of boost, pointed towards the exhaust side of the turbo working very well. The general opinion was that the exhaust side of the turbo was doing its job, shifting the focus onto the compressor side.

On the very first run with temperature probes fitted to the turbocharger and intercooler, immediately it was clear that things were not working properly. Turbo compressor discharge temp hit an incredible peak reading of 205 DegC. "Houston we have a problem!" Incredibly, the OE STi intercooler was able to reduce peak outlet temperatures to 100 DegC, impressive performance for a stock part, but still a totally unacceptable reading. Such massive turbo discharge temperatures are a sure sign the turbo is running way outside of its efficiency range, but why?

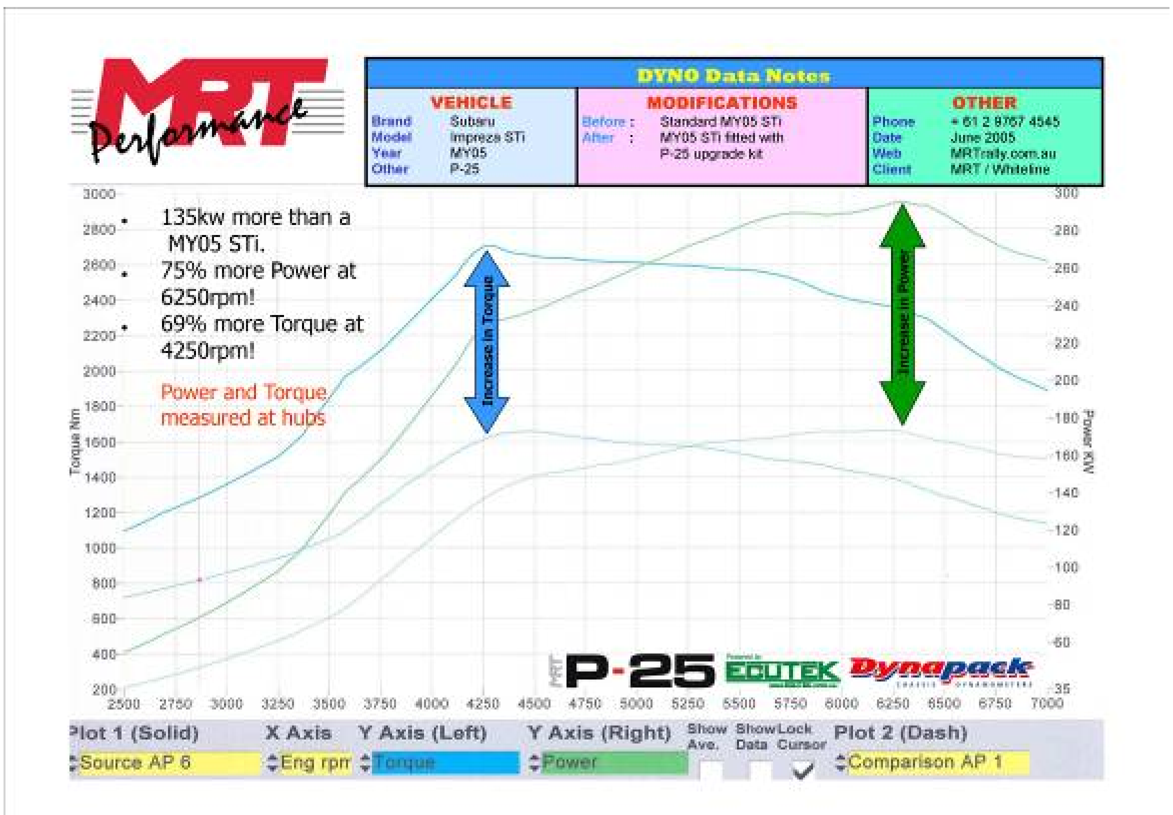
Over a coffee break, it was theorised that perhaps the intake system was a restriction, so pressure drops across the OE airfilter, air mass sensor and OE plastic turbo intake were tested. Surprisingly, both the OE airfilter and air mass sensor recorded barely measurable pressure drops. The turbo intake pipe was a different story, with a maximum pressure drop of 0.35 bar @ 7000 RPM, pointing to a significant intake restriction – but was it enough to explain such massive turbo discharge temperatures? The factory plastic turbo intake pipe was substituted for a large capacity silicone intake and the previous tests were repeated. Subsequent dyno tests showed a marginal increase in power, along with a 22 DegC reduction in turbo discharge temp. Encouraging, but still less than satisfactory. Rechecking turbo intake pressure drop showed that the new silicone intake had reduced pressure drop to under 0.10 bar at 1.4 bar manifold pressure.

Having literally run out of easy bolt-on options on hand it was decided to lower maximum boost pressure in small increments in order to determine peak operating pressure of the current turbo combination. In increments peak boost pressure was lowered, until finally at 1.2 bar boost the turbo hit a sweet-spot with discharge temps coming down out of the stratosphere to a more realistic 126 DegC. A measure of how fine the line was, even raising boost pressure by as little as 0.10 bar caused discharge temps to soar back up to 165 DegC. Comparison of the dyno graphs showed that although peak torque was lower at 1.2 bar, maximum horsepower was actually higher at the lower boost pressure than before.

Regardless of this, maximum power and torque was still well below the target level, so effectively it was back to square one. There were two schools of thought, those that believed that the turbo compressor was still too small, while other thought that it was the cylinder heads and camshaft profiles holding the engine back......"

Cylinder heads and cams turned out to be the key to finally making the P-25 come alive and earn a living, along with the addition of some specially made exhaust headers. But you get some appreciation of the difficulties faced by the engineering team, and an example of just a very small part of the development process, that included countless hours of dyno and track testing time.

An EcuTeK reflash of the OE engine management was used to re-map all critical operating parameters of the engine control system, including all important boost and detonation control. Fuel system upgrades consist of a heavy duty fuel pump, 650 cc injectors and billet high capacity fuel rails with twin pressure regulators. Final results vindicated all the effort spent getting everything right, with the engine punching out a sensational 297kW @ 6,250 RPM and 514Nm @ 4,250 RPM measured not at the engine flywheel, but at the hubs on MRT's Dynapack dyno.



P25 vs Std STi

Chassis

Even in stock standard form, late production DCCD equipped STi's handle well. But there are some noticeable shortcomings with the factory suspension setup. Corner attitude is still biased towards understeer, while shock and spring rates have the curious distinction of delivering a stiffly-sprung uncomfortable ride, but fails to deliver adequate suspension control when the going gets tough. The addition of an electronically controlled centre differential (DCCD) also brought a new set of suspension setup challenges, due to some very different torque distribution characteristics.

Whiteline spent a huge amount of development time both on the road and race track, perfecting the right combination of spring, sway bar and shock rates, along with suspension geometry and wheel alignment values. Even the OE tyres were carefully examined and figured into the final handling package. The stock Bridgestone Potenza's were found to provide healthy amounts of grip, but as they are hybrid road-intermediates are incredibly noisy transmitting a lot of NVH. At time of print Whiteline and MRT were still testing a variety of tyres so as to offer some replacement options as the stock tyre as fitted to the STi is actually not available in Australia.

Pic P25 Suspension Parts

After an equally exhaustive suspension development program, Whiteline achieved the desired aim of producing a suspension combination that offers better ride comfort and compliance over stock, but with racetrack levels of grip and handling proficiency. Whiteline's P-25 handling pack consists of:

- Whiteline Group 4 coil over premium shocks, adjustable bump and rebound damping and spring platform height.
- Motorsport grade coil springs.
- 22mm front and rear sway bars and poly urethane bushings.
- Front anti-lift/castor kit.
- Redesigned low compliance steering mountings.
- Front alloy strut tower brace.
- Rear camber adjusters and performance wheel alignment package.

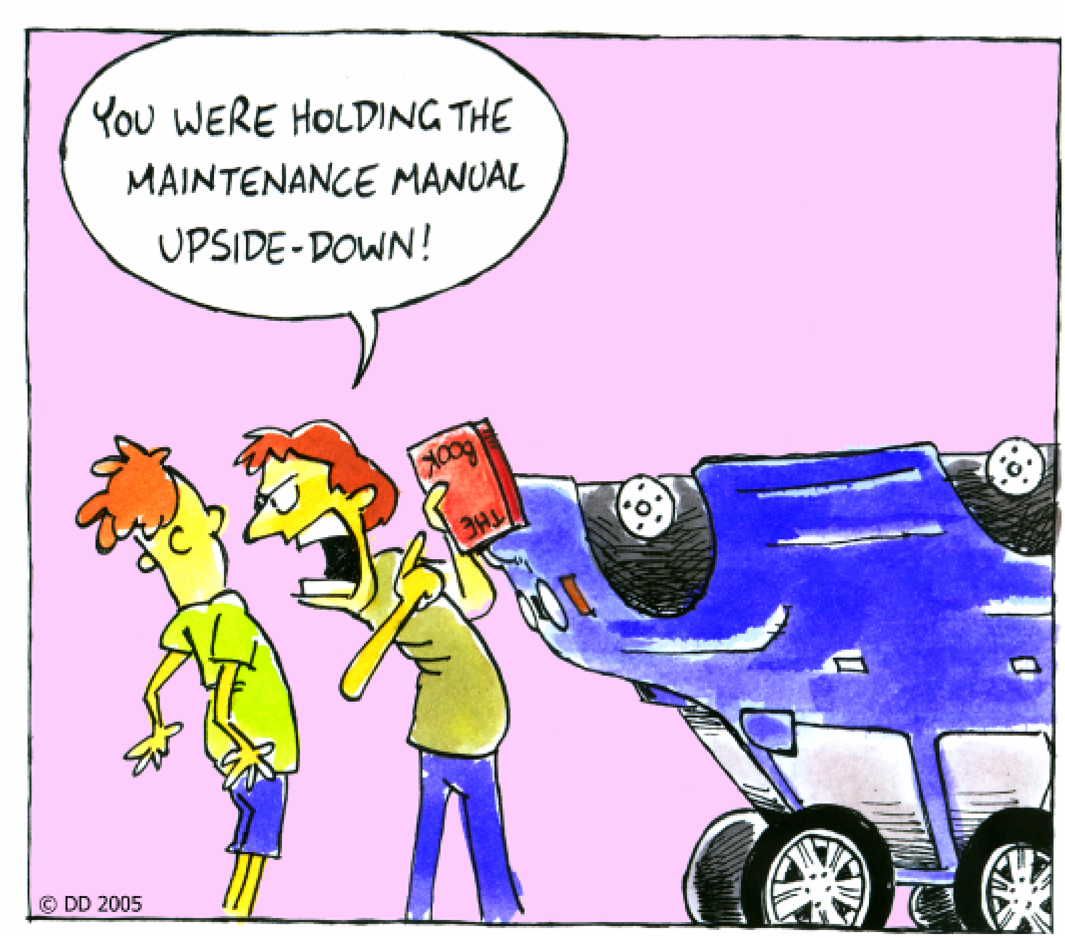
A further indication to the commitment towards maximising tyre grip on the P-25, all cars are corner weighted for precise adjustment of static weight distribution as part of the normal suspension setup of the car, prior to delivery to the customer.

For more information and the results of press evaluation of the P-25, which was too late for inclusion in this book, see www.mrtrally.com.au and www.whiteline.com.au/project/P-25.htm. On specifications alone, it is easy to see that a new benchmark in total performance product engineering has been set.

Hopefully this will act as an incentive for some of the other Subaru performance workshops to follow suit, and raise the cumulative level of engineering skill industry wide. After all, this type of engineering program results in improvements and techniques learned flowing on to a whole range of other performance products, benefiting all Subaru owners.

Testing Can be Fun

Chapter 8



Maintenance

Maintenance

Correct maintenance is essential for ensuring that your pride and joy continues to give long lasting and reliable service. Even if you do not have the time or equipment available to do your own maintenance, simply ensuring that those entrusted with the job on your behalf, will go a long way to boosting confidence in your car. Correct maintenance does not mean simply getting the local garage for a $49.99 grease and oil change. The WRX requires its own specialised servicing procedures. These are clearly detailed in the owner's manual. As an enthusiast owner, you will of course have read this from cover to cover.

8.1 Maintenance Checks

Your WRX is a high performance car that has the job of carrying you, your family and friends at speed, so treat it accordingly. In addition to routine scheduled maintenance, get into the habit of checking the car on a weekly basis.

Pay particular attention to the following items:

Tyres – should be round and black! Seriously, do not confine your checks to just the tyre pressures alone. Look in under the wheel arch and check the state of tread wear. Are you familiar with the tread wear indicators moulded into the face of each tyre?

A War Story

Not that long ago a client dropped a WRX into MRT for some work. He described the car as needing a "good service" as it's a bit down on power and sounds funny. He also added that money has been tight of late, so it has been awhile since the car was last serviced. On removal of the sump plug to drain the engine oil, only a couple of evil smelling black blobs of treacle-like substance came out. 20,000Km of neglect and hard driving had turned the oil in his engine into sludge, and the odd sounding noises from the engine were its bearings crying enough! Needless to say that money for the unfortunate owner is even tighter now after paying for a full engine re-build. We can only hope he didn't have to live on pet food for 6 months as a result.

Pic Tread Wear Indicator

Are the tyres wearing unevenly? The early stages of premature tyre wear can often be tricky to spot, so if doubt check with your tyre re-seller. An cheap and easy to fix wheel alignment problem can very quickly ruin a set of expensive rubber. While checking the wheels, don't neglect the spare! See chapter on *Wheels and Tyres* for more detailed information regarding tyre pressures.

Under car checks – prior to grubbing around under your car, take a good look at where it was parked. Pay particular attention to the ground under the engine and transmission. Any serious leaks from the powertrain should be immediately obvious. If your can see any evidence of fluid leaks, wipe down the offending component and then check all engine bay levels to ensure that nothing is dangerously low on one fluid or anther. Then take the car for a short drive and re-check. If in this short period of time, a significant amount of fluid has reappeared, "Houston, we have a problem", seek professional advice.

Oil Filler Cap and Dipstick

Engine oil – check the engine oil level from the dipstick. The best time to do so is first thing in the morning, when the car is cold and all the oil is back in the sump. Make sure that the car is on level ground; otherwise any sort of angle can lead to an incorrect reading. Between the full and empty lines on the dipstick is exactly one litre. Don't ask how many fluid ounces, pints or fractions of an imperial gallon this is. Top up the engine with oil of the same viscosity rating that is already in your engine. If you are unsure about what it should be, check with your service agent.

Not as Thick as Some

Back in the not too distant past, before the advent of multi-grade engine oils, those living in cold climes were faced with yearly oil changes in tune with the changing seasons. That is, using engine oil with a thinner grade during winter and thicker stuff for summer. This is pretty much a thing of the past now, as modern oils have special long chain polymers added that keep oil thin at very low temperatures. Then as if almost by magic, they progressively thicken as the temperature increases. Reading viscosity numbers is not difficult, 5W-30 oil as an example, the first number denotes its thickness at low temperature, which in this case is suitable for temperatures as low as minus 25 Deg C, (or lower) while the final number is its thickness rating for up to a maximum of 40 Deg C ambient temperature. More is not necessarily better, as there is a definite fuel economy advantage with lower viscosity oils, as less energy is used driving engine parts through thinner oil. This means power will be down slightly and fuel consumption slightly higher, when using 20W-50 oil in ambient temperatures that are better suited to 5W-30.

Remember that it is possible to have too much of a good thing. Do not be tempted to overfill your engine with oil, as this can raise the oil level in the sump high enough to interfere with the crankshaft, causing foaming of the oil, which in turn can create problems with boost and variable cam control solenoids. Subaru recommends engine oil with a SAE viscosity rating of 5W-30 for turbo engines operating in climactic conditions ranging from below zero Celsius (or lower), up to a maximum ambient temperature of + 40 Deg C. This is a very broad range and should be satisfactory for the majority of owners. However, Subaru does have the following caveat in the WRX owners manual as final word on engine oil. "If the vehicle is used in desert areas, in areas with very high temperatures, or used for heavy duty applications such as towing a trailer, use oil with the following grade and viscosities are recommended:" *API classification SL or SJ and SAE viscosity number 30 or 40, 10W-50, 20W-40, 20W-50.* See chapters *Engine Mechanical* and *Track Days* for more information on engine oils.

Autotrans Dipstick

Version I-II Power Steering

Version V-VI Power Steering   *VersionVII-VII Power Steering*

High Performance Gear Oils
Many owners report useful improvements in gear shifting and general feel after switching to synthetic gear oil.
Especially relevant as transmissions begin to age and get hard to shift. See *Drivetrain* chapter for more information.

Automatic Transmission and Power Steering Oil – the fluid in both the power steering and auto transmission (if fitted) should be a translucent red colour. If it is very dirty or has a strong burnt odour (don't be afraid to give it a bit of a sniff), have the offending system flushed and the fluid replaced. For both auto transmission and power steering, fluid levels should be checked with the engine running and at operating temperature. When checking the transmission, make sure that the gear lever is in "park". Do not overfill either the power steering or auto transmission, the type of hydraulic fluid they use expands greatly when hot. An over-full transmission or power steering will result in messy oil leakage, and erratic transmission operation. Use only the recommended grade of automatic transmission fluid as outlined in the owner's manual. The wrong grade of fluid can seriously reduce the lifespan of your transmission.

Manual Transmission Level Dipstick

Manual transmission oil – Subaru conveniently fit a dedicated dipstick for checking the oil level in the transmission. The engine must be switched off, and is best done when cold and on level ground. Manual transmission oil should be a translucent yellow in colour with a slight odour of Sulphur. Black, burnt smelling or contamination from metallic particles all signal some sort of trouble with the manual transmission. Seek professional advice. Again, don't overfill with oil and check your owner's manual for the correct grade. See chapter on *Drivetrain* for more information.

Version I-II Overflow Bottle

Version VII-VIII Overflow Bottle

Coolant – engine coolant level is checked by inspecting the level in the overflow bottle. If the engine is cold, the coolant level should be close to, or on the low mark. Once the engine is hot and at operating temperature, the coolant level will move closer to the full mark due to expansion. If topping up is required, add a mixture of clean (preferably de-mineralised) water and high quality engine coolant. Always try to top up the cooling system with the same brand of coolant that is already in the engine. In some situations, coolants from different manufacturers mixed together can sometimes reduce the coolants anti-corrosion properties. The cooling system should rarely need topping up, and if you find that repeated refills are required, have the cooling system inspected for leaks and defects. If the cooling system is critically low on coolant after a leak, refilling is via the header tank that is bolted to the top of the engine. Do not remove the pressure cap when the engine is hot, as the header tank makes up a part of the pressurised cooling system of the engine. Serious burns can result from removing the pressure cap on a hot engine.


Version I-II Header Tank


Version III-VI Header Tank


Version VII Header Tank

As a side note, Version I-II header tanks are prone to springing leaks without warning, while paint chips found on the inside of the tank can interfere with the sealing of the pressure cap. See the *Cooling System* chapter for more detail.

Radiator hoses – both top and bottom hoses should be checked visually for any signs of leakage or damage. On a cold engine, hose condition can be checked by giving them a good squeeze. If they are not soft and pliable in feel, they are beginning to age, and may need to be replaced.


Subaru Radiator Hoses

Brake and clutch fluid – before checking fluid levels, always ensure that the area around the filler caps is clean and free of contaminants before removal. Brake fluid comes in a variety of colours, but as a general rule it should never be heavily discoloured or dirty in appearance. If this is the case, have the brake system flushed and the brake fluid replaced. Low brake fluid can indicate two things; the first being a sign that the brake pads are wearing low. As the brake pads wear, more fluid fills the calliper pots to compensate for the thinner pads, causing the fluid level to drop in the reservoir. Low fluid can also indicate a leak somewhere in the brake system. If required fluid top-ups are required, a serious fault may exist with your brakes. Have the braking system checked pronto, or a major failure of the brake system could be imminent. When topping up the system, use only fluid from a clean and unopened bottle. Brake fluid readily absorbs moisture from the atmosphere if left in an unsealed container, and will seriously reduce its resistance to boiling. See *Stopping the WRX* and *Track Days* for more details.

Drive belts – all accessory drive belts are easy to check and inspect, courtesy of the WRX's boxer layout. Best done with a cold engine that is not running, both the power steering/alternator and Airconditioner belts should deflect by no more than 10-15mm under firm thumb pressure. Inspect the small v-shaped ribs set into the belt. They should be in good condition and be free from major cracking.

Badly Worn multi-v Belt

Battery – The WRX draws a large amount of electrical power to drive all of its accessories, making the factory battery work extremely hard for its living. In warmer climes the battery will evaporate its electrolyte quite rapidly. As the level of electrolyte in the batter drops, it exposes the internals of the battery, sharply decreasing its lifespan. Check the battery terminals to make sure that they are clean and tight. If there is a build up of white acidic deposits on the battery terminals, a solution of hot water and sodium bicarbonate (baking soda/power) will safely neutralise the acid. Note! Use extreme caution to ensure that you don't get acid in eyes or over exposed skin, clothing or paintwork. Battery acid is extremely corrosive. Treat with care.

Heavy Duty Battery

Windscreen washers/wipers – lift the windscreen wipers and check the blades for wear and damage. Wiping the blades with a soft cloth removes road grim and other gunk, improving wiper operation. When adding detergent to the screen wash reservoir, go easy, especially if it supplies water for an intercooler spray system, or you could have a bubble bath on top of your intercooler. For those that live in a part of the world where you can go skiing in your own backyard, and have an intercooler spray system with a separate reservoir, don't forget to add antifreeze to this as well as the screen wash reservoir. This will protect the intercooler waterspray system from pump damage due to freezing.

A War Story

How much trouble can a simple spark plug cause? Recently a customer found out the hard way after fitting some "performance" plugs to his WRX. Claimed to be the latest word in platinum tipped, plasma shaping electrode technology blah, blah, they didn't cause a problem immediately, but within a short period of time the WRX started cutting out intermittently. Many hundreds of dollars in labour later and a lot of time spent off the road, the mysterious cutting out problem was solved by simply fitting the stock NGK plugs back in. It seems that the replacement plugs were causing harmful electrical interference, playing havoc with the immobiliser system fitted to Aussie WRX's

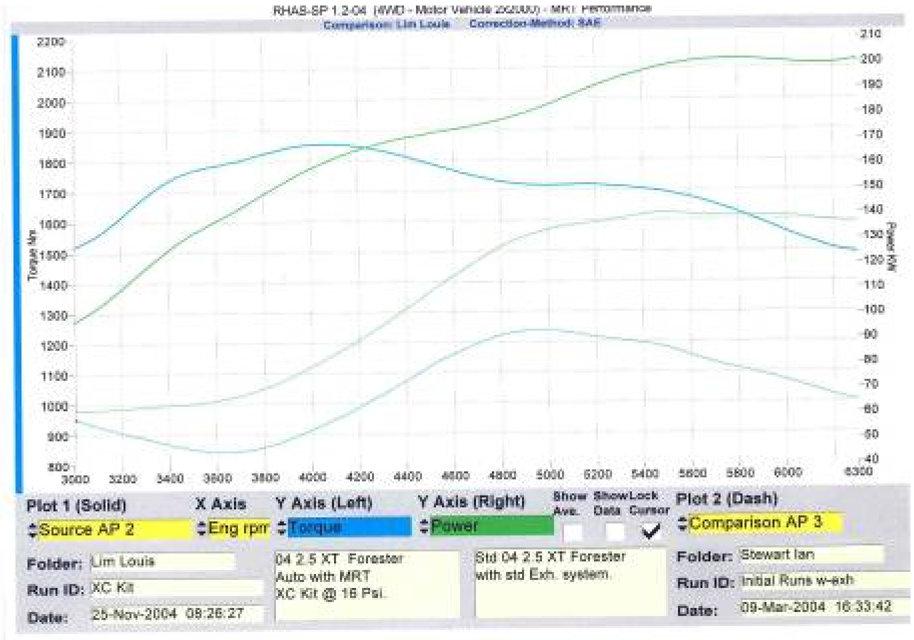
8.2 Extreme operating conditions

The WRX will benefit from additional servicing if subjected to harsh operating conditions. These include driving the car hard or track racing it; operating in harsh climactic extremes and / or dusty and unpaved roads. Driving a prolonged high speeds, towing or even repeated cold starts followed by short trips than never get the engine up to operating temperature, all require additional servicing. If your car is modified and is making more power over stock, extra load will be placed on the entire drivetrain, so don't skimp on servicing. Check with your workshop for advice if unsure. If they don't know they should. Find another workshop! As a general suggestion, performing intermediate oil and filter changes between the recommended Subaru service intervals will help prolong the service life of your car.

8.3 Spark Plugs

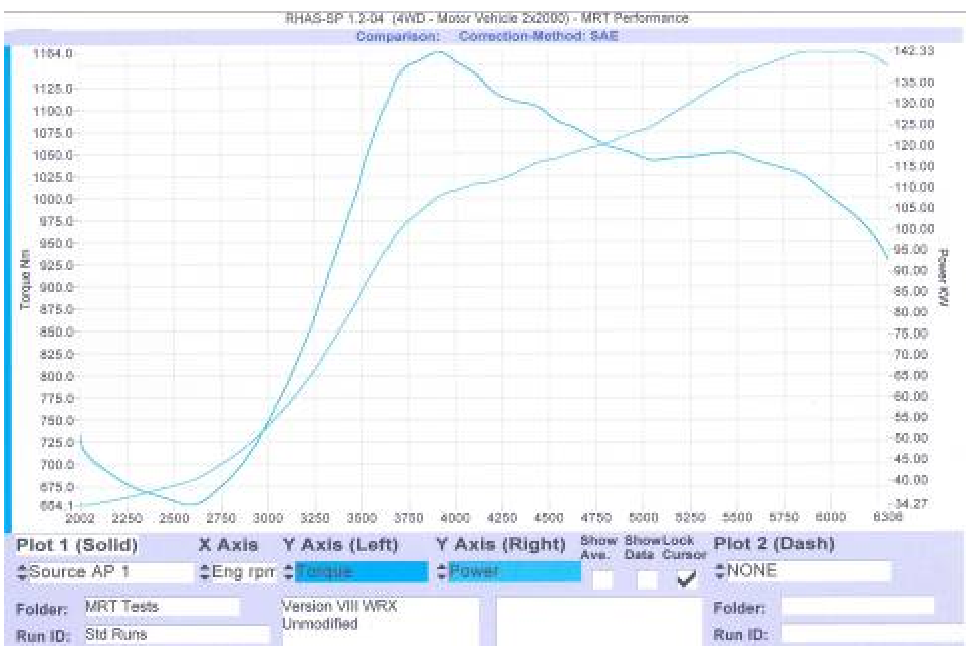
Platinum Spark Plugs

Platinum tipped spark plugs are fitted as standard to the WRX engine. Subaru recommend a spark plug change interval of 50,000km, however the use of fuel additives or leaded fuel will reduce this figure, while easy use (highway driving) will prolong plug life. Some manufacturers use platinum tipped spark plugs on turbocharged engines and quote change intervals of 100,000 km or more. What can we infer from this? Not much. At A$30 each you make the decision. If fitting the plugs yourself (not recommended unless you enjoy pain) pre-gap them to 0.75mm (or slightly less for high turbo boost). MRT recommend you switch them at the recommended 50,000 km interval. It may be superfluous, but your WRX is worth it. Keep the old plugs as spares. (See *Engine Management* Chapter for more details)



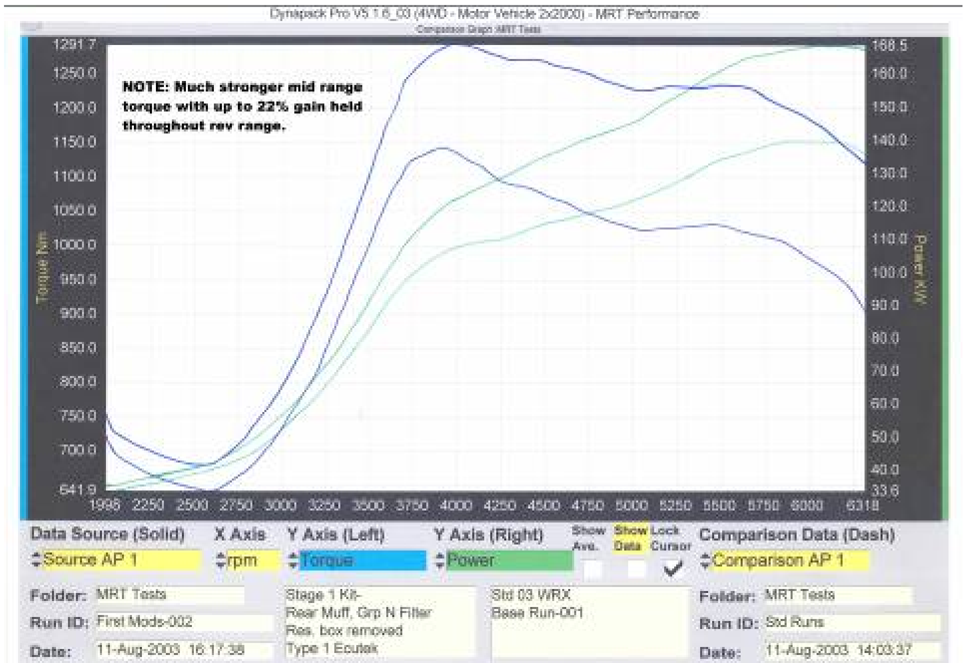
Dyno Graph Before and After

Most dyno printouts will have the test results graphed against three main parameters, engine RPM (or road speed), tractive effort (torque applied to the wheels) and actual power at the wheels. As touched on before, any type of chassis dyno that rates power and torque as flywheel is only estimating actual engine power figures, so we will only look at what is being delivered to the roadway.



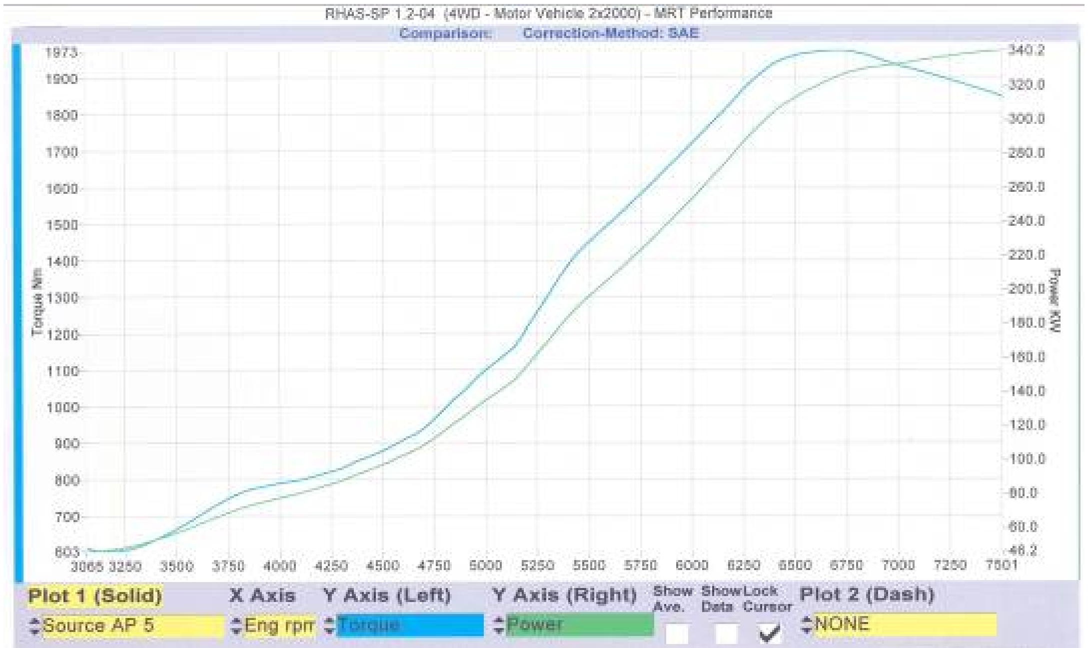
Version VIII WRX Unmodified

A standard un-modified car is a good starting point when analysing dyno curves, and are a direct product of all the cost vs performance constraints facing the manufacturer. It is never going to set the world on fire, but it is pleasant and un-offensive to drive, and more than likely will still be running in 10 years time given the right servicing. Key features of the standard car is the way power and torque build quickly, with maximum torque around 3,600 RPM with a nice spread right up until 5,600 RPM, at which point it starts to drop away. Power builds nicely all the way till about 6,000 RPM, where it gets a bit breathless and beginning to taper away close to the redline.



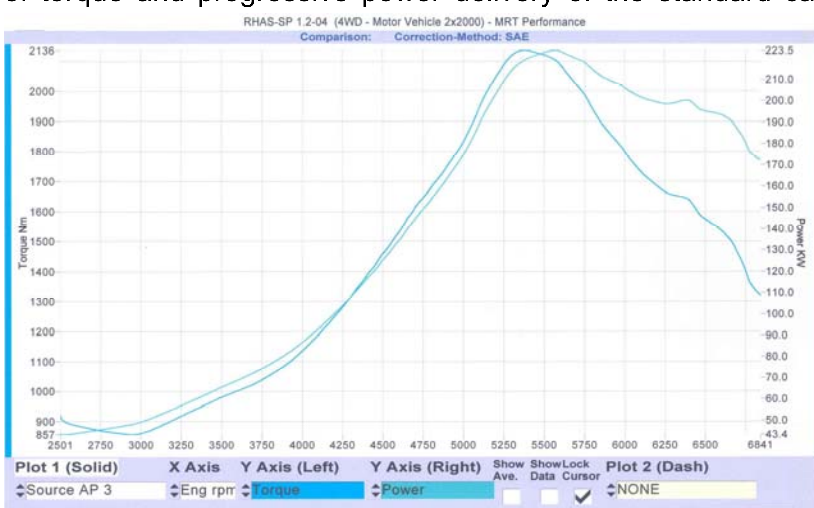
Version VIII WRX Std vs Modified

Looking at the same cars dyno graph after a few simple mods the differences may not be immediately noticeable in its shape, except that it has got a lot more power and torque everywhere, especially at the top end where power does not drop off as significantly. On the road this car will feel a much better device to drive, that is quicker and most importantly more fun, without compromising any of the standard cars driveability.



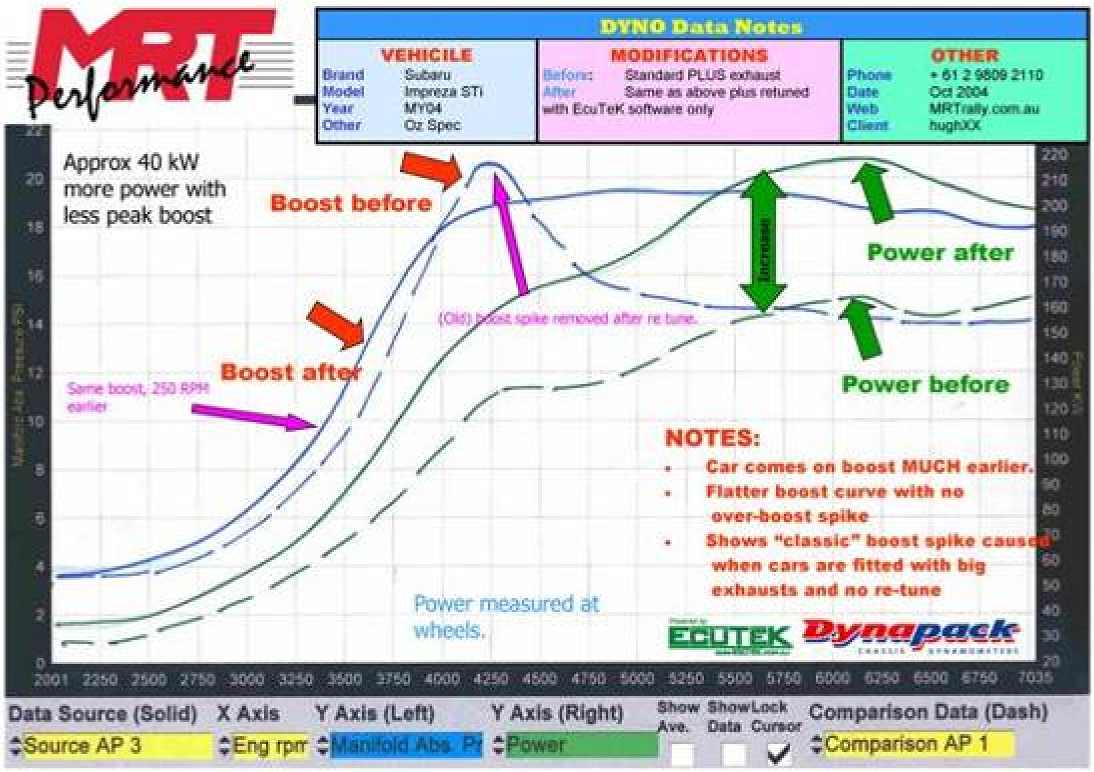
Low Compression Engine Big Turbo Top-End Screamer

Next is a dyno curve that demonstrates when no compromises are made when it comes to the goal of achieving maximum power, a no holds barred effort, featuring a specially built low compression 2.0ltr engine, big cams, ported head, large throttle bodies, intake manifold plenum and a massive turbocharger. The engine makes enormous amounts of power, but completely gone is the nice spread of torque and progressive power delivery of the standard car. Between 5,200 RPM and 6,200 RPM engine power jumps massively from 145kW to 300kW, that's 200Hp in the old numbers! Peak torque is achieved at 6,500 RPM and as long as engine RPMs are kept between 6,200 and 7,500 (its rev limit) the car is devastatingly quick to drive, if you are brave enough to keep the throttle nailed to the floorboards. Totally impractical for day to day driving and you certainly wouldn't lend it to Granny for drive down to the shops for a litre of milk!



Turbo Too Small For Engine Configuration

Then there is the case where good work has been let down through a miss-match of parts. Right up until 5,900 RPM both power and torque are increasing smoothly and strongly, at which point due to poorly selected turbocharger combination, the engine hits a brick wall and runs right out of breath. Torque drops off steeply heading south at a rapid rate, as does power, dropping by a massive 40kW towards the redline. Being too small, the turbocharger simply cannot flow enough air to maintain power and torque high in the RPM band. Out on the road the car is seriously quick, until 6,000 RPM, where it really starts to struggle alarmingly for the last 1,000 RPM before the rev limiter kicks in. Not a nice feeling!



STi Boost Spike Cause by 3 inch Exhaust System

The last dyno graph illustrates the pitfalls of modifications without matching engine management modifications. This Version VII STi had almost every bolt-on known to man fitted up, but with all the extra airflow potential generated by a 3" exhaust system, the factory computer could no longer control boost properly, going into a self-protection mode, causing the terrible lumps and bumps in the power and torque curves. Out on the road the car drove as bad as it looks on paper.

Dynapack Dyno On-Site

Dyno Scaling
Does your "monster tune" WRX dyno graph look like a couple of sickly worms all on their own in the middle of the page? Don't despair; it could just be a case of the scales needing adjusting on the X, Y and Z axis of the printout.
Even a 300kW stove hot Subaru power curve will look anaemic, if it is lost in the middle of a power scale that goes from 0 to 1,000kW, the same goes for poorly selected torque and RPM scaling. Check with your dyno operator if unsure.

Dyno graphs are an excellent source of information, and any serious tuner will have dyno graphs that clearly show power and torque curves both before and after modifications are carried out, clearly indicating what the gains are, and how that translates out on the road. Vague assertions that an exhaust will do this, or part X is guaranteed to double power no longer holds weight without supporting documentation to back up such claims.

Poorly Scaled Dyno Graph

Chapter 9

Suspension

Suspension

In this chapter we will be discussing what suspends your WRX and keeps it from dragging on the ground. As this book is written for the enthusiast driver, we will also attempt to explain some of the theory behind how to improve the handling of your car, and assist you to make some sense of the bewildering array of products and advice out there. Be advised, this section deals improving suspension performance. Dropping your WRX onto its bump stops just to make it look good is a cosmetic improvement only, and will turn your well-engineered Subaru into an evil handling device.

Making sense of it all

Listening to wise people dispensing suspension system advice can be a confusing and sometimes frustrating process, like trying to program a VCR using instructions written in Swahili. While it would be impractical to list all suspension-related terms, here are a few key definitions;

Camber – the angle of a wheels centreline compared to vertical. Negative camber is most desirable, and this is when the top of the wheel tilts in slightly in comparison to the bottom when viewed from the front.

Caster – The angle between the vehicles steering axis and a vertical line, as viewed from the side. Positive caster is most desirable and is when the steering axis leans toward the rear of the car, like a shopping trolley wheel but reversed.

Toe - The difference between the front and rear edges of tyres mounted on an axle. Toe-in means the front edges are closer together than the rear edges and tyres point inward. Toe-out is the opposite, with the front edges are farther apart than the rear edges and the tyres point outward.

Roll – During cornering, weight is transferred from one side to the other towards the outside of the corner, causing the chassis to “lean” in the same direction.

Roll Centre – The theoretical vertical point (either front or rear) around which a vehicle will roll during cornering.

Pitch – When weight is transferred resulting up and down movement across the front or rear axles or wheel pairs in opposing movements from moments of either acceleration or deceleration.

Heave – Synchronous motion of the entire vehicle or suspension system in either compression or rebound.

Warp – The suspension state that occurs when there is movement chiefly in pairs. This can be across a single axle or wheel pair, where one wheel compresses while the other extends. Or between two axles or two sets of wheel pairs (front and rear), one axle “twists” in one direction and the other axle “twists” in an opposite direction. The final example is between diagonal wheel pairs, such as the situation where the right front wheel compresses and the left rear wheel extends.

Spring Rate – Describes the stiffness of a spring, or resistance to compression. Can either be *progressive* where a spring will get stiffer the more it is compressed, or *linear*, maintaining a uniform stiffness throughout its span of travel. Expressed in Newtons per millimetre.

Shock Absorber Rate – The programmed way in which a shock absorber damps energy released by the oscillation of a spring. Shock rates are expressed in Newtons per millimetre of travel for a given shock shaft velocity.

Unsprung weight – Parts of the suspension system that is not directly suspended by the spring such as the tyre, wheel, wheel hub and portions of the control arms. This mass inhibits the speed at which the suspension responds to changes in road conditions.

Understeer – Handling characteristic whereby the front of the car “pushes” and runs wide of the corners apex. The front begins to loose grip first in relation to the rear wheels.

Oversteer – Handling characteristic whereby the rear of the car becomes “loose” and runs wide of the corners apex, often attempting to swap ends with the front. The rear begins to loose grip first in relation to the front wheels.

Static – Suspension characteristics as they exist with the vehicle stationary. Typically used in terms of alignment, geometry and weight distribution.

Dynamic – Suspension characteristics under the influence of motion and prevailing road conditions.

9.1 Standard WRX Suspension Overview

Front Suspension *Rear Suspension*

The WRX has McPherson struts front and rear. Spring and shock absorber functions are combined into a single unit integral with lower control arms front and rear. Sway bars are fitted front and rear. It is a suspension system that has roots dating back to the Liberty / Legacy models of the late eighties, a simple and effective suspension layout. Even Subaru's all-new Version VII Impreza continues to use the front and rear strut theme. Early on in the design phase of the Version VII it was decided to continue with McPherson struts at the rear because of its strength and reliability in motorsport applications.

What's In a Name?
Shock absorbers and sway bars are words used extensively throughout the suspension chapter. But just to muddy the situation, are also known as dampers and stabiliser bars in other parts of the English speaking world, despite being one and the same part. For the sake of consistency, and to reduce the propagation of confusion the aforementioned names will not be used. Oh, and just to clear the air completely, shock absorbers don't actually soak up road shocks, while the addition of sway bars are not going to have your WRX wobbling drunkenly down the road. Clear? Excellent!

9.1.1 Front Suspension

Version VIII STi Front Suspension

The WRX front suspension features an "L" shaped metal lower control arm that is anchored at one end to the engine cross-member and to the chassis rail at the other. (STi models and non-North American version VII and later WRXs use cast alloy arms to reduce unsprung weight.) The front control arms are rubber bushed at both mounting points and ball-jointed to the wheel hubs. Caster is preset by the positioning of the control arm to chassis bushing along with strut top location in relation to the lower control arm, and is not adjustable in standard form.

The newer Version VII WRX has additional caster pre-set into its suspension system, as the front suspension strut towers have been moved further rearwards and closer to the firewall in comparison to the old GC8 body, which is a welcome improvement. Camber adjustment of the front is possible by altering the strut to wheel hub mounting angle, using a factory supplied eccentric strut clevis to hub bolt. Toe adjustment is made by adjustable steering tie-rod ends. A sway bar is used to control body roll, linking left and right control arms and is attached via rubber bushings to the front suspension cross-member. Subaru replaced the old rubber bushed type nylon sway bar links with ball type units for the Version VII WRX, and are similar to those units previously used in the GC8 Version IV and V STi. The front springs are progressive rate and damping is achieved by twin-tube gas pressurised double acting hydraulic shock absorbers. Most late model STi versions use inverted mono-tube gas pressurised shocks. Steering inputs are transmitted to the front wheels by a variable ratio power assisted rack and pinion unit. Steering mounts were re-designed for the Version VII and again for the current model Version IX.

10.1.2 Rear Suspension

Version VIII STi Rear Suspension
(Tarmac Rally car)

Four lateral control arms and two trailing arms make up the rear suspension. The front bushings on these trailing arms behave similar to a tramp rod, allowing some vertical movement and rocking of the rear drivetrain to improve NVH, dampening actual dynamic throttle behaviour. Control arms are attached in pairs along with one trailing arm to each wheel hub at one end, and the chassis at the other. All control arms and trailing arms are rubber bushed at both ends. Camber is preset from the factory and has no standard means of adjustment. Toe angles are set by adjusting the rearmost control arm to chassis mounting point by means of an eccentric bolt. A stabiliser is also used at the rear to control body roll, linking left and right lateral control arms and is attached via rubber bushings bolted to a very tall chassis mounted bracket. Sway bar links even on Version VII and later WRX's retain the same plastic and rubber bushed items as used on previous models. Only the STi pick up the trick ball type links. Rear springs are progressive rate, and shock absorbers are twin-tube double acting units.

10.1.3 On-Road Behaviour

Like most cars, Subaru has tuned the suspension settings of a standard WRX to cater for a wide range of drivers. This means handling characteristics have been set for the lowest common denominator, or drivers with dubious skill levels, and those that demand ride comfort over performance. Understeer is almost universally considered the safest handling trait for average drivers, so understeer you get, and plenty of it. Unfortunately, understeer is not a lot of fun for the enthusiast driver, and is ultimately far slower than a neutrally handling car.

So what has Subaru done to "dial" an understeering attitude into the car's chassis? Once this is understood it becomes easier to appreciate the manner in which we go about improving the situation, to achieve more neutral behaviour. The biggest single factor influencing this trait actually has nothing to do with the suspension, and is a trait of the AWD system used by Subaru. Covered in more detail in *The Drivetrain* chapter, all Subaru's that do not use the new six-speed transmission can be described as having front torque biased AWD, and will *always* understeer because of the competing grip functions between steering and drive.

Drivetrain characteristics aside, two main areas of suspension design can be identified as the cause of this generous understeer. Firstly there is the conservative front and rear roll-stiffness ratios Subaru's suspension engineers have chosen for the car, while compromised front suspension geometry is the second technique used. Both points can be mitigated, and will be covered in detail later on in this chapter.

However, it should be noted, that a couple of important changes were made to the Version VII, specifically widening of the front and rear track by 20mm and an increase in the rear roll centre height of 33mm, contributing to a seemingly more neutral corner attitude. This coupled with some additional positive caster from chassis changes, Version VII and onwards WRX and STi have significantly improved turn-in feel compared to the old GC. Curiously, these changes (caster increase and roll centre changes excepted) were not transferred to the Version VII 5 door wagon, sticking instead sticking with GC track dimensions, making this variant a truly different animal to drive, with noticeably inferior turn-in.

Driven to Distraction

A bit of a mouthful, but an important concept nevertheless, is that AWD does not increase a vehicle's capacity for mechanical grip, as this is influenced by factors such as weight distribution, tyres, geometry etc. Instead, AWD as used by the WRX dramatically increases the size of the available median performance envelope, while at the same time flattering less skilled drivers. In plain English, a driver of an AWD can operate the throttle pedal without much consideration to subtlety, using a pair of the proverbial size nine work boots, and get away with it. Compared this with the driver of a high powered 2WD car, who needs ballet shoes and a softly, softly approach when squeezing on the loud pedal.

In summary, the newer GD sedan series car is a much better handling device than the old GC, however, the fact remains that the WRX is still only an average handling car that is carried by its excellent all-wheel drive traction. Sorry if this offends, but when back to back compared to other "performance" cars on the market, a prime example being the highly responsive Mitsubishi Evolution series, the WRX is still a bit of a blunt instrument. When pushed hard the WRX behaves more like an overloaded front wheel drive car, rather than a "sporting" saloon. Its excellent traction saves it from mediocrity, but with plenty of scope for further improvement.

9.2 Suspension Components and their purpose

Tyres

Yes, they are an important part of your suspension, in fact the most important performance component in the suspension system and is the only link to the road. Everything discussed in this chapter (in fact anything in this book relating to increasing performance) revolves around maximising contact between tyres and the road surface, and the relationship between suspension settings for a given type of tyre class. Covered in more detail in the chapter *Track Days*, we will concentrate on improved suspension for use with high performance road tyres, and not slicks in this section. You may have fitted the world's best and most expensive suspension components, or an enormously powerful engine, but if your tyres are poor quality or badly worn, you probably should have hidden the money in old socks under the bed.

Springs

OE Spring Set

The primary purpose of the spring is to control deflection of the suspension and absorb road "shocks" as the wheel rolls over bumps and dips in the road surface, keeping the tyre in constant contact with the road, and more mundanely, suspend the chassis from the road surface through a flexible mechanical connection to the wheel hub assembly. Actual spring rate selected is a compromise between three requirements; passenger ride comfort, load carrying ability and its influence on handling characteristics. When it is all done and dusted, a spring must delivery a "sporty" but comfortable ride, and at times be called onto carrying a full load of passengers and associated paraphernalia.

Sway Bars

Can be considered as an extra set of springs with the task of resisting the natural tendency for the car to roll or lean when cornering. Body roll reduces the tyre's contact patch with the roadway as it counteracts suspension geometry, while at the same time limiting the amount of weight transferred to the wheels actually doing the work, further reducing tyre grip. The same holds true when the vehicle is in warp. Sway bars are a major contributing factor towards redressing these negatives by resisting weight transfer in a controlled and tuneable fashion. It is not all undiluted joy, as they interfere with the independent travel of each wheel, especially over rough and broken road surfaces.

Pic WRX Rear Sway Bar

Shock Absorbers

A steel spring that is compressed and then released will continue to oscillate or bounce back and forward uncontrollably for a sizeable length of time, as the spring dissipates energy that has been put into it. A thrill seeker hanging off the end of a bungy cord is a good example of undamped oscillation. Suspension without shock absorbers would bounce its way down the road like a pogo stick from one bump to another. Apart from sea-sickness quickly setting in, controlling the car with any sort of precision would be an impossible task for the driver. An un-damped (or under-damped for that matter) suspension system fails in its primary purpose of keeping all four tyres in constant contact with the road under all circumstances.

Pic STi "Inverted" Shock Absorbers

Shock absorbers "damp" suspension oscillations and are calibrated or "valved" to do so in a controlled and predictable manner. Energy from both compression and extension moments of the springs are fed into the shock absorbers converting kinetic energy into the form of heat. A commonly overlooked fact is that the shock absorbers must also deal with and control any oscillation generated by sway bars in both roll and warp.

What's the Diff?
The introduction of the electronic centre differential control system (DCCD) on the STi for mainstream markets has opened up a new and far more complex world for suspension tuning. Although this system is extremely effective and elegant in its simplicity, it is extremely hard to explain to the average enthusiast. The exact engineering theory relating to how DCCD and other differentials work is a bit out of the scope of this manual. What can be said is that companies such as Whiteline are well on the way to delivering new products that use this exciting technology for chassis setup, and the never ending quest for better handling.

Suspension Geometry

Pic Version VIII STi Rear Control Arms

Is the specific way various suspension bits 'n pieces are mounted to the chassis, relative to the road surface. More importantly it also describes the way in which the suspension has been designed to react under different loads. Control arm design and the way it pivots can best be described as a series of levers. In the same way that increasing or decreasing leverage changes the amount of effort required to complete a task, changes to the suspensions geometry can be made to resist the cars tendency to "dive" under brakes and lift during acceleration. Further changes can be programmed in by the manufacturer by means of special bushings and links that "deform" in a controlled and predictable manner. This improves steering response and ultimate grip and is commonly referred to as "passive steering" or dynamic toe change, and is a very important suspension tuning technique in use nowadays.

Drivetrain

As touched on earlier on under On Road Behaviour, the setup of the drivetrain and the type of differentials used will have a large bearing on suspension settings such as alignment angles, toe and roll stiffness. A good example of this are the DCCD equipped STis and the new six speed transmission. Delivering approx 50% less torque to the front wheels when compared to the WRX, an STi with WRX spec suspension parts and settings is a recipe for a handling disaster, or conversely the other way around. See *Drivetrain* for more details.

9.3 Establish your Goals

We know that there is a good deal of improvement to be had in the WRX suspension system, but we need to look into this a bit deeper. What do you wish to achieve? Suspension professionals define "good handling" as revolving around predictability of response. That is, ultimate handling is not measured as the amount of understeer or oversteer, as this is too dependent on driver preference. However, a car that does not respond predictably and directly to driver inputs or the environment is a "bad handler", no question! While there are some good suspension modifications that are good value and have limited trade-offs, significant improvements in performance are going to come at a cost. Not just in cash, but ride comfort, road noise, and reduced ground clearance, requiring special care over speed-humps, traffic islands, driveways and off-road. Everything's a compromise, improving handling will come at the expense of something else, so be certain of what you want to achieve, and what you are prepared to give up.

Reality Check

A common mistake is to copy the suspension modifications used in certain categories of motor racing, especially the heavily restricted "show-room" standard class of racing, which forces competitors to sometimes resort to extreme measures being taken with the few modifications allowable by the rules. What works in this form of road-racing, or even off-road racing will not necessarily work when transplanted into your WRX. A good example is excessive lowering, as you cannot see what modifications have been done to suspension geometry to make the car work at this extra low ride height. If you are planning on some sort of semi-serious competition work, a balanced approach to modifications will give far better results and less stress on the car. See chapter on *Track Days* for more detail.

POWER V. HANDLING

Take two identical-model WRXs. Then, stage by stage, increase one's power output while working the other one's suspension – all to a realistic budget. At the end, which one'll lap quicker: The one with 40 extra kilowatts at the treads, or the one with nigh on five grand's worth of suspension mods? Or is the real winner a car with the lot done to it? Let's take a look… **WORDS:** Greg Conway **PHOTOS:** Brandon Thorne

Chosen for their unyielding popularity, relative ease of modification and easy availability of parts, these two GD-series MY03s proved the perfect guinea pigs for suspension stalwarts Whiteline and power-up people, MRT Performance. The mission? To firstly compare similar costed pure power improvements against pure suspension improvements (Round 1), then to see what changes would occur when both camps improve the alternate aspect mildly on each car within a similar cost budget (Round 2).

The cars: MRT Performance supplied its M-Power project vehicle which was initially tested with pure power mods as delivering 40kW more power, at the wheels, than standard. The M-Power car had been fitted with MRT's "Power X8 Kit", priced at A$3795.00 fitted (see full breakdown on page 103).

Whiteline Automotive supplied their P-Rex III project vehicle. At the outset, it had been fitted with purely suspension mods as contained within the company's "Handling Pack" (valued at A$839.00). This includes adjustable sway bars and critical alignment products (see full breakdown online). It also had Whiteline "Group 4" adjustable springs and shocks (value: A$3390.00) – Whiteline's new range of height and rate adjustable true 40mm mono-tube coil overs. Total cost: A$839.00 + A$3390.00 + A$560.00 (fitting) = A$4789.00.

Both had been fitted with Disc Brakes Australia (dba) 5000-series disc brake rotors (pictured above) and MRT Sports brake pad compounds.

"These were fitted to both test cars to increase the consistency of the lap times. Both cars were fitted with new pads and rotors and then bedded in the same. The dba rotors are a higher specification than the OEM rotors, the MRT Sports pads are also of a higher-spec than OEM. This means more laps, driven harder,

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will result in times that are less likely to be effected by brake fade," MRT Performance's Brett Middleton explained.

Whiteline's Jim Gurieff concurred, adding: "Brett and I decided that the demands of this sort of track test would be best served with a control brake package to avoid having to back off and nurse brakes when going hard – something that would be inevitable once we had some big power. So, even though they may not have been necessary in the first round, the lap times in Round 2 needed better brakes to avoid holding back or forcing the driver to compensate. The brake package used was typical of what a serious but atypical WRX owner would do in this situation."

The test method? Simulate both street and club/track conditions, bring out a bog-stock MY03 WRX as a control car, get the same experienced drivers to pedal 'em all (see breakout – 'The Drivers') and haul out a ute-load of measuring equipment (see breakout – 'The Measuring Equipment'), and data log/document every relevant variable back-to-back (ambient air temps/track temps/humidity all relatively constant) to show what each car does dynamically. It should be noted that tyre pressures were standardised at 40psi cold all 'round for all cars after consultation with veteran racer, Lakis Mantikas, based on his experience in club racing on standard tyres.

"We're looking at running as many variables out of the equation (as possible). That's why we've got the two drivers – both have different styles but both are good at what they do," Jim explained.

Standing Start

Location: Wakefield Park Raceway, Goulburn. Each of the cars sauntered up to the "wave on" line then, when given the signal to proceed, launched like all buggery up the entry lane. This was so the onboard EcuTeK Delta Dash Subaru ECU Logger and Race Technology Satellite Logger could capture each car's 0-100km/h time. Whiteline used their DL90 data logger and this was cross-referenced against MRT's "Digital Dash" unit to ensure reliability of readings.

Then they'd plant the pedal and get stuck into three hot laps before coming in to pit. Technicians from both camps would then pounce on the car with its smouldering brakes and furnace-like radiating heat.

Measurements were taken of brake rotor temperatures to give an indication of how hard / fast the car was driven. "These are an indicator of how hard each car needs to go to achieve an outcome," Jim Gurieff explains. "For example, more power and more speed without chassis balance would mean harder braking to get around a corner as the entry speed needs to be lower." He says it's not an absolute measure but it's interesting nonetheless for relativity and comparison purposes when doing this sort of test.

"It also allowed us to test our MRT Sports brake pads," Brett added.

Temperatures were also recorded for each brake pad, tyre, strut… plus the MRT top-mounted intercooler inlet and outlet.

"This allowed us to compare to our MRT replacement twin-entry top-mounted intercoolers as well as to back up, in future tests, with front-mounted intercooler data. This also effects the performance of the ECU as the OEM unit will add timing (and generate more power) when inlet temps at the throttle are lowered," Brett continued.

"By measuring and logging inlet temps with the after-track tests and with EcuTeK Delta Dash via the OEM ECU, we can measure any potential change in power, meaning if the car suddenly gets a colder inlet charge for some reason and it's noted in our logs, we can then check the related Ignition map within the OEM ECU and see if the Subaru ECU has added any timing and hence relate that back to any potential change in lap times that we may or may not want! Remember, we must be consistent when testing so, if a car is faster,

The MRT 'Power' car – What it's got

OE wheels, tyres and tyre pressures. DBA 5000-Series disc brake rotors at the front and DBA 4000-Series disc brake rotors rear (see p.100) with MRT Sports pads all 'round.

NB: An aftermarket MRT Performance top-mounted intercooler kit, fitted during the Round 2 test session, saw the MRT Power Car drop 0.5 seconds off its lap time. "It reduces the air intake temperatures for more power and allows increased airflow because there's less restriction," Brett Middleton explained.

MRT Power XB Kit (suitable for all MY99/00 and MY03 models; MY01/02 owners add catless uppipe):

- 1 x 3-inch MRT rear muffler (or Cannon-style muffler at no cost option)
- 1 x MRT centre pipe with high-flow cat
- 1 x MRT engine pipe with custom-fitted splitter turbo outlet for improved response
- 1 x MRT Cold Air Intake pipe with filter
- 1 x 400hp in-tank fuel pump replacement
- 1 x EcuTeK MRT Type 1.5 ECU software upgrade
- 1 x intake resonatorectomy and all labour to fit/tune/test vehicle

COST: A$3735.00 fitted

Fast Reference: www.MRTrally.com.au; www.Whiteline.com.au; www.EcuTeK.com.au

we need to know why, and not just assume it was due to a suspension change or such. At the same time we are getting more base data for later testing of further power upgrades," he added.

By now both cars were being photographed at various turns and travelling "at full noise" down the main straight. Jim Gorieff put it in perspective: "The speed down the straight is a function of two things: First, the driver's entry and exit speed. This is very important. Speed and, second, the amount of grunt under the right foot. Entry speed is important but exit speed more so, specifically how much power you can apply from apex to corner exit which in itself is a function of chassis balance and power," he said.

"In Round 2 we're seeing what happens when we upgrade the power by, say, 15 per cent, on a car that's got its suspension pretty much at the pinnacle in so far as road use, compared with a car that's got a 30 per cent increase over standard output with what would be typically a street suspension package which would be just springs and shocks really matched to work together."

Driver Brendan Helsham, a man with over 17 years' motorsport experience, said the differences in feel behind the wheel in Round 1 were readily apparent. "P-Rex III felt firm. It pitched only slightly across undulations (in the track). The car felt quite neutral. You can give it a little bit of throttle and just drive straight out (of the corners). It managed 165-170 kays on the straight," he reported.

The Round 1 MRT car left him frowning in contrast – not for any lack of power output but for its handling!

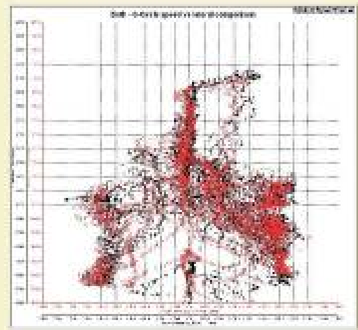
"It's really very lazy in the way it changes direction. A bit sloppy really."

Ex Bathurst racer and more senior steerer, Lakis Manolakis, thought he'd been a bit harsh. "I think it handles a bit better than my road car. Maybe the extra power makes the handling feel better. I expected a bit of understeer out of the MRT car but it was actually quite progressive."

The Whiteline car inspired confidence, Lakis said. "It's a lot more neutral. You can go into a corner a lot quicker. The car's a lot flatter – it doesn't transfer weight as much nor overload the tyres. You can sort of throw it around; there's none of that uncertainty – you know what it's going to do."

ROUND 2

The MRT Performance 'M-Power' car was upgraded with Whiteline's "Sports Pack – Control" kit, costed at A$1810.00 (plus A$350.00 fitting). Total: A$2160.00. This includes matched, lowered Whiteline Control grade springs and



Whiteline adjustable-rate sports shocks. A Whiteline wheel alignment was performed and the most appropriate settings implemented.

P-Rex III, in Round 2, was upgraded with MRT's "Power XA Kit", which delivered a dyno-tested and tuned 20kW more power at the wheels, at a fitted price of A$1695.00. This kit includes a new rear Cannon Muffler, new panel filter, intake modifications and a fully remapped Subaru ECU using EcuTeK tuning software. (refer to www.EcuTek.com.au).

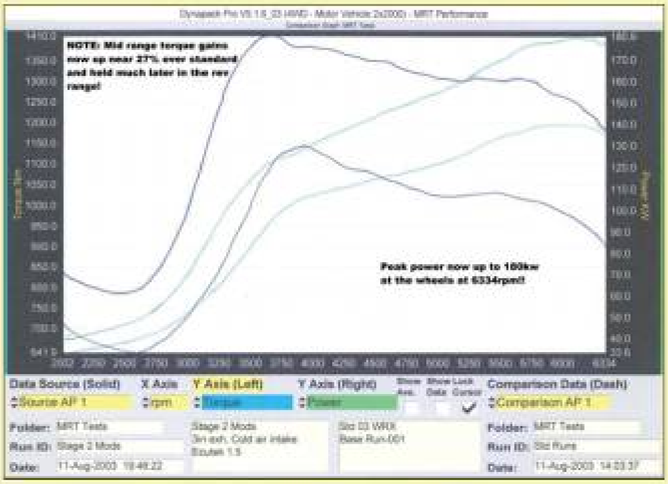
Total Round 2 costings: M-Power: A$5955.00; P-Rex III: A$6484.00.

Result: Money spent on chassis and suspension equals more grip and more speed.

FINAL RESULTS

Fastest lap, Round 1: MRT's M-Power at 2.30 seconds faster than the base MY03 WRX control car.

Fastest lap, Round 2 (after mods to each car): Whiteline's P-Rex III at 3.54 seconds faster than



the base MY03 WRX control car.

Quickest 0-100km/h, Round 1: Whiteline's P-Rex III at 6.05 seconds.

Quickest 0-100km/h, Round 2: MRT'S M-Power at 5.58 seconds.

Highest Top Speed, Round 1: M-Power, with 171.2km/h.

Highest Top Speed, Round 2: P-Rex III, with 174.8km/h.

General: P-Rex III has the highest cornering speed and shortest incremental times in all cases, except the Turn 8 exit.

Round 1 saw 40kW (35%) more power overcome state of the suspension setup in lap times but only through acceleration between corners. Even with standard power, P-Rex III had consistently higher corner speeds only to be overcome on the straight. This is particularly evident in results of average time taken between turns 6 and 7 where the chassis is more important.

More power with out other changes does not automatically equate to faster standing start acceleration times. M-Power could not deliver the 35 per cent more power with standard suspension.

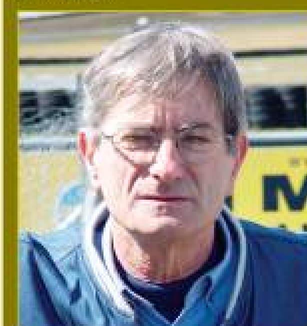
With better suspension in Round 2, M-Power was able to realise its power superiority in 0-100 km/h time.

Whiteline's Jim Gurieff continued: "So on the one hand we've got all the finesse with a little bit of power and on the other a lot of power with just a little bit of finesse with the chassis and we want to see what the difference is *vis* last time. Both cars are faster in every sense, but, given our testing, the one with all the chassis finesse marginally edges ahead.

"Both cars picked up a lot of ground, not just in lap times but they're generating consistently more G-forces. The Whiteline car can do that because it can carry a lot more speed, and so its exit speeds are higher which means it's generating a lot more G's, whereas the MRT car, which has got some suspension work compared to Round 1, so that extra power that it's had can actually be used and put down to the ground.

THE DRIVERS

Brendan Helsham
Age: 35
Occupation: IT Consultant
Experience: 17 years in motorsport; started with go-karting and club racing. "It's a hard thing to get out of the system."



Lakis Mantikas
Age: 55 years young
Occupation: Real Estate Consultant
Experience: Raced Minis for over a decade; also raced an RX-3, V6 Capri and a twin cam Escort. First raced in the Bathurst 1000 in 1966. Last raced there in 1978. Member of the Impreza WRX Club of NSW.

Power vs Control Challenge - Results Summary

*Refer to track map for turn references

Best "Round 1" result in yellow
Best "Round 2" result in pink

Performance Aspect	Units	M-Power Round 1	P-Rex III Round 1	M-Power Round 2	P-Rex III Round 2	Sti MY99 Base	WRX MY03 Base
Fastest lap - difference from std WRX	Seconds	-2.30	-2.17	-2.87	-3.54	-1.52	
0-100 kmh time	Seconds	6.10	6.05	5.58	5.70	5.69	6.65
Mean high lateral G's	G force	0.89	0.93	0.92	0.93	0.89	0.87
Highest speed	kmh	171.2	169.8	173.9	174.8	173.8	168.7
Turn 1 mid - average max speed	kmh	78.1	79.8	81.2	83.9	79.8	74.7
Turn 3 mid - average max speed	kmh	89.7	90.5	91.1	91.6	89.9	88.6
Turn 6 to 7 - average time	seconds	9.3	9.0	8.8	8.7	9.2	9.5
Turn 8 exit - average max speed	kmh	82.3	79.0	82.9	83.7	81.9	77.8

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MRT Performance tested its MRT top-mount intercooler replacement at the end of one of the days and it proved to not only allow more ignition timing to be added but facilitated the generation of more power and the achievement of faster track times.
"In fact, it was a whole half-a-second per lap faster. That may not seem much, but it's a heap of time in a track lap!" MRT's Brett Middleton claims.

"It's a win-win, but they'll be a wash up when the final figures are in. The 0-100 times are really interesting, because while there was no power increase to the MRT car yet there was easily two- to three-tenths of a second improvement in the standing start.

The Whiteline car, with its 15 per cent power increase, actually saw an equivalent sort of increase in the standing start time.

"One without the other, in either case, is not a solution to anything.

"We purposefully didn't get involved with the likes of sway bars and alignment products and so on, with the M-Power car because even though we gave it a wheel alignment, we didn't change any geometry significantly with anti-lift and castor change. So the bias of the car, in so far as understeer and oversteer, would be pretty much as you'd get from the factory, albeit with a little bit if tweaking with damper rates. So that's what we wanted to show: if you do the most fashionable and popular thing, this is what you actually get out of it. But, I can tell you now, if we actually put a couple of bars on it and changed the geometry we would have easily picked up half a second.

"So if you honestly crossed the MRT car with the Whiteline car, in other words grabbed the $4500 worth of suspension off the Whiteline car and coupled it with $4000 worth of power upgrade from the MRT car, then the sum of the parts would be dramatically different to what these are doing here to day – at least half a second per lap faster."

An STi beater? Perhaps, according to Middleton: "If you further upgraded the car to a full MRT XC kit with over 50kW more than standard, you would have a fantastic package that would way out-do a current STi in both power and handling, at almost half the cost!" he concluded.

The Whiteline 'Suspension' car (P-Rex III) – What's underneath

The Whiteline "Handling Pack" (valued at A$839.00), including adjustable sway bars and critical alignment products (see www.whiteline.com.au for a full breakdown). It also had Whiteline "Group 4" adjustable springs and shocks (value: A$3390.00) – plus Whiteline's new range of height and rate adjustable true 40mm mono-tube coil overs. Total cost: A$4789.00.

The Measuring Equipment

MRT supplied its EcuTeK Delta Dash, which logs all data recorded by the Subaru ECU at a high rate, while Whiteline came with GPS software, accurate down to 30cm.

Whiteline's Race Technology DL90 data logger software determines a vehicle's position, in relation to geostationary satellites in geosynchronous orbit, in conjunction with precise accelerometers, Whiteline's Jim Gurieff explained.

"GPS gives mainly general positioning data for analysis whereas accelerometers (G sensors) actually supply acceleration values every 100th of a second, in lateral and longitudinal planes: Lateral for cornering and longitudinal for braking and acceleration."

"With the ability to flow a much larger amount of air, the M-Power WRX really started to come alive," Brett said of the car's pre-Round 1 tuning.
"The cold air intake replacement and full exhaust system have led to a dramatic reduction in turbo lag with the car now proving to be incredibly responsive throughout the rev range. This culminates in a peak power gain of over 40kW at the wheels more than a standard MY03 WRX, and a torque curve flatter than the Salt Lakes!" he exclaimed. The main differences, Brett says, come from the modified car's ability to run near perfect air/fuel mixtures at all stages throughout the rev range because of the EcuTeK ECU upgrade.

9.4 Basic Suspension Modifications

It will come as a pleasant surprise that a few of the biggest improvements to the suspension of the WRX are some of the least expensive, and don't seriously affect the refinement, comfort and practicality of your WRX. These cheap 'n cheerful mods are listed in order of performance.

9.4.1 Wheel Alignment

Apart from fitting better quality tyres, this is one of the best value for money and simplest improvements you can make. Manipulating the wheel alignment of the WRX can dramatically improve the feel of your car. New cars are no exception, it is worth an alignment check as most times the factory does not get the wheel alignment right, and dealers don't check this properly prior to delivery. Even at best, manufacturers specify wide alignment tolerances that are unacceptable to suspension specialists. It is common to find a brand new WRX, driven directly from the new car dealer onto a wheel aligning machine to have up to half a degree variation from side to side, but still is technically within factory tolerances. If your car has travelled any sort of distance, normal wear and tear, parking bumps and poor roads all contribute towards poor alignment, with rear toe settings especially prone to misalignment. A final important note is once any sort of suspension or steering service work has been done, wheel alignment settings must be checked without fail.

The following alignment suggestions work well for a high performance applications, and suit a wide range of modifications, from stock through to modified suspension mods, although it is important to remember that there is no such thing as the definitive set of alignment values. Age, suspension specification and intended use all have an influence on final alignment angles. Use only as a starting point.

Wheel Alignment

Front Axle

Toe: Zero. Static toe is not required, as under acceleration the front wheels are "pulled" forward by engine torque, introducing dynamic toe in, which improves directional stability. The opposite occurs under heavy braking for dynamic toe out.
Camber: 0.75 to 1.5 Degrees of negative camber. Negative camber counterbalances the effects of body lean through a corner, maintaining maximum tyre contact with the road surface when it is needed the most increasing grip. As standard the front struts have factory camber adjustment up to a maximum of approximately 0.75 Degrees. Secondary adjusters will be required if more adjustment is required. See Alignment Products.

Rear Axle

Toe: Between 1.0-2.0mm toe out per side (2.0-4.0mm in total) this tends to set the rear suspension in a more "unstable" state, but improves responsiveness as the rear wheels will follow the front axle line more readily. Setting toe to the upper limit (4.0mm Total) will maximise this effect, and is of use especially with cars that still have OE rear sway bars. But is unsuitable for DCCD equipped STi variants. For these cars a value of between 0-1.0mm of toe out per side (0-2.0mm total) should be used.
Camber: There is no standard camber adjustment in the rear. Check to ensure that camber is even left to right, as this can be a weakness even from new. Significantly different camber values may indicate bent or damaged suspension components. Camber bolts are easy to fit, look for around 0.75 to 1.25 degrees if you have done this. See below for alignment products.

Note
These settings are based on a WRX with a standard driveline. Fitting heavy duty or locked differentials will dramatically alter the optimum alignment settings. See the *Drivetrain* chapter for more information on this.

10.4.2 Alignment Products.


Camber Bolts


Cross-Member Lock pins

Subframe bolts fitted

The WRX is very limited when it comes to adjustment of alignment angles and often either through performance requirements or just to correct minor mechanical problems, additional adjustments are required. Camber bolts in the rear are an easy means of camber adjustment where none existed before, while an additional camber bolt in the front (fitted in place of the original lower strut clevis bolt) easily and quickly increases the amount of total negative camber possible.

Rear cross-member locks on the other hand do not provide additional movement, but actually restrict it. The rear suspension cross-member of the WRX moves around on its rubber bushed mounts, introducing an element of unplanned and imprecise rear steering, contributing to an unsettling feeling for the driver. STi's with the larger R180 rear differential don't have rubber bushes mounting the rear cross-member to the chassis and are solid metal. Subframe lock bolts are still a benefit, as spirited driving can cause the rear subframe to move around as its mounting bolts are a smaller diameter than the bolt holes in the subframe. Camber bolts start at A$95 a pair for quality items, while subframe lock bolts cost around $A55. NVH increases slightly with rear subframe locks, but is unaffected by camber bolts.

Pic Adjustable Strut Top

10.4.3 Heavy Duty Bushes

Poly Suspension bushes

Rear Subframe Bushes

Manufacturers love rubber bushes, because they are squishy and good at isolating noise and vibration. Anywhere powertrain or suspension components meet with the chassis, normally some sort of rubber bushes are used. The compressible nature of rubber is a downside to this, which causes any major rubber mounted mechanical component to readily move around under load. This effect being multiplied in the case of components with multiple rubber bushes (such as a suspension subframe and control arm assemblies). In real terms this translates into greater variations between dynamic and static alignment settings.

Steering Rack Bushes

This is why all good replacement suspension bushes use Poly Urethane (PU) material instead of rubber. PU is available in different hardness ratings, but all grades share a similar property, that is PU bushes "flow" under load instead of compressing. This means more loads are transferred with greater precision compared to rubber. The inevitable downside are an increase in NVH levels inside the cabin, but by choosing which bushes to replace carefully, increases in bad vibes can be kept to acceptable levels.

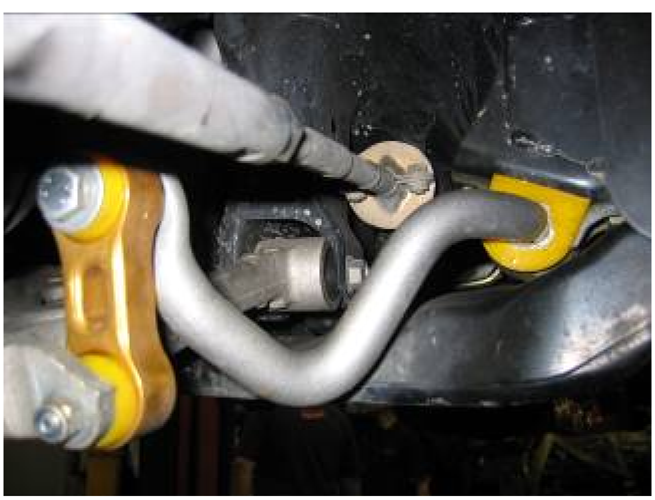
Buyer Bar-ware

I know it is cheesy, but not all sway bars are created equal. Spotting badly designed or poorly manufactured sway bars can be a difficult task and is not like a bad set of springs that either didn't fit or develop a severe case of droop after a couple of weeks. Keep the following points in mind when purchasing sway bars: Buy from a reputable supplier that has a proven track record in the business of performance suspension parts. A manufacturer of industrial grade suspension parts for heavy vehicles may not have a handle on the subtleties of making a WRX corner. Avoid using hollow sway bars, although used by all the very best race teams due to light weight, hollow sway bars in a race car are manufactured to extremely high standards and cost many times more than the cut price specials available for road use. In general hollow sway bars available for us mere mortals very quickly go soft and become next to useless.

Areas on the WRX that benefit from PU bushes include sway bars (even if you still have standard sway bars), steering rack mounting clamps, transmission cross-member and rear subframe cross-member. Heavy duty PU replacements start from A$50 for a set of steering rack bushes and are the pick of the bunch for value for money. Other bushes are worth consideration, but are mainly of value for those planning to go racing.

9.4.4 Sway Bars

The suspensions roll stiffness, is one of the main areas Subaru used to de-tune the handling of the WRX, and is a contributing factor to the amount of understeered served up when cornering enthusiastically. The rear suspension is particularly sensitive to changes in roll stiffness, although the Version VII and newer cars are better in this regard. A general rule for the WRX is increasing rear roll stiffness promotes oversteer, while softening it will tend to understeer more. This makes the rear sway bar on the WRX a very powerful tuning tool. An easy way to understand the effect of rear roll stiffness is to consider weight transfer. When cornering, weight is transferred across to the wheels on the outside of the turn. By increasing rear resistance to roll, weight that normally ends up on the outside rear wheel is moved diagonally towards the outside front wheel increasing its grip. Relatively speaking this reduces rear wheel grip, and is a case of "sacrificial tuning" which in turn promotes more oversteer.



Front Sway Bar

An adjustable 22mm rear sway bar is an excellent choice as it offers the driver the flexibility to adjust handling characteristics to suit personal preferences or prevailing conditions and start at around A$260. It's worthwhile to note that once a stiffer rear bar is fitted, rear toe out settings can often be reduced back to around 0.5-1.5mm per wheel (1.0 to 3.0mm total) for WRX. DCCD equipped STi variants with a thicker rear bar should be reset to between 0-0.5mm per side (0-1.0mm total).

Heavy Duty Rear Sway Bar Mount

Increasing front roll stiffness sharpens up initial turn-in and increases over-all grip, but must be done in a sequence. Never fit an upgraded front sway bar without first fitting a stiffer rear bar, or have both sway bars fitted at the same time. Fitting a heavier rate front bar on its own will only increase the amount of understeer already dialled into the chassis under all driving conditions. A 22mm fixed diameter bar is a good compromise and starts at A$185. Adjustable units start from A$260.

For the budget conscious, or those simply interested in exploring how the car responds to each component, it is perfectly acceptable to fit sway bars one at a time, while respecting the order in which this should be done. Sway bars love better, stickier tyres. If you're impressed by increased grip levels with standard tyres, try better rubber and you will be amazed.

Rear Sway Bar Mounts

Most non-turbo Imprezas and Foresters don't come with a rear sway-bar, but for very little coin, bunging on a rear 'bar will dramatically improve grip and overall driving satisfaction. Sway bar kits are available that come with all hardware needed to connect the sway bar ends to the rear control arms, along with new sway bar to chassis rail mounts. These heavy duty items are also good for cars that are using very heavy rate rear sway bars. Sway bar diameters greater than 22mm are so stiff they can cause breakage of the OE mounts. Heavy duty mounts start at A$80, while a complete rear sway bar kit including mounts start from A$280.

The downside of increasing roll stiffness is that the rear of the car becomes more nervous at the limit of traction, or during transient manoeuvres such as mid-corner throttle lift-off or braking, all of which shift weight in a sometimes unpredictable manner. While the sway bar has increased ultimate grip, it will reduce the amount of warning given to the driver before the tyres break traction. This is all relative, and while the combination of sway bars mentioned above will increase grip and reduce understeer, its not going to turn your WRX into an unmanageable monster, requiring the reflexes of Michael Schumacher to catch it when it lets go. But it will be different. See the *Reality Check* at the end of the suspension chapter for more detail.

Billet Sway bar links

9.4.5 Sway Bar Links

Replacing the standard equipment plastic and rubber bushed sway bar to control arm links with either reasonably priced steel and PU bushed links, slightly more expensive machined billet aluminium or genuine trick STi (but hugely expensive) alloy and rose-jointed ones are another worthy upgrade and are equally useful with either standard sway bars or upgraded ones. The original plastic and rubber links cause two separate rates of roll stiffness when cornering. Initially, as the car turns-in, the plastic links and rubber bushes compress giving one distinct rate of roll, up to the point of maximum link compression where it begins to work against the sway bar, giving another distinct but stiffer rate of roll, another classic example of differences between static and dynamic behaviour. This adds up to a soggy and unstable feeling while cornering, as it wobbles between the two different rates of roll, which does nothing for driver confidence.

Subaru have woken up to this phenomenon and have finally solved the problem with the Version VII and later, specifying rose-joint style sway bar links front and rear on STi models, while oddly enough on the front only for the WRX. Upgraded links start from A$95 for steel and PU bushed, A$145 for anodised billet alloy units and around A$550 for STi items. If you have fitted Sway Bar links and still have standard rubber sway bar bushes, replace them with heavy duty poly, as increased loads will quickly wear out the standard OE item.

10.4.6 Anti-Lift Kit (ALK)

During hard braking or sustained deceleration and acceleration, weight is transferred back and forwards, creating pitch in the front rear suspension systems. This is not always a good characteristic to have, as it alters chassis dynamic behaviour to the point that it may overpower or panic the average driver, especially if attempting to brake and steer at the same time. As always the manufacturer will aim to build in some safety margin, and in order to retain relatively benign handling, Subaru has designed the front suspension to resist diving under heavy braking and lift under acceleration. Unfortunately this makes the car susceptible to front end stiction and all of the associated effects this has. (See break-out box on the ALK for more details) In response to this problem, leading Australian suspension supplier, Whiteline Automotive designed a new geometry kit specifically to strike a more favourable balance between the "anti" characteristics built into the car by Subaru and its propensity to power understeer. Specifically made for the WRX, but with variants to suit other Subaru high performance cars based on the same floor pan and suspension layout.

The Anti-Lift Kit

Redefining the ALK

The original ALK is a triumph of beardy and blokey type technicians, created using hard won experience in order to improve the underperforming WRX front suspension, as opposed to a bunch of pointy heads clutching slide rules and theorising. What happened next was a case of why the ALK works as well as it does, getting lost in translation. Now it is time to clear the air and it revolves around a contemporary design concept used for moderating suspension weight transfer known as "*anti*". Subaru and other car makers build this function into pitch moments for both braking (*anti*-dive) and acceleration (*anti*-lift) in deference to a wide range of driver skill levels. This resistance to movements in pitch makes for stiction problems and somewhat unpredictable behaviour, in so far as the car behaves benignly but not in the way the driver would expect. Stiction is a term describing the "binding" or resistance in a suspension system and is counterproductive towards the aim of improving handling as it creates instantaneous resistance to suspension movements during pitch. While not being a 100% correct example of stiction, as stiction in the true sense is to do with shock absorber binding, it remains a valid description nevertheless. Translated into plain English, when under acceleration, power delivery, traction and resultant front wheel loadings are compromised by binding in the front suspension. This un-weights the front wheels reducing ultimate grip generating the wheelspin hard driving WRX owners are familiar with. The ALK addresses this by removing most of the "anti" geometry, reducing suspension binding, translating into softer effective spring rates (under acceleration only), modified front roll resistance and increased compliance in pitch. Although this sounds like a bad thing, ultimately understeer is reduced, wheel articulation improves and front wheel loadings are evened out. Even though the scientific explanation has changed, (and we have to tip our hats to the pointy heads for this) the ALK's benefit remains undisputed

The kit consists of complete replacement extruded Alloy control arm mounts fitted with low compliance PU bushes that give a three-fold improvement in suspension behaviour. Reduced tolerance PU supports the control arm far more precisely, distorting less under load for more precise control. The new alloy control arm mount re-locates the control arm pivot point downwards removing most of the "anti" geometry built in by Subaru free of charge. As a sweetener, it also relocates the pivot point outwards increasing static positive caster by approx 0.75 degrees, which along with reduced compliance bushes maintains 2.0 degrees or more of dynamic positive caster. Why is positive caster so important? High levels of positive caster equates to *dynamic negative camber* on turn, exactly when camber is needed most of all, maximising tyre contact patch during roll. Turn-in response is improved, directional stability benefits as does steering self-centre and feel, while leaving tyre contact patch when pointing straight ahead for braking and accelerating (unlike large amounts of static camber) relatively unaffected.

Lastly, the ALK addresses the often dramatic power understeer experienced by WRX's (and those based on the same floor-pan) under acceleration, increasing traction and allowing engine power to be applied earlier and harder when exiting a corner.

ALK Installed

Compromises after fitting an ALK are few, ride quality remains unchanged with no effect on spring and shock absorber rates, and with only a modest 10-15% increase in NVH transmission through into the cabin. For more serious use, a motorsport version with poly bushes with even less compliance are also available. Pandering to those demanding more comfort, a "soft" version is also available. Buy them all and have an ALK to suit your every mood! ALK's start at A$235 a pair and can be fitted with basic hand tools in under an hour. Don't forget to have an alignment check done after fitting. For Version VII and onwards cars, spacers are supplied to allow the "U" shaped front chassis brace to be re-fitted without fouling on the relocated control arm mounts. STi offer direct replacement stiffer inner control arm pivots that control suspension forces more precisely as they deflect less under load, however, they don't have any of the geometry benefits of the ALK.

Pic Caster Bushing Forrester

10.5 Serious Suspension Modifications

At this point, if you have followed our advice, you will have achieved some fairly dramatic improvements in the handling of your WRX at a pretty reasonable price, certainly for under A$1,500 here in Australia. At this point costs escalate significantly, and in some circumstances the cost vs benefit ratio drops off. Think carefully about your goals and intended usage before venturing on.

10.5.1 Springs

A cut above your average boulevard cruiser, the standard spring rates fitted to the WRX are fairly good in keeping with its sporty image, although biased towards ride comfort rather than ultimate performance and leave plenty of room for improvement. It is true that some people fit lower springs because they think it looks cool, however, if improved handling is your intention, replacement springs should be selected with the following two goals in mind;

The first is to fit springs of a higher spring rate to reduce suspension deflection in reaction to suspension loadings. This improves contact between the wheel and road surface when it's dynamic loading through weight transfer and road irregularities are highest. Stiffening spring rates will help stop the suspension from compressing to its limit and "bottoming" out on the bump stops under severe and enthusiastic use, while at the same time improving weight distribution during pitch and heave suspension moments. Bottoming out on the bump stops suddenly mid corner will drastically affect and/or disrupt the cars cornering attitude. Secondly is to fit stiffer shorter springs (decreasing static ride height), which lowers the vehicles centre of gravity, and thus decreasing body roll through improved dynamic behaviour.

Lowered Spring Set

Progressive vs Linear Rate Springs

An age-old argument of almost biblical proportions between spring manufactures, resellers and suspension professionals, which unfortunately, leaves the poor consumer stuck in the middle and badly confused. Its true, progressive rate springs sound sexier than plain old linear springs. And also true is that OE vehicle manufacturers will use progressive rate springs to give a degree of initial compliance in a suspension system with a large amount of wheel travel, but is of little relevance to a suspension system that is lower, stiffer and ultimately interested in comfort a distant second over performance.
What is far more important are spring rates that properly match the intended application, and one that works in harmony with all existing hardware. Bear this in mind the next time a reseller force feeds you the virtues of progressive rate springs over linear rate.

Roll Centre? Huh?
Another less well understood and appreciated pitfall encountered when lowering a WRX by large amounts is the effect it has on the front roll centre. Lowering a WRX by as little as 35-40mm can put the front roll centre below road level, effectively negating the influence of stiffer springs, sway bars and geometry.

As with most things, even when heavily biased towards ultimate suspension performance, a new compromise is soon reached, where the improved handling brought about by stiffer lowered springs is offset by a much harsher ride, and an inability for the unsprung weight of the suspension to adequately follow road irregularities causing a loss in grip or roadholding. This compromise differs according to its intended use, and from person to person.

If you plan to do a lot of track days, and are prepared to drive slowly on well-made roads, you will opt for a suspension setup that is far stiffer compared to another person who intends to drive hard on all types of road conditions, from smooth freeways to lumpy back roads. As mentioned before, springs of a lower static height reduces the cars centre of gravity, and increases cornering grip, but must be seen as another set of compromises. As the ride height is lowered, the suspension is forced to work through a reduced distance, requiring higher spring rates to resist bottoming out, further decreasing ride comfort.

Reduced ride height also cuts the amount of ground clearance your WRX has, and obstacles such as speed humps, kerbs, drains and driveways that were previously no problem can become a major issue. Generally a ride height reduction of between 25-30mm is the recommended maximum for road use. Lowering the ride height by greater amounts will reduce available suspension travel to the point where the suspension system will ride completely on its bump stops, which are not designed to suspend the car. If your car has been lowered to this stage, forget about trying to get your car to handle.

As a simple rule of thumb, the better the intended road surface, the less theoretical spring travel you need, but don't think for one minute that even a typical freeway is as good as a race track, let alone normal city roads. A car set up predominately for spirited street use needs more suspension travel and a higher ride height than you might first think, if it is to maximise contact between the road and tyre.

A set of new linear rate lowered springs tuned specifically for the WRX that work well at a lower ride height and with standard shock absorbers (in good mechanical condition) will cost around A$320 plus fitting. Of course make sure you get a front and rear wheel alignment done, as a new lower ride height equals changed camber and toe.

Why can't I just cut my existing springs?

1) *Many aftermarket lowered springs are designed to be captive (held in place) even with the suspension system at full extension or droop. Here in Australia this is a legal requirement, with implications including insurance coverage for vehicles fitted with springs that do not remain captive. Cutting a spring by even a small amount will reduce its free height, possibly to the point where it can become loose at full suspension extension.*
2) *Most springs are designed to a fairly tight tolerance of material volume to load carrying capacity ratio. In plain English, that is the amount of steel used to manufacture the spring is hopefully enough to suspend the weight of the vehicle and its occupants over its intended lifetime with normal use. Lopping off some coils and you will dramatically reduce the amount of load carrying material, which almost always results in a badly over-stressed coil that will at best case sag prematurely, or worst case fail catastrophically.*
3) *Reduced ride height is normally coupled with a proportional increase in spring rate to offset the smaller amount of suspension travel available. The speed at which the suspension is compressed needs to be slowed enough to make sure that the suspension does not punch right on through the shock an on to the bump stops. OE springs or even aftermarket springs that have been cut will not have sufficient spring rate to handle the reduction in available bump travel.*
4) *Even the cutting method is a problem. Heat applied to the spring by way of a gas cutting torch or friction disc ruins the careful heat treating processes that are used in the manufacture of all high quality springs. Heating and then cooling the metal past its original temper permanently changes its metallurgy and severely reduces its elastic properties.*

9.5.2 Shock Absorbers

In a repeat of a familiar theme, it comes as no surprise to learn as with the springs, standard WRX shock absorbers are biased more towards cost and ride comfort than outright performance. But it can be said as being a reasonable compromise for road use, and are correctly *matched* to work in sync with original spring rates. If you have fitted stiffer than standard springs, upgraded stabiliser bars and/or the standard shock absorbers are a bit long in the tooth, new shocks become an essential purchase. Alternatively, if you prefer thrashing over back roads, poor surfaces, pot holes and other road nasties, you might find that the standard shock absorbers get a bit breathless even with stock springs and sway bars.

Shock absorbers that no longer mix it with the big boys normally have problems due to either age or badly mismatched spring and sway bar combinations, or just plain over enthusiastic use. As shocks age, seals and valve packs wear, tolerances increase and generally loose interest in the job at hand, while oil leakage can reduce the physical quantity of oil contained within the shock

Stiffer rate springs and sway bars generate much larger amounts of kinetic energy within a suspension system for the shock absorber to deal with. Shocks that have not been designed to cope with this increase in energy will very quickly be overpowered, with the higher rates of suspension movement "punching" through the shocks damping threshold. This leads to the final mode of shock absorber failure, which is when the process of converting the kinetic energy of a suspension system into heat occurs faster than the shock can deal with and dissipate that generated heat. Overheated hydraulic fluid looses its viscosity in comparison to its cold state, starts to foam, introducing air bubbles into the fluid all of which greatly undermines its damping capability. Often, as in the case of a set of overheated brakes, given enough cool-down time, damping efficiency will return. Most of the time that is. Multiple hot/cold cycles will eventually lower shock oil viscosity, ultimately contributing to a reduction in performance.

Cultural Differences and Suspension

Expectations on what constitutes a well set-up suspension package varies greatly, depending on what part of the world you reside in. Japanese consumers tend to demand rock-hard spring and shock absorber settings, and one can only theorise that perhaps in a country where there are more cars than road space to fit them, in order for a suspension system to *feel* sporty when crawling through endless traffic jams, it has to be rock hard. North American tastes, on the other hand, after years of 55 MPH speed limits, long straight smooth freeways and a diet of Detroit built V8 powered heavy metal lean towards a softly-softly type ride. Europeans are different again, expecting their cars to be capable of eating long stretches of autobahn or autostrada comfortably and at high speeds, but count on being able to fling their car with abandon through tight and twisty mountain passes without falling off the edge. This requires the suspension being a bit on the firm side in order to do so. We Australians have a foot in all camps, demanding good ride comfort versus handling compromise for highway comfort, while still appreciating the odd blast down a bit of challenging road (Police and Radar permitting). We also have to live with a highways department that doesn't spend anywhere enough money building and repairing our roads, passing off some sections of lumpy road as our national highway that would have the average Frenchman exclaiming "*Merde, you call zis a road?*" Bear this in mind when sourcing suspension components.

Adjustable Shock Absorbers

All things considered equal, after adjustable sway bars and springs, high quality, carefully selected shock absorbers that offer either rebound, or both bump and rebound adjustment are the next most important suspension tuning tool for improving suspension performance in your WRX. While low quality or poorly selected ones will seriously detract from overall suspension performance, no matter how many knobs or adjustments it may feature.
Pic Group 4's

Generally shocks that advertise as offering a span of adjustment that boasts limo-like ride comfort for the street and rock-hard damping for the racetrack falls into the category of the impossible dream. Shocks that are adjustable for bump and rebound will only offer an advantage over non-adjustable units if its original base shock rates (That are not user adjustable) have been programmed in to allow meaningful adjustment in the first place. It is a waste of time and money to have a shock that must be wound up to maximum hardness in order to stop the car from riding like a '75 Cadillac Eldorado, and conversely one that even on its softest setting attempts to shake your teeth loose on anything but billiard table smooth surfaces.

Pic Shock Changover

Primarily adjustable damping allows the user to better "zero" in on a shock absorbers sweet-spot, or the point at which it's damping rate best interfaces with the rest of the suspension system for a given set of driving conditions. Adjustment also allows the user to better compensate for the effects of wear and tear, as even the best quality shock absorbers inevitably start to wear and loose efficiency.

Of equal importance is oil capacity, and the part that it plays towards combating heat related loss of damping efficiency. Twin-tube OE style shocks have small diameter pistons and a comparative small volume of oil contained within the shock absorber body. Even the inverted mono tube items fitted to late model STi variants are skimpy when it comes to oil capacity. It is not uncommon that OE shocks can loose up to 50% of damping performance within two laps of use on the racetrack. A larger diameter shock piston equals a larger volume of damper oil and more resistance to shock fade, and is an important piece of information when purchasing new shocks.

EDFC – Duh?

Another great Japanese acronym that stands for Electronic Damper Force Controller. Despite being a bit of a mouthful, its an interesting concept nevertheless. EDFC consists of four electronic adjuster modules (one for each shock) controlled by an in-cabin mounted head unit. It offers the flexibility of being able to alter damping from the comfort of the drivers seat, and without having to get your hands dirty grubbing around under the car. Its actual performance value? Unknown, as I guess it all comes down to how well they set the basic manually adjustable shock in the first place.

Shock Absorber Choices

Replacement shock absorbers fall into two loose categories, first of which are inserts which require some heavy cutting and drilling of the standard strut bodies in order to fit the new insert, putting it out of the realm of most DIY installers. Choose carefully too, as short of buying another complete set of strut assemblies, once those inserts are fitted, you're stuck with them! Koni inserts for the WRX are a good example and will cost around $A 2400 for a set of four inserts. Count on paying for at least four hours of labour to modify your OE struts and fit the new inserts. Koni inserts are adjustable for rebound damping, but come in two different models, one featuring on-the car adjustment, while the other requires the entire strut to be removed from the car, spring and strut-top disassembled for adjustment. Koni inserts are not gas pressurised, but can be repaired, rebuilt or have its valving modified without having to throw the whole lot away.

Pic Replacement Strut Assembly

Next are the complete strut replacement type of shock absorbers, and constitute the segment with the greatest range of replacement shocks for your WRX, and can be broken into a series of further sub-categories. At the bottom of the food chain are the cheap and nasty knock-offs of the real thing, and are of little interest or relevance to this book, or to owners of a high performance car like the WRX.

Where it gets interesting is the huge array of replacement shocks that fit nicely into the medium price range and contain entry level cheap 'n cheerful units, right up to more expensive premium grade shocks. Most shocks in this category will bolt in as a direct replacement for the OE part with just basic hand tools. Manufacturers such as Bilstein, Tanabe, Cusco and many others are represented in this category, making it next to impossible to list and review all. This aside, good examples of entry level type units are the KYB AGX series that feature adjustable bump and rebound, and re-uses the existing coil spring and strut top. A good performing shock absorber, a car set of AGXs start at A$1200

Pic KYB AGX Shock

Tien manufactures good quality shocks and offers a range spanning everything from entry level basic replacement struts right up to the more highly priced all singing and dancing units. These sport bump and rebound damping adjustment, racing style coil over springs and height adjustable spring platforms, and new strut tops with rose-joint style bushes with in built vrnier type camber adjustment. Tien shocks with these features start at A$3800 for a car set.

Whiteline's range of Group 4 shocks are a good example of premium performance road shock absorbers, featuring class leading 46mm large diameter single piston valve packs calibrated for custom damping settings, adjustable bump and rebound, height adjustable spring platforms and European manufactured coil springs. As a measure of how good Group 4s are, most leading Club and SOLO championship cars are now running these premium shocks. Group 4s start at A$3390 for a car set, but does not include new strut tops and re-use the OE unit or equivalent aftermarket item.

Last are the stratospherically priced cross-country/road race/rally type suspension packages. Normally found hanging off exotic and frightfully expensive custom built race cars such as an A$800,000 WRC car. Ignoring the car for one minute, modern competition shocks are an engineering master piece in their own right, using exotic materials like titanium, featuring adjustments not just for rebound and compression damping, but also high speed, low speed and even the damping moments in-between that defy description. Other goodies include external or remotely mounted gas/oil reservoirs and hydraulic bump stops. With most motorsport categories heavily regulated restricting engine and transmission development, focus has shifted back onto the humble shock as it's more and more being seen as one of the biggest ways to improve a vehicle's performance. With active or electronic controls banned in most racing categories, it's been a case of back to basics in the race to build a better mechanical mouse-trap. Leaders in the field of damper innovation include AST, Ohlins, Reiger, Proflex and Penske. Sensing an opportunity for retail sales, most of these manufactures now offer damper and spring kits for more pedestrian road cars, but still cost a comparative bomb. Proflex or DMS struts for your WRX start at A$5000 and don't include strut tops.

Coil-Over-the-Top

Coil over shocks are very much the rage these days, everybody's got one! Height adjustable coil over shocks were created originally for a very specific motorsport use. Used to allow precise changes of individual wheel heights to "balance" the weight of the car and is referred to by suspension specialists as "corner weighting". Having now moved over into the realm of automotive fashion, we now see coil overs for as little as A$1000 with ride height adjustment. Typically consisting of a very average shock with some additional hardware hanging off it and is really only useful for cosmetic lowering and show work. A good quality *rate* adjustable shock will beat a low quality height adjustable shock hands down performance wise every time.

Pic Rally Suspension System

Regardless of your budget or intention, be sure to always ask the following questions:

- Are the replacement shocks matched as part of a complete suspension set?
- If not, will bump and rebound base setting match what is already fitted to the car?
- How much will the ride quality change?
- Do the shocks require any routine maintenance?
- Is there a recommended modification path after fitting shocks to further improve performance?

9.5.3 Strut Tops

Adjustable strut tops for the WRX have been around for some time now and offer a couple of benefits over the standard part, and are a worthwhile addition. Firstly, most replacement strut tops offer some sort of in-built camber adjustment system for the front which works in addition to the stock OE camber adjusters built into the strut clevis. Some models can be fitted in a different orientation, turning them into caster adjusters. Units are also available with combined caster/camber functions. All replacement strut tops feature upgraded top bearing/bushings. Cheaper lower cost units use traditional bearings and low-compliance poly urethane, while more expensive ones use motorsport style rose jointed bearings. This type of joint locates the shock absorber precisely with low friction zero compliance bearings.

Rose Joint strut Tops

PU Bushed Strut Tops

For ultimate performance, zero compliance rose-jointed bearings cannot be beaten, but do transfer large amounts of NVH and can wear out surprisingly quickly. A set of rose jointed strut tops with camber adjustment start at A$820 for a full car set. Poly Urethane style strut tops require less maintenance, and don't transmit as much NVH, but operate with less precision. PU bushed front and rear items cost the same, but have a finite limit to how heavy a spring rate can be used before the bush failure will occur.

9.5.4 Adjustable Rear Control Arms

These parts provide a similar function to camber and toe adjusters, but for the rear suspension. Motorsport style “turnbuckle” type adjusters allow large changes to both rear camber and toe to be made. With such a massive span of adjustment available, actual changes to the overall track of the rear suspension can be made, hence allowing “real” tuning of the car’s handling behaviour. However, this new found freedom is not without its risks. Such is the degree of adjustment there is any number of pitfalls to be avoided, such as drive-shafts pulling out the rear differential on full droop due to over enthusiastic increases in rear track. It also makes it easier to get into an aligner’s nightmare, with competing adjustments making it possible to achieve allsorts of weird geometric shapes. Very much the domain of serious suspension tuners, they have very little relevance off the race-track and on the street. A set of adjustable rear control arms start at A$490.

A worthwhile inclusion to adjustable arms is a neat product recently released by Whiteline. The OE rear toe adjusters are a bit flaky, and is one of the biggest culprits towards the rear end “going out of alignment”. The OE type of friction type toe adjusters are locked in place allowing toe adjustment by the arms only. Very useful for racing where you can clip as many apexes as you like without worrying about alignment problems. Toe-lock-out kits start at A$146.

Pic Whiteline Adj Rear Control Arms

10.5.5 Chassis Bracing

Defines any sort of product fitted with the aim of achieving increased body rigidity, which in turn improves suspension operation as its constituent parts are more securely mounted with less flex, loss motion and other carry-on. It is also a front line warrior in the battle for maintaining a closer match between static and dynamic alignment settings. The best known examples of this are strut braces. Less commonly known as, but more accurately as strut tower braces, they link the top of each of front or rear strut tower to its opposite number. These have good car-park cred and look a million bucks fitted to the engine bay, but do serve an important role. Braces that fit to the underside of the chassis are also available for the older GC series (Subaru addressed this with version VII and later cars), although car-park cred is harder to establish being hidden under the car.

Pic Front Strut Brace

The intention in both cases is the same though; to increase torsional rigidity of the monocoque chassis and preserve static alignment settings. During spirited driving, suspension loadings can build to such a limit that some twisting or bending of the body shell takes place (especially evident in the old GC bodyshell). This manifests itself in the form of unpredictable handling and more squeaks and groans. Strut braces transfers a percentage of suspension loadings from one side of the bodywork to the other, reducing what would otherwise be soaked up in body flex. A less understood effect of this is an increase in effective spring rate at the wheel. As the bodywork is more resistant to flexing, a little more suspension loading is transferred directly onto the wheel. Canny drivers will actually pick up on a small increase in understeer after fitting a front brace, or oversteer having fitted a rear one.

Rear Strut Brace

Underbody Brace

Strut braces are of less value on a bog-stock road car, but really become a worthwhile addition as soon as springs, shocks and stabilisers with stiffer rates are fitted, and all the associated increases in suspension loadings exerted on the chassis. Anything that enhances chassis rigidity is a good thing, a car with a more rigid chassis is always a far sweeter device to drive. Although it may be tempting to ditch the heavy "u" shaped reinforcing bar fitted to the underside of Version VII and later cars, the advantage gained by a small decrease in weight, really does not stack up against the negative affects on the base vehicles design integrity. Strut braces start at A$160 for a front strut or rear brace. STi manufacture a masterpiece of aerospace aluminium and carbon fibre strut brace will lighten your wallet to the tune of A$1,200 Ouch!

What's new on the horizon?

Innovation in the aftermarket performance industry shows no signs of tapering off, and the suspension industry is no exception, with serious operations continuing to pump out new products for both the WRX and the STi.

The Forrester GT and XT are the newest kids on the block in the performance SUV segment, and have its own set of unique suspension demands courtesy of its jacked-up ride height. Companies like Whiteline already have conversion kits to remove the self-levelling rear suspension to allow decreases in ride height in order to improve suspension performance, a modification that is becoming increasingly popular on this closely related (to the WRX) platform. Group 4 performance shocks should be available by the time you read this.

Good quality chassis bracing products are becoming more prevalent, as companies begin to realised the opportunities to improve handling with products that look great, without compromising ride or NVH. Equally this sort of stuff rarely infringes on road rules regarding modifications etc. As all good suspension specialists say, "there is no such thing as TOO much chassis rigidity", weight permitting of course.

Development of automotive electronics continues to become more common. We are all used to upgrades for an engine ECU, but it is fast becoming a reality for suspension and chassis tuning. As touched on before, companies such as Tien already offer cockpit adjustable shock absorbers, companies such as MoTeC and Whiteline are working on solutions for the DCCD centre differential.

From a non-Subaru point of view, tyres and shocks continue to improve and with it change the ideal options for mechanical components. No better evidence is the way in which the pointy end of motorsport engineers and technicians alike have been preoccupied with reducing physical spring rates, along with a corresponding improvement in shock absorber performance, in the quest for greater tyre to road grip. At this stage, this continual downward spiral in spring rates is only limited by current tyre technology.

Pic STi Carbon Strut Brace

9.6 Conclusion

Since the first edition of *Training WRX* way back in late '99, like most facets of the WRX performance industry, the range of suspension parts has grown explosively. On the whole this has been a good thing for WRX owners. Parts that previously were either un-available to us mere mortals or were priced out of an average budget, are now readily available and at the right price. This is not all good news, as at the same time the market has been flooded by extremely cheap and dubious quality suspension parts, making it harder to spot the "good stuff" out of the general avalanche of items being sold for the WRX.

What hasn't changed is that after the engine, upgrading your suspension is one of the most expensive performance upgrades. Treat it accordingly and seek professional advice. Serious suspension specialists will take the time to ask plenty of questions, in order to find out exactly what you are expecting to achieve, and will have a range of suspension packages ready made to suit those needs. If they don't, walk away and find someone that does.

It cannot be stressed enough how important it is to use components designed to work together as part of an overall plan, and not to try and build a suspension set-up from different suppliers. Taking the approach that ACME springs are the best and ACE sway bars are the best and then simply acting as a "blender" for these products by fitting them on your car, invariably results are half-baked result, wasting time and money.

Do plenty of research, learn what you can and use that information to make informed decisions about the options presented. We suggest that you upgrade the suspension following the basic modification path as outlined above. Upgrading step by step is a worthy consideration, as that way you will appreciate the effect of each modification and start to define your personal requirements around the inevitable compromises of ride, handling, grip or road holding, NVH and most importantly cost.

Reality Check

This shouldn't be considered as a disclaimer, but more as important advice learned by others the "hard-way". Modifying the suspension on your WRX is a serious business. Improving suspension performance accomplishes the goal of turning your road car into more like a racing car, and all of the associated compromises this entails. Your WRX will handle better and have much higher levels of grip, but in un-skilled hands, any loss of control at these elevated speeds results in an accident that will be far more destructive to person and property. It is not our intention to scare you away from the path of suspension upgrades, but merely to appreciate that your WRX will behave differently than stock, and to bear this in mind before trying for ten tenths around your favourite corner.

Chapter 10

Stopping the WRX

Stopping the WRX

Times have changed, the WRX tuning industry continues to get better and better at the job of enhancing your Subaru (one hopes!), power outputs are climbing, making cars faster and faster, almost in a performance arms race of sorts. One thing that hasn't changed though, is the prevailing attitude that finds the braking system in your WRX as being by and large overlooked by owners seeking to improve the performance of their car. Another thing that hasn't changed is the laws of physics governing the motion of an object, and it's a sure bet nothing will change on that front any time soon. There's no free lunch, the faster your WRX, the harder it will be to slow down, and as unglamorous as brakes may be, running out of road is a terrifying experience. This section is all about keeping those skid marks on the road and out of your drawers.

For Pointy Heads Part One
Newton changed the way we understand how things work in just about every facet of everyday life, when he published the three laws governing motion, the first being; *"Every object in a uniform state of motion tends to stay in that state of motion unless an external force is applied to it"* Brake force and not an un-movable object being the best choice for significantly altering your state of motion.

10.1 How the Brakes Work

For Pointy Heads Part Two
Grossly simplified, and sure to annoy anyone with even the slightest understanding of vectors, Newton's second law of motion states "*Force of an object equals the relationship between its mass and acceleration*" A heavy car travelling at speed is going to have a lot of force behind it, and it is going to take lots of stopping. There. Simple is better.

When you push on the brake pedal, the piston that is inside of the brake master cylinder forces incompressible hydraulic fluid, through connecting lines and hoses to the brake callipers. Actual applied pressure to the callipers is according to a preset front to rear ratio or "bias" which is discussed in the next section. Brake pressure is also split into two separate circuits, the idea being that in the event of a brake system failure half the brake system will still work. On the WRX brake pressure is split into two diagonally split systems. The front left wheel is connected to the rear right wheel to make one circuit, with the remaining front right and rear left wheel making up the other. Applied fluid pressure acts on brake pads, which are "squeezed" against the brake discs from both sides. Immediately, through friction, some of that hard-earned fuel used getting your WRX into motion is converted from kinetic into heat energy and lots of it. This is the reason why ventilated disc brakes are almost universally used in racing and road cars right down to the lowliest of econo-boxes.

For Pointy Heads Part Three
Newton's last law is much simpler, and strangely enough applicable to any and all situations life may throw at you. "*For every action there is an equal and opposite reaction*" This applies to even the idiot in traffic that insists on trying to cut me off. For those of you still discounting the work of Newton and his apple, perhaps Darwin's theory of evolution is a better basis for discussion.

Brake Balance or Bias

As a car decelerates under braking, vehicle weight is transferred forward and onto the front axle. This requires brake force to be regulated or "biased" to take into account of weight transfer, which increases front wheel grip at the expense of the rear. If not for this adjustment in brake force, the rear wheels would lock up and skid, while the fronts still had plenty of excess braking traction available. This biasing is known as brake balance and regular viewers of motor racing will often hear discussion regarding the effect of fuel loads, track conditions and tyre wear on brake balance, and how it is constantly adjusted throughout the race to suit. A rally cars rear bias is higher than normal so that the driver can throw the car sideways if needed by deliberately locking up the rears before the fronts.
Production cars use a complicated pressure regulating valve that adjusts brake balance automatically, without any sort of driver intervention.

The very best types of adjustable brake balance commonly used in motorsport is a simple system where two master cylinders are used, one for the front wheels and one for the rear, operated by a common bar, that is, in turn, moved by the brake pedal. The pivot point of the "balance bar" can be adjusted, usually by a cockpit mounted driver adjustable knob. Moving the pivot point towards one master cylinder and away from another changes the amount of pedal force that is converted into brake pressure by both master cylinders, altering the brake balance front to rear. Cost, complexity and incompatibility with production anti-lock brakes make it impractical for all but serious competition.

Pic Balance Bar Brake Setup

Anti-Lock Brakes

The point at which maximum brake force is transmitted onto the road surface is the moment just before the wheel stops turning and locks. When you lock up the wheels from excessive pedal pressure, you loose the ability to steer your car and stopping distances increase greatly. Once the wheels lock and start to skid, grip reduces markedly, and control of the vehicle is lost as it no longer responds to steering inputs and continues on travelling in the same direction it was when the wheels first locked. This means in an emergency situation the driver is unable to steer around obstacles on the road, taking a greater distance to stop the car completely. ABS (Anti-Lock Braking System) monitors wheel speed and regulates brake force applied to each wheel by way of rapidly pulsing hydraulic pressure according to changes in rotational speed to achieve the point of maximum braking. This is the rapid pulsing felt through the brake pedal when ABS is active.

ABS Unit

Under a few situations, such as fresh snow or loose gravel, ABS actually increases stopping distances. As a wheel never locks completely, it cannot dig through the top layer of loose material and into the harder material below. ABS also stops the tyre from building up a wedge of loose material which can also help slow the car. This is purely a technicality, as in the majority of cases the ability to steer the car outweighs the extra stopping distance. If the driver can brake and steer at the same time, you stand a much better chance of not needing the services of a crash repair shop.

Another Acronym

EBD or short for electronic brake distribution was first introduced here in Australia on the Version VII STi. ABS system operation is further augmented with the addition of EBD, which constantly adjusts brake system pressure when in operation. EBD works like a sophisticated brake proportioning valve, optimising brake system performance in accordance with such things as dynamic weight transfer and prevailing road surface grip. Overall stopping distances decrease with EDB, along with a marked increase in stability while braking hard.

10.2 Improving the Brake System

Reality Check

Brakes on the WRX improved greatly with the advent of the '99 Version V. While many of the recommendations contained within this section are equally applicable for Version V and earlier cars, owners of '99 models (and later) are at a less of an imperative to dramatically improve their brakes much past improved brake pads. Conversely owners of '98 Version IV and earlier (Including North American WRX Models) need plenty of help in the Braking department if they are called on to do serious duty through enthusiastic usage.

Slowing your WRX depends on friction. Friction turns the kinetic energy of motion into heat energy, and the measure of a brake system is its ability to deal with the ferocious temperatures generated. As brake system temperature rises, the frictional co-efficient of the brake pads and disc surface drops, steadily reducing the brake pad's ability to grip the disc. This is commonly referred to as brake "fade". (See chapter *Track Days* for more details on brake fade.) In extreme circumstances total brake failure can result. Therefore, in order to improve brake performance, we need to increase the amount of friction a brake system can generate, while at the same time managing heat more efficiently.

Pic Brembo STi Brake Calliper (std.)

10.2.1 Brake Pads

Brake pads provide a socially acceptable means of achieving the required amount of friction with the brake discs, without the more extrovert showers of sparks and screeching associated with metal to metal contact. Brake pad material is the easiest and most cost-effective way of improving brake performance, and should be the first item on the list to be changed. High performance brake pad material is designed to maintain its co-efficient of friction at greater temperatures than standard. Standard equipment pads are a victim of a compromise between cost, refinement and performance.

Reality Check

All brake pads are not created equal! As in most things, you get what you pay for. Aftermarket replacement brake pads can sometimes be worse than the original part. Premature fade, wear, excessive dusting, vibration and noise are all pitfalls of substandard brake pads. $19.95 super-special brake pads are unlikely to set new standards in performance. Conversely, there is no need to spend huge amounts of money on racing brake pads if you never tax the standard parts. Consistency is the name of the game, inconsistency in pad grip can manifest itself in the form of brake shudder, premature wheel lock and possible loss of control.

10.2.2 Upgraded Brake Pads

Performance brake pads are loosely grouped in three categories: Better than standard for fast-road applications, featuring pad materials have a higher resistance to fade, while still retaining the niceties of the original equipment pad. These can be had from as little as A$190 an axle set. Midrange road-track combination for a compromise between road going manners, while offering a much higher level of braking performance for those odd track days when you want your car to morph from Mr Jekyll into Mr Hyde. These are available for around A$300 per axle set. Competition grade brake pads can cost A$420 or more per axle set, and have downsides such as poor performance when cold, dusting and noisy operation, but take an amazing pounding when pushed to the limit. Probably only of benefit for racing. See chapter *Track Days*.

Those lucky enough to have a Version VII or later STi with gold coloured Brembo brake callipers should expect to pay around A$80 on top of the prices quoted above.

Pic Performance Brake Pad Set

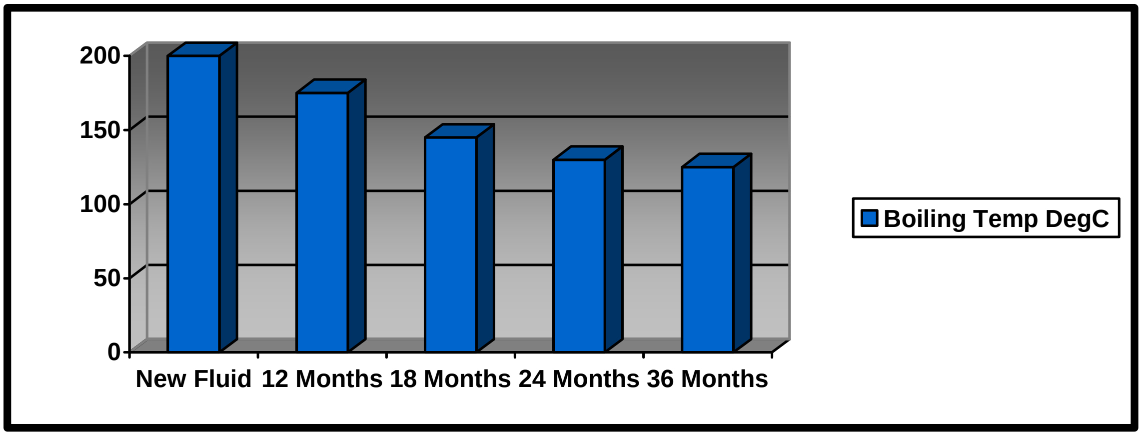
10.2.3 Brake Fluid

The fluid squeezed to within an inch of its life every time you apply the brakes is often neglected. The best braking system in the world is worthless if it's been filled with cheap poor quality fluid. Brake fluid must be capable of withstanding the fierce amount of heat energy generated by the brake system without boiling. Once brake fluid begins to boil, pockets of vapour begin to form in the brake system. These pockets of gas are a very *bad thing*, as they are readily compressed reducing braking power and feel. In extreme situations boiling brake fluid will result in brake failure.

Another problem with brake fluid is that it is hygroscopic, which is to say that it readily absorbs water, even from the surrounding air. This moisture builds up over time, contaminating the brake fluid and greatly reducing its tolerance to high temperatures due to the much lower boiling point of water. The answer to this is to minimise exposure to air, and to change it regularly. Subaru recommend brake fluid to be changed every 24 months or 50,000Km. Consider this the absolute maximum, and if your car is driven hard, do it every 12 months. Use fluid of at least a Dot 4 rating.

For Pointy Heads Part Five

Long before people were zooming around in cars with hydraulic brakes, in the 1700's English scientist Robert Boyle studied the behavior of gas under different pressures. Boyle's Law states (Again grossly simplified) "*Any increase in pressure on a gas in a sealed system will result in a proportional decrease in the volume occupied by the said gas*" Gas instead of incompressible fluid in your brake system is a catastrophe. Who said the stuff learned at school would never be used again?



Effects of Water Contamination on Brake Fluid Boiling Point

Very expensive Dot 5.1 competition grade fluid marketed by Brake specialists such as AP, Brembo and Alcon is readily available at a cost of around A$85 per litre. This type of brake fluid has a very high boiling point and is less hygroscopic. However, it still needs to be changed regularly and cost is a bugger compared to Dot 4, which can cost as little as $15 per litre.

Silicone based brake fluid of a Dot 5 rating is for specialised applications only. Silicone Fluids are not recommended for motorsport or road use and are predominately used for military applications. Silicone fluid has several disadvantages, biggest of which is its total incompatibility with conventional brake fluids, immiscibility with water, poor lubrication properties and high compressibility. Silicone fluid is also known to cause problems with rubber seals found in some original equipment brake systems.

See chapter *Track Days* for common brake problems and special requirements before hitting the racetrack.

Throw Out the Anchors!

Ok, its exaggerating the situation a little bit, but any owner of an even mildly modified GT/XT Forester will immediately be familiar with the speed at which the stock stoppers run out of puff. Equipped standard with two piston callipers on the front and single piston non-ventilated rears, it's a brake package from a previous generation of WRX. Thankfully, salvation is close at hand, and upgraded four piston callipers and larger diameter discs fitted as standard since the Version V WRX are an easy bolt-on and for not a lot of coin either. 296mm front discs start from A$150 each, while four piston callipers can be purchased from your local Subaru dealer from around A$750 each. An upgrade package like this will transform the way your Forester stops.

10.2.3 Brake Discs

The next easiest area of the WRX braking system to improve is the brake discs or rotors. Replacement discs normally feature either cross-drilling, slotting or both! Slots or grooves in the surface of the brake disc help prevent pad glazing while dispersing pad gas produced when braking heavily. Additionally they allow the removal of pad dust and road grime that can get between the disc surface and brake pad. Cross-drilling of brake discs achieves similar results, that is, maximising pad friction between brake pad and disc. It is important to note though, cross-drilled brake discs require a degree of pre-heating and cooling after hard use to prevent thermal shock from causing heat cracks propagating between drillings.

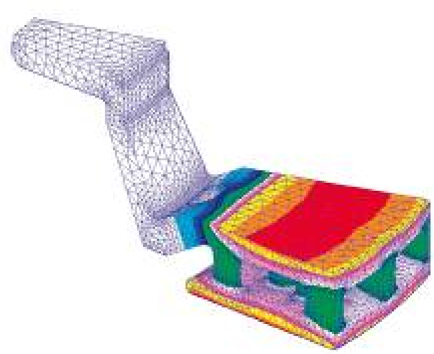
Here in Australia, DBA produce an excellent range of bolt-on replacement brake rotors for all Subaru makes and models. DBA has its discs manufactured out of specially selected cast-iron alloys used because of their excellent heat resistance properties rather than cost. All final machining and quality control is done completely in-house to tolerances that are far in excess of original equipment specifications.

Improved direct bolt-on replacement front and rear brake discs start from A$150 each. Incorporated in its design is the unique "kangaroo paw" internal air extraction system, and specially finished hub profile that acts like a heat dam reducing disc to hub heat transfer. Slotted 326mm discs to suit the Gold Brembos start at A$210 each.

Putting the Recycler Out of Business

It used to be a task performed with monotonous regularity during rallies. Depending on event, sometimes the front brake discs had to be replaced with new items anything up to three times per rally. MRT's service crew moaned constantly "Not new discs again" and wished for something like a broken gearbox or busted driveshaft to liven things up. Very quickly a veritable mountain of used brake discs accumulated out the back of MRT's workshop. The only person content with the situation was the metal recycler. This is now a thing of the past since fitting DBA 5000 series front discs and alloy hats. They even come with heat paint that changes colour depending on maximum disc temperature. Everybody is happy now, except for the recycler, who longs for "the good old days"

DBA Kangaroo Paw Disc



DBA Heat Dam technology

Hot news (no pun intended) is the availability of low cost motorsport style front discs for the WRX from DBA. Known as the 5000 series, it fixes a problem that has plagued anyone that has attempted to go racing with even high performance one-piece discs. Traditional one-piece discs have big temperature gradients across the entirety of the disc. The outer friction surface runs far hotter than the inner piece that mates with the wheel hub, causing large amounts of stress between the cooler hub centre and the much hotter outer edge, and is the biggest contributing factor towards disc cracking. Using techniques found in Motorsport, DBA engineers devised a system whereby the brake disc is bolted to a machined alloy hub centre or "hat". Far less heat is transferred into the wheel hub through the hat, while the friction surface maintains a much more even temperature. The brake disc can also "walk" to a small degree on its mounting hat further reducing stresses. 5000 series brake discs are available with red or blue hats to suit Subaru's with most calliper combinations starting from A$500 ea.

Pic 5000 Series Brake Disc

10.2.5 Brake Hoses

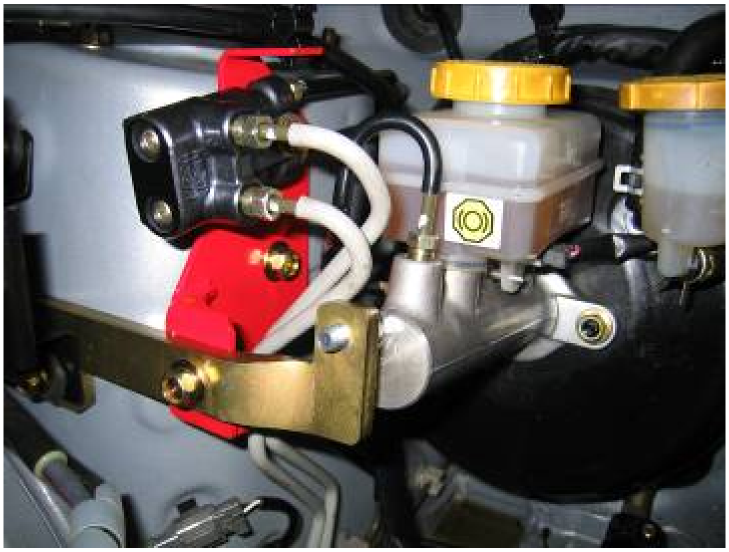
Together with rigid steel brake lines, they are the conduit through which brake force is transferred from the master cylinder to the brake callipers and pads. Of most interest for us is the flexible line that allows movement of the suspension between the Calliper mounted on the wheel assembly and the chassis. Original equipment rubber / plastic brake hoses can be counted on for years of reliable service, but have one major drawback. They swell minutely when you press on the brake pedal. This swelling is only an infinitesimal amount, but it contributes to a springy / spongy feeling in the brake pedal as the hose balloons instead of transferring pressure.

Braided Brake hoses

Brake pedal feel can be improved considerably by fitting motorsport grade flexible stainless steel braided brake lines, consisting of a thick nylon inner tube, clad with a fine stainless steel over braid terminated on the ends with “Aeroquip” fittings. Braided brake lines still swell under pressure, but by a lesser amount than the original rubber / plastic items. Greatly improved pedal feel, reduced pedal travel and improved driver confidence are positives from fitting upgraded brake lines.

Non-standard braided type brake lines must be certified for road use here in Australia and are subject to very high standards of construction and assembly. Custom made brake lines must be put together by professionals, and is not something to be done on a DIY basis. This is VERY important, poorly assembled or fitted brake lines can cause total and unexpected brake failure if the braided hoses separates from its fittings. You don’t want to be stopping your WRX with your heels like Fred Flintstone. Get it done right the first time. Although, no doubt MRT Performance sells cowboy boots with Carbon/Kevlar heels for those that want to do it Fred’s way, a better option is a set of performance brake lines starting from A$260.

10.2.6 Brake Master Cylinder Brace



Master Cylinder Brake Support Bracket

Flexing of the brake master cylinder / vacuum booster assembly where it attaches to the engine bay firewall / bulkhead is a major contributing factor towards a spongy pedal, while also increasing pedal travel. For a graphic illustration of this, turn the engine off, then get an assistant to repeatedly pump the brake pedal firmly while you watch the master cylinder / vacuum booster assembly and you will see how the entire unit deflects by up to 5 - 10mm each time the brake pedal is depressed.

Bracing the brake pedal assembly with a specially designed bracket that attaches to the strut tower will substantially reduce pedal travel. Cheap and cheerful, available for either RHD or LHD (around A$120) they are easily installed with basic hand tools. While not directly contributing to brake force, the brake support bracket will let you better feel and modulate applied brake force and are excellent value for money.

10.2.7 Major Brake Replacement

P10.10 Insert Pic
Ultimate Brake Package Disc and Calliper

If you have a Version IV or earlier car, or a North American spec Version VII, consider fitting Subaru's own four piston brake callipers to the front. Version IV and earlier cars will also require the larger diameter 296mm discs. North American Version VII and later WRXs have the bigger diameter discs fitted already. An upgrade to the larger callipers and discs is a relatively easy way of quickly bringing the braking standard of your car up to current specifications. A conversion kit consisting of new front callipers and brake discs will cost around A$1950.

We can all be envious of Version VII and later STis that have those amazing Brembo brakes fitted to their vehicles. For those of us mere mortals that don't have access to that vehicle, there is a solution. To be spoken with head bowed and in a deep voice: *The Ultimate Brake Package*….. For serious enthusiasts that demand the best, and have the sponduliks (money) to pay for it.

Alcon Brake Package Calliper and Mounting

In another good example of how far companies doing business in the WRX performance industry have come, is the extensive array of complete bolt-on replacement brake packages at a price that has fallen dramatically over the last few years. Some kits feature four and sometimes six piston callipers gripping enormous 330mm discs. Such is the size of these disc / calliper combinations 17 inch wheels are mandatory to provide enough clearance. It is not all good news, as there are poor quality brake kits out there that offer little or no improvement over standard, with the exception of looks. Again, check to ensure that the brake lines contained within the kit conform to regulations applicable to your part of the world.

The *Ultimate Brake Package* offers breathtaking performance, capable of slowing your car at such a rate that your eyeballs with try and leave your skull. Superbly engineered and mounted callipers provide beautiful pedal feel and progressive operation, while large alloy hat mounted ventilated discs handle prodigious amounts of heat. Directly proportional to performance is price, good quality kits start from A$4,500. Bear in mind that these brakes may or may not be compatible with standard ABS. Check carefully before purchasing, disconnecting the ABS may be a price worth paying for the *Ultimate Brake Package*, but be sure that you are making an informed decision.

Rear brake upgrades are also now available for earlier model and North American models. The solid rear discs can be replaced with ventilated items along with a slightly different single piston calliper that is physically wider to accommodate the thicker vented disc. Two new callipers and discs will start at A$1,450. Current model "22B" style fixed two piston callipers can also be retro-fitted, but requires new hub backing plates, discs and some small parts for the handbrake. Labour costs make this one an expensive option, but parts start out at A$2,100.

Reality Check

The measure of a true performance car is its ability to stop as effortlessly as it accelerates. Even on a tight budget, substantial improvements can be made even for as little as A$220. There is no excuse for skipping these crucial, if un-glamorous items.

10.2.8 Replacing Brake Discs and Pads

Avoid fitting new brake discs and pads at the same time. New pads should always be fitted with old discs and new “green” discs with old pads. Why? Because with use, discs form a heat-hardened surface allowing them to bed in new, soft pads. Similarly used pads will also become heat-treated and are the best way of bedding in new green discs. However this assumes that all used parts are mechanically sound and in good condition. Badly worn or scored brake discs should not be used to bed in new pads, and pads that have worn to suit the contours of scored or warped discs cannot be used to bed green discs. Unless stated specifically by the supplier, never “stand” on the brakes after fitted new pads or discs. Overheating brakes in the early stages of the bedding process will overcook pad and disc material and result in reduced longevity. Sometimes badly worn or damaged brakes will necessitate discs and pads being fitted at the same time. Even more effort should be put into the bedding in process. The longer the time, and more frequent the cycle of heating and cooling before the big “test”, the better most pads and discs will perform. This in one case where stop-start city driving is useful!

Chapter 11

Intake and Exhaust

Intake and Exhaust

Filter This Out

Another perennial argument between advocates of oiled foam vs oiled cotton gauze (K+N) vs the standard paper filter. Which one is best? I'm sure to open a can of worms here, but the foam filter comes out on top by a small margin in pure flow terms, followed closely by K+N, with the stock paper filter last, again only by a small margin. Where it gets interesting is both filtration quality and capacity. The tables are well and truly reversed here, with foam filters languishing in last, with K+N only slightly better, while the stand-out winner is the stock paper filter. Oiled foam filters don't do a real good job of filtering out very fine particles out of the air, and become overloaded with the grunge it does catch very quickly. K+N filters do a better job, but again become overloaded quickly under heavy dust loads. The humble paper filter, courtesy of its larger surface area keeps coming back for more, significantly out-performing aftermarket filters in extreme operating situations and in cases where servicing is grossly neglected. Japanese style open cell foam filters (which generally are supplied un-oiled!) or ones using stainless mesh are even worse in this respect. Designed to work in the concrete jungle that is suburban Tokyo, these filters are only good for stopping large rocks and small furry creatures from being sucked into your engine.
What do you learn from this? Simple, if you live in a dusty environment and have an aftermarket filter, enjoy the power, but clean it regularly!

Both the air intake and exhaust system are fine examples of the cost vs legal vs "keep the masses happy" type constraints under which Subaru build cars. Consequently, there are some very reasonable gains to be made for not a lot of coin in these areas. An added bonus is that once properly sorted, an aftermarket exhaust and intake can help put back some aural character sadly lacking from the standard WRX. Increasing the power of a turbocharged engine depends on getting air in and out of the turbocharger as fast as possible, no real finesse needed here. But, inevitably, the devil is in the detail. By and large quality, presentation and performance of parts has improved greatly since the first edition of Training WRX, however there are still some of the same pitfalls (along with new ones) to watch out for. In this chapter we will investigate what improvements can be made to the stock intake and exhaust.


Version VII OE Air Intake system


Stock WRX Muffler

11.1 Air Intake

In standard form, from Version VII to current, Subaru have finally fitted a proper air intake system that uses a plastic intake scoop that draws air from above the RH headlight, whereas previous models took air from a snorkel from the front of the engine bay. All models make use of a large plastic resonator/water separator box that sits inside of the RH inner guard, feeding air into the airfilter box. On Version IV and later intake air flows from the filter, through an air mass sensor, under the intake manifold and into the turbocharger.

Version I-II Airbox and Intake System

Version I-II cars differ slightly, in that after the AFM, intake air went through a second resonator box before doing a right-angle turn down into the turbocharger that drew its air from behind the intake manifold.

Before any mods are done, a decision needs to be made between a little intake noise, or a lot. This comes down to keeping the stock airfilter box, for a low-key approach, or going the whole hog and opting for a complete replacement airfilter. Often this choice will be made for you, especially in the case of an FMIC, as space limitations require the use of an aftermarket type filter over the standard Airfilter box.

There are four main things that you can do to improve the intake system on your WRX, listed in order of expense:

1. Remove the plastic resonator (a.k.a resonatorectomy) and fit an aftermarket flat-panel filter insert into the stock airfilter box.
2. Do the above and go one step further and fit a “Cold Air Duct” from the front bumper brake cooling duct to the airfilter box intake in the inner guard.
3. Ditch the standard airfilter box completely and substitute for either a pod-style open filter, or a relocated inner-guard remote airfilter and matching cold air pipe.
4. Replace the factory plastic under the intake manifold turbo air inlet pipe with a higher flow moulded silicone item.

Keeping it Clean

Yet another point of contention between proponents of foam or cotton gauze airfilters is the relative ease of cleaning and maintenance of one type over the other. K+N style filters are the clear winner here, especially when using specialised K+N cleaning solvent and filter oil, which is conveniently available in an aerosol can. It’s as easy as spraying the stuff on, leaving it to soak for a few minutes and then rinsing the filter out under the tap. After shaking out excess water, half an hour in the sun is all that is required to dry the filter, at which point it is re-oiled. Job-done. Foam airfilters on the other hand require solvents such as turpentine or kerosene and a careful washing action to free the foam element of trapped dirt. Again, after shaking out the excess solvent a quick sun bathe for the filter dries it sufficiently for re-oiling. Foam filter oil is a terribly sticky compound, almost like golden syrup, and has to be slowly “kneaded” through the filter element, using the minium amount of oil possible. Then there is the problem of disposing of the used solvent, as well as trying to rid your hands of that clingy filter oil without transferring it onto everything you touch. Ah, the price of performance.

11.1.1 Resonator-Ectomy

Still very much a favourite of DIY’ers and spend-thrifts alike, especially if you chose to do it at home in the garage, as it costs nothing except an hour or so spent grubbing around under your car, messing with those fiddly plastic clips Subaru use. Applicable to all model WRXs right from the Version I all the way to current, it is worth around 2kW at the wheels, if you intend on using the stock airfilter box. Follow these steps:

1. Raise the front of the car onto a set of proper automotive jack stands. Do not skimp and use the factory car jack as it is a $10 part. That is unless you have a $10 noggin.
2. Remove the factory airfilter box, this is to access a 10mm headed nut that secures the resonator to the inner wheel arch. Remove this nut along with the short plastic engine bay intake snorkel.
3. Remove the right front wheel in order to gain access to the inner guard and wheel arch area. Remove the plastic fasteners, starting at the rear of the black plastic wheel arch liner. Once you have the wheel arch liner pulled back sufficiently, remove the resonator, which looks like a rigid black plastic bladder approx 20cm across.
4. At this point you can either re-fit the factory Airfilter box leaving clear access into the inner wheel arch, or you can saw off the bottom of the resonator and re-fit the original top half of the resonator, or finally you can purchase a ready made item to help smooth air flow into the airfilter box.
5. Job Done! The resonator will make a useful, um, well nothing at all really. Re-cycle the ugly bugger. Your car will sound almost exactly the same as before. There will be a slight swishing noise under acceleration, but will only be audible with the windows down.

Sticky Situations
Airfilters oiled with a little too much enthusiasm are bad news. They leak oil all over the place and can lead to oil deposits affecting the way an air mass sensor operates. (See *Engine Management* chapter for more details) In extreme circumstances it can even cause air mass sensor failure, especially in Version V and VI models. This does not automatically mean all oiled airfilters should be avoided, as even the OE paper filter is impregnated with oil. Moderation is the key, go easy on the oil!


Air Intake Resonator

11.1.2 Cold Air Ducts

A resonator-ectomy procedure can be taken one step further, by the addition of a cold air pipe. A piece of large diameter of pipe is used to take air from the front bumper bar or brake cooling duct to the airfilter box inlet. Some more elaborate types of air intake could potentially help pressurise the airfilter box at high speed through a basic ram affect.

Common sense is required though, as potentially it can interrupt the flow of cooling air to the front brakes, and its new much lower intake position leaves it open to the possibility of drawing water into the engine during wet weather or water crossings. The same holds true in extremely cold climes, as powdered snow can be drawn in, filling up the airfilter box. Basic cold air ducts start at around A$150 right up to as much as A$700+ for a moulded carbon fibre item.

11.2.3 Complete replacement Airfilters

Gaining popularity of late is a range of nicely made mandrel bent alloy air intake tubes. These parts take the place of the standard airfilter box completely, and remotely mount either an oiled foam or K+N style airfilter in the inner guard. On Version VII and later cars the OE AFM is relocated into a specially calibrated holder incorporated into the cold air pipe.

Version VII-VII WRX Cold Air Intake

Version VI and earlier cars still make use of the factory AFM housing, and this is usually incorporated into the new cold air intake pipe by way of a flanged joint. Again, due to a much lower intake point, care must be exercised when crossing even shallow amounts of water. Relocating the air filter into the inner guard also makes it act like a magnet for road grime etc, requiring frequent cleaning. Cold air intakes with a remotely mounted airfilter kit start at around A$450.

Version VII Rampod Airfilter

Version V-VI Rampod Airfilter

Alternatively, a direct bolt-on airfilter kit can be fitted in place of the standard airfilter box. This keeps the airfilter within the engine bay, and although engine bay air temperatures are generally higher than ambient, this is still offset to a degree by improved (hopefully) flow efficiency over stock. Version VII to current cars use either a cast alloy or machined billet alloy adaptor that mounts the stock AFM. Either an oiled foam or K+N style filter then clamps to this adaptor. Version VI and earlier cars re-use the factory AFM holder and use some sort of flanged joint to attach the new high performance filter. Airfilter kits including mounting brackets and necessary hardware start at around A$250.

Complete replacement airfilters have loads of car-park cred and are easy to spot. This makes it a target of choice for the constabulary here in Australia, as newly passed EPA legislation requires airfilters to be completely enclosed, or be deemed illegal for road use. Noise is another consideration, with earlier Version I-II WRXs being incredibly loud through the intake system due BOV location, sounding very much like hell's Hoover. Later model IV to current are no where near as loud due to their revised BOV placement off the intercooler, merely sounding like Darth Vader with a chest cold. Some find the sound of the turbocharger greedily sucking air, along with the BOV dumping on and off music to their ears, while others find it just plain tiresome.

11.2.4 Silicone Intake Pipes

More relevant for monster tunes, or those chasing the last few neddies from an engine, a replacement silicone turbo intake hose is a worthwhile consideration. When compared to the stock OE item, airflow is improved by a combination of a larger internal diameter, along with smoother radius bends in the silicone item. Available to suit Version III and later cars only, they come complete with all the required fittings for crankcase breather hoses, BOV return and boost control vent pipes.

OE Turbo Intake Pipe

High Flow Silicone Intake Pipe

Somewhat tricky to fit, it is actually possible (by snapping off the crank breather fittings from the plastic OE intake pipe) to remove it without lifting the inlet manifold. Then its just a case of perseverance, a few select curses in Japanese or any other stern words of choice, along with half an hour or so of messing around in order to insert the new intake pipe, and connect up breather hoses etc. All told kiss good-bye to around 3 hours of work in order to install this part. Silicone turbo intake pipes start at A$495 for the full length item that goes from the AFM to the turbo. A slightly cheaper model is available that is a copy of the factory STi silicone inlet, but does not have the nice open radius bends that the full length intake pipe has. Prices do not include installation labour, band-aids for skinned knuckles or swear jar contributions if DIY'ing.

11.2 Exhaust System

Until the advent of the twin-scroll turbo (See *The Turbocharger* Chapter) the WRX's exhaust configuration has remained essentially unchanged since inception. Some minor fiddling of pipe diameters and lengths have taken place, but that is about it. Courtesy of its boxer configuration, complex plumbing is required in order to connect the engine to the turbocharger. Short cast-iron stubs bolt to the cylinder heads to form manifold primaries, creating a two-into one joiner on each side of the engine. From the LHS primary, a stainless steel cross-pipe and flex-joint connect to the RHS primary, which includes a merge collector that joins both secondary pipes into one. This leads to un-equal length exhaust pipes, and is what gives the WRX its characteristic boxer-beat exhaust note. From here a turbo up-pipe and flex supply the turbocharger with exhaust. Some models feature a small pre-catalytic converter in the turbo up-pipe.

OE Exhaust Manifolds

Exhausting Stuff Part 1

Exhaust systems are yet another area subject over enthusiastic reporting of power gains, with some exhaust manufacturers claiming an increase of 25kW or more over stock! More a result of a mismatch between the OE boost control parameters and the new higher flow exhaust system rather then superb engineering. Australian and JDM Spec C STi are an excellent example of this problem. A new higher flow exhaust system causes the turbocharger to overboost massively in the midrange, followed by a large under-boost as the OE boost control system over-compensates. Easily solved through an ECU-reflash or a boost controller, any exhaust system that advertises as not suffering from this problem is probably not really efficient in the first place.

Exhaust exits the turbo into a cheaply made 2.5" OE one-piece dump pipe and catalytic converter assembly. The dump pipe connects to the centre section with a ball and socket type flexible joint and contains a resonator or an additional catalytic converter depending on the market and model. At the other end of the centre section, the rear muffler connects up with a simple two bolt flange.

One area that has changed considerably is exhaust system sensors. Covered in more detail in the *Engine Management* Chapter, sensor specification has become more standardised on Version VII and later models. A four wire lambda sensor is fitted to the RHS exhaust collector, monitoring exhaust gas concentrations pre-turbo. Models with up-pipe cat converters have an exhaust temp thermocouple fitted post converter that monitors exhaust temperature. Downstream of the turbo and catalytic converter(s) is a final lambda sensor responsible for keeping an eye on converter efficiency and operation.

11.2.1 Exhaust System Post Turbo

OE Turbo Dump pipe and flange

There is no disputing that a properly engineered exhaust system will really help spark up a WRX, but what is the reason for this? Three main areas need attention, and they include an overly restrictive rear muffler, relatively small diameter 2.5" connecting pipes, restrictive catalytic converters and that masterpiece of penny-pinching, the turbo dump pipe. Gas that exits through the turbo wastegate immediately smacks up against a flat plate, forcing it to turn 90-degrees, at which point it collides with the exhaust stream exiting the turbine wheel. This forces yet another 90-degree turn as the two gas flows merge, creating turbulence and a degree of localised back-pressure hindering efficient gas flow through the turbine housing.

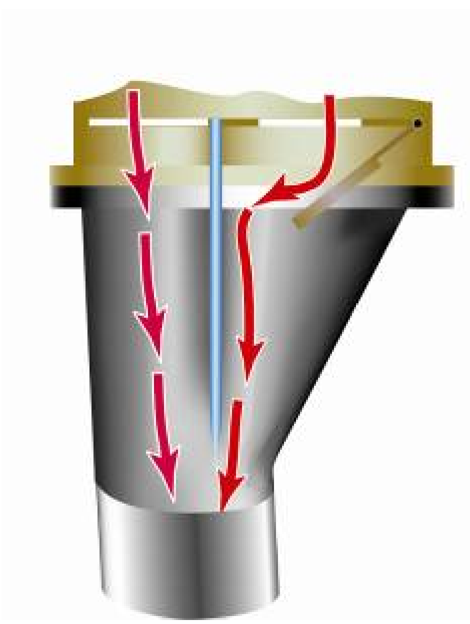
Well engineered exhaust systems will have a splitter plate that protrudes into the back of the turbine housing in order to separate both exhaust streams. Some elaborate exhaust systems keep wastegate gas streams apart for up to 500-600mm from the turbo, imitating WRC configurations. Whether or not a wastegate drop pipe is used, it is of vital importance to keep both gas streams separate and merge them into one as smoothly as possible. Poorly made exhaust systems often retain the flat outlet flange and tack on a 3" piece of pipe, or simply use a large undivided bell-mouth arrangement. Testing and data logging has found that even small amounts of turbulence present behind the exhaust turbine, caused by badly made dump pipes reduces throttle response and increases spool time noticeably.

Turbo Collector With Splitter

Exhausting Stuff Part 2

What is a catalytic converter? It sounds like something out of a bad science experiment. Exhaust gases are passed though a ceramic monolith or biscuit containing thousands of cells. Each cell is coated with tiny quantities of precious metals like Palladium and Platinum. When at its correct operating temperature, and at a very specific air-fuel ratio a chemical reaction takes place, breaking down nasty combustion by-products such as Carbon Monoxide, oxides of Nitrogen and Hydrocarbons into less dangerous compounds. In somewhat of a miracle, modern cars when operating in this clean mode will actually produce exhaust gasses that are cleaner than the air in some of the world's most heavily polluted cities. Be kind to flora and fauna alike and keep a cat in your car.

After the turbo collector exhaust gas should flow through a catalytic converter of a nominal diameter of 3". Cat converters have something of a bad reputation for hindering exhaust flow and large amounts of additional power can be made by deleting the cat. This simply is not true if the correct converter is matched to suit the application at hand. A common trick in the exhaust industry is to cut the ends off a 2" cat converter in order to convert it to 3" inlets and outlets. While technically a 3" cat, the internals are designed for a 2" pipe size. This will restrict performance! Recently, high temperature stainless steel monolith converters previously the domain of motorsport and expensive exotica alike are now available to us mere mortals. Capable of withstanding extremely high exhaust temperatures and rich fuel mixtures, these units offer no performance penalty and are quite compact in nature easing installation.



Turbo Collector illustration

Stainless Monolith Converter

Converters only begin to work at temperatures above 350DegC – this is called “light off temperature”. Good performance exhaust systems will imitate the factory exhaust by placing the cat as close to the heat source (engine) as possible. Re-locating the cat further back in a horizontal location is cheaper and easier, but increases light-off time raising the possibility of CE lights being illuminated, especially on Version VII and later cars. Another less well understood concept is that cat converters don’t like big variations in temperature and relocating it to an underfloor location can lead to fatigue failures caused by thermal shock from excessive cycling between cold and hot.

Post cat converter, well made systems will feature some sort of flex joint where the centre section connects to the cat pipe. A subject of much conjecture, a flex joint is a worthy inclusion for the sake of NVH and long-term durability. The very best type of flex joint is a 3” ball and socket design similar to the OE unit otherwise a dual layer braided stainless steel mesh flex is a good alternative.

Pic Cannon Rear Muffler

A centre section resonator as an option is another sign of a well-designed exhaust system. If you intend on a lot of free-way driving or just don’t like too much noise, a centre resonator helps dampen out much of the booming and drumming present in large diameter exhaust systems.

Lastly is the rear muffler. The two most popular choices are either a straight through "cannon" or a muffler that features internal baffling and diverters to help keep noise to a minimum. Cannon type mufflers offer the least amount of flow restriction and the most amount of exhaust noise. A lower noise option is a "triple-flow" type rear muffler, which although has a tiny performance disadvantage when compared to the Cannon unit, is a much easier muffler to live with in the long run.

Spendthrifts or those on a budget take note, very reasonable power gains can be made for limited bucks simply by replacing the rear muffler. All good exhaust systems are modular, allowing exhausts to be done in stages. Good quality turboback exhausts start at A$1,800 through to A$2,300. Expect to pay an additional A$200-400 for a whiz bang high flow stainless steel cat converter in place of the usual ceramic item depending on size. A quality bolt-on rear muffler starts at around A$630 and is easily fitted at home with a couple of spanners.

Un-Obtanium

Somewhat of a wunder-metal, Titanium matches steel for strength, but is lighter and tolerant of very high temperatures while exhibiting excellent corrosion resistance. Very much the mainstay of the aerospace industry and professional Motorsport teams for some time due to its extremely high cost, recent advances in production and manufacturing processes have driven down the cost to the point that exhaust systems can now be made out of Titanium for a reasonable price. Established Japanese tuners such as Tanabe, APeXi and GReddy are all aggressively marketing Titanium systems. Minor weight savings aside, Titanium offers no performance advantage over stainless steel. Car-park cred rating on the other hand goes right off the Richter scale for those seeking an authentic JDM look. Cat back Titanium systems start from around A$1.550.

Pic 3" Exhaust System Centre Resonator

WRX Performance Exhaust System Checklist:

- All good exhaust systems should be 3" in diameter. Larger diameter 3.5 or 4" systems may make slightly more grunt in very high power applications, but are terribly noisy and difficult to package without rattling or banging on powertrain components or the bodywork. Exhaust pipe should be mandrel bent (A mandrel is a solid rod of the same internal diameter of the pipe being bent. It is inserted into the pipe during the bending process, thus preventing the pipe from kinking, which reduces it's cross-sectional area and flow capacity)
- Stainless steel is the material of choice for a WRX exhaust system, due to its superior strength and corrosion resistance when compared to mild steel, albeit at 30% increase in cost when compared to steel. Post turbo exhaust temperatures can reach in excess of 1000DegC under sustained heavy loadings. At this temperature mild steel begins to rapidly break down, reducing its lifespan considerably. There are two grades of stainless steel, with grade '304' being the material of choice, rather than the cheaper but weaker '409' variety. Do the magnet check, it if sticks, you've got cheap stainless steel.
- Beware of mild steel systems advertised as having a high temperature coating. Normally this coating flakes off within 6-12 months leaving the steel underneath unprotected and susceptible to corrosion.
- The turbo collector must have a large flange plate that fits precisely across the face of the turbine housing. It must also have some sort of separator that divides wastegate gas from the main exhaust stream for some distance before merging the two flows smoothly into one. Note that a splitter fitted within the collector made for the stock Mitsubishi turbo (TD04 or TD05 depending on year model) will need some mods in order to fit an IHI turbocharger due to differences in the turbine housing.
- Where possible the cat should be situated in the OE position, this will help reduce problems with the CE light illuminating or emissions tests. Provisions should exist in the system in order to accurately re-fit OE exhaust sensors.
- A centre resonator option should be available, as this allows some flexibility in tuning the amount of exhaust noise present. It is comforting to drive away with an exhaust system knowing that it can be quietened if your significant "other" takes you to task over it!
- Some sort of flexible joint should exist between the cat and centre sections. Steer clear of cheap single layer flex joints as they have a very short lifespan in turbo applications.

- The entire system should be modular in construction, bolting up to the OE mounting points. Systems that don't use all of the OE exhaust mounts suffer from excessive vibration and can fatigue crack. Stainless steel has a high coefficient of thermal expansion – it grows measurably when hot and needs to be factored into the original design.
- The complete system should conform to the rules and regulations of the land. This means both noise and emissions and has important implications when it comes to resale value. Just because you like the noise, it doesn't mean the next owner will.

11.2.2 Exhaust System Pre Turbo

Replacement Turbo Up-Pipe

Turbo models that come standard with a cat converter in the turbo up-pipe should have this part replaced even if basic modifications are planned. They are quite fragile in nature and even small increases in boost pressures above stock can cause them to fail, either partially blocking the up-pipe dramatically reducing performance, or breaking off into pieces that can damage the turbocharger. Replacement up-pipes sans converter are readily available. Pipes with a double layer stainless flex joint start at A$275. Removal of the up-pipe cat and thermocouple will switch on the CE light and log a fault code. This requires a couple of minor electronic mods or an ECU reflash to prevent this from reoccurring. Check with your tuner on this. Watch out for cheap non-lined flexible joints in replacement up-pipes as they can begin to leak producing an annoying whistle. Avoid up-pipes with no flex, as a solid pipe can alternatively grow or shrink by a total of 3 - 4mm introducing the possibility of fatigue cracking.

Having Your Cake and Eating It!

Imagine an exhaust system for your WRX that is nice and quiet when tootling around town or cruising the freeway, but changes character Jekyll and Hyde like automatically when you stick your boot into it for a bit of a fang. Sound like the impossible dream? For some time now systems have been available on the market featuring diverter valve assembly that switches exhaust flow from going through the OE exhaust or out through a secondary straight through or "screamer" pipe. A bit tiresome to use as they are either on or off, and require driver input to activate. This has now changed with the introduction of the active exhaust system (AES) designed and manufactured here in Australia. AES uses a butterfly mounted just upstream from the rear muffler driven by a vacuum diaphragm enabling it to be set in a variety of positions between fully open and partially closed, regulating exhaust noise by increasing or decreasing exhaust back pressure. While a few road cars already use butterflies fitted to the rear muffler (twin-turbo B4), what makes this system radically different is its electronic control system. AES uses an electronic brain-box monitoring exhaust back pressure and throttle opening, enabling control of butterfly position according to driving conditions, so that under full throttle, or above a certain boost pressure the butterfly in the exhaust opens fully for maximum performance (and noise) easing back into stealth mode when the pressure is off, without any driver input. Kinda neat in concept, one can picture re-enacting the scene in the movie Red October where Sean Connery barks the order "engage the silent drive" time and time again. AES systems start at A$700 excluding installation.

HKS Exhaust Headers

Many different choices are now available as replacements for the OE exhaust manifolds. In the past it was either pay massive amounts of money for a set of hand-crafted one-off items, or use crudely made copies of the original part. This is now a thing of the past, and there is no shortage of choice or options in this respect. Questions over when or why this mod should be done still remain though. Normally the stock manifolds are a reasonable bit of kit and do their job well, but in the case of highly modified 2.0 and 2.5ltr cars, significant improvements in mid-range and top-end power can be made by switching to a set of quality replacement headers.

Spotting a good set of headers is a much harder task, but basically it boils down to paying peanuts will get a monkey every time. A set of bargain basement $A599 poorly designed pipes are hardly going to be the key to big power gains. There is a very close relationship between pipe diameters and primary pipe lengths and need to be right in order to make serious power. Good replacement headers will feature equal length primary and secondary pipe lengths to take advantage power gains through exhaust tuning.

Headers manufactured by the leading Japanese tuners are among the best performing and best quality units on the market, as these parts are virtual masterpieces of fabrication and worth big car park cred as long as your mates are no more than 30cm tall. This comes at a price though, a set of HKS headers as an example with slip-joints start at A$2,200 including up-pipe. Check carefully what comes with the kit, as some headers require you to reuse the stock turbo up-pipe, while others can often interfere with the "U" shaped chassis bracing fitted to Version VII and later cars. Other brands of aftermarket headers can also encroach on space used by larger capacity competition type engine oil sumps. Careful attention must also be made to insulating critical parts from radiated heat, as they don't have the same elaborate heat shields as the OE part. Radiator cooling fan wiring and connectors are particularly prone to heat damage caused by un-insulated headers.

WRX

RA Manifolds *WRX OE Manifolds*

For the budget conscious, or those with a canny eye for a bargain, early model RS Liberty/Legacy OE headers use larger internal diameter pipes and different shaped cast-iron collectors for improved exhaust tuning. Version I-II RA engines use different length cast iron primary pipes.

Single Outlet Rear Muffler *Twin Outlet Rear Muffler*

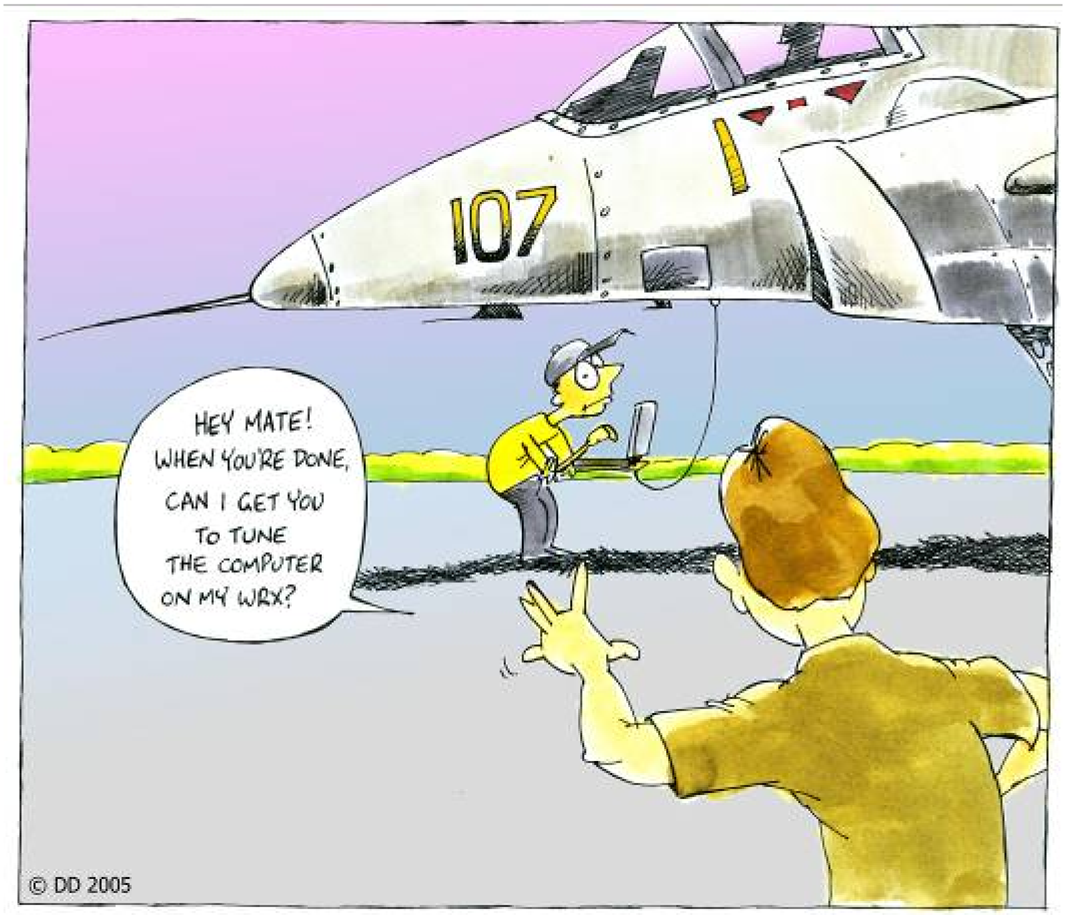
Conclusion

Both the intake and exhaust system are two of the best value for money improvements that not only improve performance, but also make your WRX sound and feel more exciting, while providing a solid base for any future modifications. Choose wisely and benefit from the experience of others. You have to live with your new exhaust and intake on a daily basis. Make the wrong choice and it could grow into something you hate. Not to mention leading to a lot of time by the hard shoulder having your details checked by Mr Plod.

AES System Installed

AES Controller

Chapter 12



Engine Management

Engine Management

Easily the most important piece of the performance puzzle when it comes to increasing the power of a WRX engine. Without powerful electronic management systems, we might as well be back in the performance equivalent of the Stone Age, rubbing sticks together trying to make fire and belting things with rocks. Imagine attempting to make 450kW out of a 2.0ltr turbocharged engine with carburettors, distributors and points? Well, in all probability there are talented operators that exist, given enough time and money that could prove this statement wrong, but you get the picture. As cheesy as it sounds, engine management are the brains of the car.

Subaru fits the WRX with an extremely sophisticated and powerful Engine Control Unit (ECU), especially in Version VII and later model cars. The ECU operates like any other computer; taking information from a wide variety of sensors, processing the collected data, and based on this, generates a number of output functions. It is these output functions that determine actual engine operating parameters such as the amount of fuel injected, ignition advance and turbo boost pressure to name but a few. These are complex calculations, with the input/process/output routine repeating on a continuous basis over and over again. In addition the ECU continually error checks the validity of inputted data, and its own internal calculations compared against actualoperation and performance in order to keep the engine operating safely.

Flashing

Normally conjures images of individuals in long raincoats taking part in very socially un-acceptable pastimes. Thankfully there is none of that behaviour in this fine publication; the kind of flashing I am talking about is *flash-programming* of ECU ROMs. Flash programmable ROMs are a family of memory chips that can be erased and reprogrammed on-the-fly countless times. Used in wide variety of electronic consumer goods, the attraction for vehicle manufactures is obvious; ECU hardware can be standardised for use across a wide range of cars with only a calibration data change required. More importantly, upgrades or “patches” can be easily applied throughout the life of the car in response to possible engine management or emissions issues. In typical form, the aftermarket has wasted no time latching onto this feature, with companies such as EcuTeK, Cobb and Techtom exploiting this new found functionality, marketing engine calibration software of varying sophistication. So much so, craggy grease-stained blokey type mechanics are no longer the real horsepower heroes, as this title has shifted across to pointy-headed software programmers. It is revenge of the nerds, real-time and in your motorcar!

Flash 99 Subaru ECU

In this chapter we will investigate the electronic "brain-box" of the WRX; what makes it tick, and what technology is available to (hopefully) improve engine management and increase engine power.

12.1 System Designations

The evolutionary process of the WRX engine management systems can be described in four broad steps, with the advent of flash re-tuning of the OE ECU being the defining factor. Flash tuning is something of a revolution in the aftermarket performance industry, and will be discussed later in this chapter. OE Subaru ECU's are divided into the following:

- **Pre-flash** – Version I-IV ECUs were very much the dark ages when it came of performance tuning. Early models could be modified with the addition of a plug-in chip, but with limited results.
- **Flash 99-00** – first Subaru ECU to allow commercially viable flash re-tuning, in addition to a sophisticated ECU generated data stream, accessible via the OBDII data port. Fuel and ignition timing are calculated by referencing grams per second of air mass against RPM.
- **Flash 02** – current generation ECU, as fitted to WRX models and Australian spec STi. Supports active variable camshaft system (AVCS) but not drive by wire (DBW). Uses a much more sophisticated fuel and ignition calculation, expressed in grams per cylinder charge, determined by a combination of mass air flow, manifold pressure and throttle position.
- **Flash 04 –** the very latest ECU system used by Subaru, continuing on with the control architecture of Flash 02, with the addition of key features such as DBW throttle control and CAN bus communication protocols. Used by range topping XT Forester and USDM STi variants as well as the MY06 onwards Impreza WRX and STi. Liberty/Legacy GT models feature double AVCS (both intake and exhaust cam control).

Although attempting to cover the intricate details of each and every system would be an exercise in tedium, we will take a bit of a peek at what makes the current generation of Subaru ECU so sophisticated.

12.2 Flash 04 ECU Operation

ECU Inputs

Version VII-VIII Air Mass Sensor

There are a surprising number of sensors providing data to the ECU:

- **Cam/Crankshaft position sensors** – provides information from which the ECU can determine the exact rotational position of the engine, RPM and rate of acceleration. This is used to enable sequential fuel injection, or the control of individual fuel injectors, in addition to sophisticated miss-fire detection functions. Base ignition timing is also calculated from these two sensors.
- **Camshaft position** – on engines equipped with AVCS, additional sensors in the cylinder head monitor camshaft timing for closed loop valve timing control.
- **Air mass sensor** – calculates the actual weight of incoming intake charge and is a major determining parameter used by the ECU to calculate both injection time and ignition advance. Flash 02 and later equipped air mass sensors feature an in-built air temperature sensor that further improves sensor accuracy.
- **Intake air temperature** - STi only, (MY99/00), measures inlet air temperature for fine tuning ignition and boost compensations.
- **Manifold pressure or MAP sensor** – monitors manifold air pressure. Used by the ECU to determine injection time, ignition advance, boost control as well as an overboost safety cut function.
- **Throttle pedal position sensor** – DBW equipped engines use this sensor to “request” a given throttle position depending how hard the driver stands on the “loud” pedal.
- **Throttle position sensor (TPS**) – DBW equipped engines have two sensors measuring actual throttle butterfly position at the engine. Used to verify that commanded throttle position is being applied correctly. Non-DBW equipped engines have only one TPS sensor. TPS is another determining factor in the calculation of fuel and ignition delivery.

- **Front and rear Lambda or "Oxygen" sensors** – used by the engine for closed-loop fuel control and the monitoring of catalytic converter efficiency. Cat converters operate efficiently only around a very narrow air fuel ratio band of around lambda 0.99 or 14.64:1 in air fuel ratio.
- **Engine coolant temperature sensor** – used to adjust fuel mixtures and engine idle speed for cold starts, and to switch radiator cooling fans on and off.
- **Knock sensor** – a specially tuned microphone that the ECU uses to "listen" for the tell-tale sounds of detonation. Ignition timing and fuel mixtures are modified from feedback supplied by this sensor.
- **Vehicle speed sensor** – cooling fan operation, idle speed, speed limiters (JDM models) and fuel shut-off on deceleration are modified in reference to road speed. Boost control is also modified to provide "soft" speed limiting by reducing boost pressure at high road speeds on certain models.

Round in Circles

Open loop and closed loop is a couple of terms used to describe two different ECU control strategies. Closed loop is an operating condition that occurs at low load with a warm engine, where catalytic converter performance is given priority over engine power. The ECU operates in an unbroken loop, commanding a base fuel delivery, which is in turned trimmed in response to information from the oxygen sensor in order to maintain fuel mixtures at lambda 1. (Lambda 1 = 14.74 Air / fuel) Increasing load and RPM past a predetermined amount forces the ECU out of closed loop, into a state imaginatively called open loop. In this mode the ECU ignores lambda sensor output, fuelling the engine with priority given to maximum engine power.

Sensor Failures

As a general rule, most electronic components fitted to the WRX have proved to be extremely reliable in service, with one notable exception. Air mass sensors fitted to Version V and VI cars are a bit on the fragile side, especially when used with aftermarket airfilters. This type of air mass sensor uses a "hot film" sensing element. The ECU monitors the amount of cooling effect air has passing by the heated sensing surface, and from this datum can calculate with a high degree of accuracy the actual weight of the intake charge. Less desirable is the effect of contamination by particulates and oil residue can have on sensor operation. Even small amounts of dust or oil can be enough to reduce sensor output by up to 30-50%, seriously compromising engine operation. Correct operation can sometimes be restored by carefully cleaning the sensor element with electronic contact cleaner. Note, not contact lubricant, as this will make any sensor contamination issues worse. Cleaning is not always successful, as these sensors do suffer cumulative damage. Professional repair workshops will make a special point of checking this part during routine servicing.

Additional inputs are taken (depending on exact model) from sources such as; tumble valve position, ignition and starter switch, neutral position switch, A/C request, blower fan, rear demist switch, fuel level, fuel tank pressure and temperature. Whew!

Pic Crankshaft Sensor

During the processing phase, where all this information is digested, such is the critical nature of throttle control, DBW equipped ECUs make use of dual processors that constantly cross-check DBW system operation and performance.

ECU Outputs

Once processing is complete major actuators directly controlled include:

- **Fuel injectors** – inject a precisely metered quantity of fuel onto the back of the inlet valve.
- **Ignition coils** – triggered by the ECU to create a spark event at the individual ignition coils / spark plugs.
- **Boost control solenoid** – modulates turbo boost pressures to pre-set levels.
- **Fuel pump control unit** – the ECU varies fuel pump duty cycle in response to changes in engine load.
- **Radiator fan relay** – cooling fans are switched on and off directly by the ECU in response to changes in engine temperature and A/C status.
- **A/C relay** – A/C compressor clutch operation is commanded by the ECU.
- **DBW throttle actuator** – engine idle speed, commanded throttle position are constantly and cruise control are controlled by the ECU in response to A/C operation, cooling fans, electrical loads and cold start, road speed etc.

Pic Version V Fuel Injector

More mundane functions controlled by the ECU include; tumble generator actuator, CE light, tachometer, alternator control, carbon canister purge valve, fuel tank pressure control and engine electrical system.

12.3 Adaptive Learning

Incredibly, despite this enormous workload, the ECU is capable of learning! Feedback gathered from both the Lambda and Knock sensor allows continuous fine-tuning of base fuel and ignition mapping in response to engine wear or environmental conditions. These changes are then adopted on a semi-permanent basis, until such time as either the ECU is reset, power is disconnected completely, or operational conditions force a new round of adaptations.

12.3.1 Fuel Mixture Control

Pic WRX Oxygen Sensor

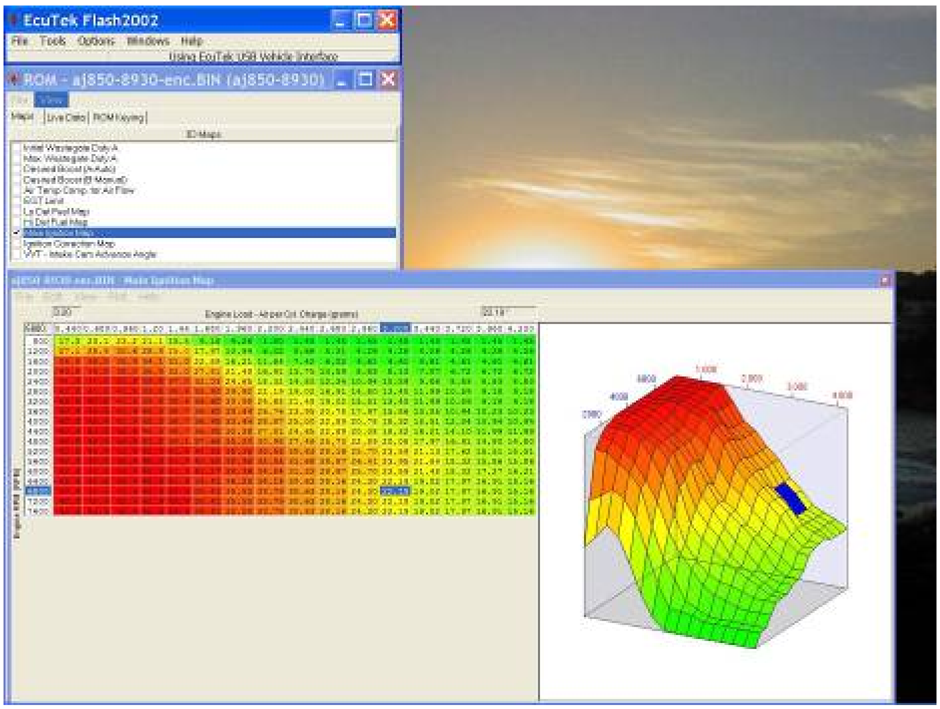
While the ECU is operating in closed loop, corrections will be made to base fuel mapping either richer or leaner, in order to maintain cat-friendly fuel mixtures. Primarily this function is designed to compensate for issues such as engine and sensor ageing, fuel quality and environmental conditions. It is not intended to compensate for gross fuel system changes, such as bigger fuel injectors or low fuel pressure. Fuel adjustment based on oxygen sensor data only occurs during closed loop, and plays no further part in engine fuelling when in open loop. Corrections made while operating in closed loop are remembered by the ECU and are applied as a correction to base fuel mapping.

Air Mass Sensor Calibrations

A poorly understood concept is the relationship between air mass sensor operation and the inner diameter of the tube this sensor is mounted in. Version V-VI engines use a 90 mm unit, while Version VII and onwards use a different type of air mass sensor and use a 68 mm diameter sensing tube. Any increase or decrease in size, however small will have an effect on engine management calibration. Take for example a replacement airfilter kit and air mass sensor intake pipe that has an inner diameter 1.5mm bigger than the 68mm OE unit. This equates to an increase of 4.5% in cross-section and while not sounding like a significant amount, it does have a noticeable effect on fuel mixtures and ignition timing. Particularly at high RPM and loads, where the reduced air mass signal fools the ECU into thinking that the engine is under less load that it really is. Many airfilter kits on the market for late model WRX and STi exploit this fact in order to claim big power gains by fitting their intake. Less desirable is that these power gains are achieved by running the engine far too lean, and with too much ignition timing. Other problems caused by badly made airfilter kits include turbulence resulting in disruption of airflow across the air mass sensor causing significant errors in calculating fuel and ignition values.

12.3.2 Active Ignition Timing Control

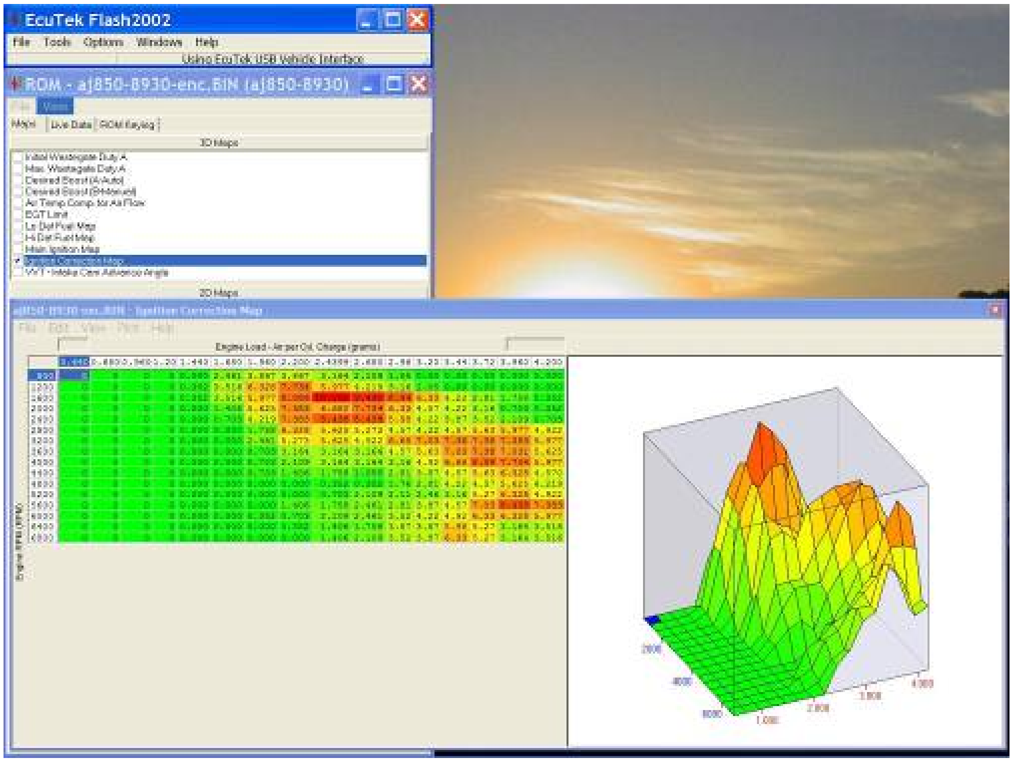
Subaru's own interpretation of closed loop ignition timing control is quite ingenious, and is worth investigating in some detail, as it is on the whole poorly understood and appreciated. Active ignition timing control, as it is known as by Subaru has the desired aim of always attempting to run the highest amount of ignition advance possible in response to changes in fuel quality.



Flash 02 Base Advance Map

There are two different ignition timing maps, the first being a base map, containing ignition advance values to suit the lowest grade of fuel the engine is ever likely to use. In normal circumstances, these are the least amounts of ignition advance the engine should run in most situations. The second map, imaginatively known as the ignition advance correction map contains advance values, that when combined with that of the base map, should equal the maximum amount of advance required to efficiently use the highest grade of fuel the ECU has been calibrated to suit.

Active ignition timing control is broken up into three very specific zones of engine operation:



Flash 02 Advance Correction Map

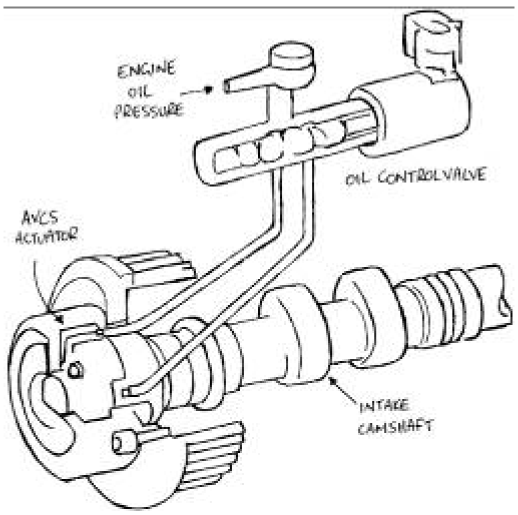
Low load – in situations such as idling, cruise, light city driving and when the ECU is operating in closed loop, there is a very specific maximum amount of ignition advance useable. In industry jargon it is called MBT (minimum best timing), or the minimum amount of advance needed for an engine to make best possible power. During light loads it is very easy to achieve MBT irrespective of fuel quality used. Attempting to run more advance, even with high grade fuel will not result in any real increases in power, but does have serious implications for exhaust emissions. As a consequence, the advance map component of overall ignition timing contains no advance values to be applied on top of base ignition advance at low load.

Medium load – this is the area where Subaru's timing control system comes into its own, especially around the point at which peak torque is achieved. In these situations the advance map contains high advance values, as it can be very hard to achieve MBT before the engine starts to detonate. Contributing factors to an inability to achieve MBT under boost around peak torque can include low octane fuel, ambient temperature, intercooler performance and of course the actual amount of boost pressure used. But when conditions are right, active ignition timing control has enough capacity to significantly increase the amount of ignition advance, so as to achieve MBT. Thus making the most of higher quality fuel and in so doing, maximising performance and fuel efficiency, while keeping combustion and exhaust temperatures low.

High load – ignition timing values in both the base and advance maps begins to flatten off at high RPM. The OE ECU ignores Knock sensor feedback after 6000 RPM. As the Knock sensor is only a specially tuned microphone, it can become difficult to differentiate between detonation events and background engine noise at high load and RPMs. Consequently, ECU mapping is conservative, opting for “safe” advance values for less sensitivity to fuel quality.

The ratio in which the advance map is applied to base ignition timing is called the “advance multiplier”. Often referred to as the “happy” factor by tuners, the OE ECU will use a scale of zero to 16 and is the number of sixteenths of the advance map that the ECU is willing to use. 16 being very good, 8 neutral and zero very poor. This ratio can be considered as a “coarse” function of ignition timing learning, and is expressed across all RPM and load ranges. For example, if the advance multiplier is at around 8, only 50% of values contained within the advance map will be applied to the base ignition map. Further fine tuning is then applied to this coarse adjustment in the form of 64 separate areas of engine load and RPM.

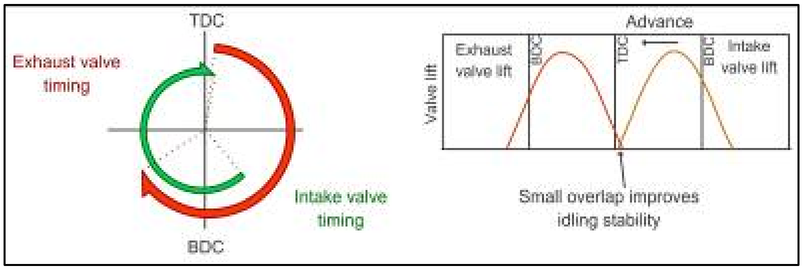
12.4 Active Variable Camshaft Control



Shortened to AVCS by Subaru, this system was first seen on the Version VII STi, and has subsequently filtered down the range (depending on market) into the WRX and Forrester models, where it is used only on the intake camshafts. 2.0ltr Liberty/Legacy engines differ, as they have AVCS on both the intake and exhaust cams. The theory behind controlling camshaft timing is not complex, and revolves around optimising cylinder intake charge filling across a much wider RPM and load band, compared to engines with fixed cam timing, thus maximising engine power and efficiency.

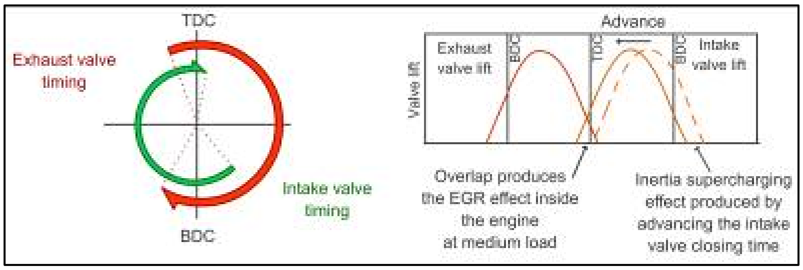
Actual camshaft timing adjustment is controlled by the ECU, based on data gathered by TPS, camshaft position, engine coolant temperature and the air mass sensor. The ECU achieves a desired cam shaft position by pulsing the camshaft oil control valve to a particular duty cycle. This in turn directs pressurised engine oil into two different chambers within the AVCS actuator which is integral with the cam belt pulley. The span of camshaft timing control is restricted to approximately 17 degrees of camshaft movement (35 crankshaft degrees) and is broken up into three basic load/RPM maps:

Idle Quality Control



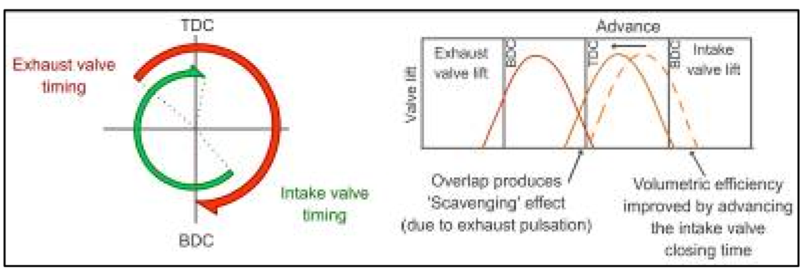
When the engine is idling, or is at very low RPM, the intake camshaft has very little dynamic advance, with comparatively small amounts of overlap between the exhaust and intake cams. This increases intake manifold vacuum for more accurate fuel metering and improved idle stability.

Medium Load



During cruise at medium engine load and RPM, a small amount of advance is applied to the intake camshaft. This causes a degree of overlap between the exhaust and intake cams. This reduces the amount of “stand-off” in the inlet manifold benefiting exhaust emissions. This small amount of overlap also creates a degree of exhaust recirculation (EGR) within the engine for reduced exhaust emissions and peak combustion temperatures while cruising in closed loop. This degree of EGR has the effect of requiring slightly more throttle opening than normal to maintain cruise engine power, which reduces manifold vacuum decreasing pumping losses associated with light throttle cruise, boosting fuel efficiency.

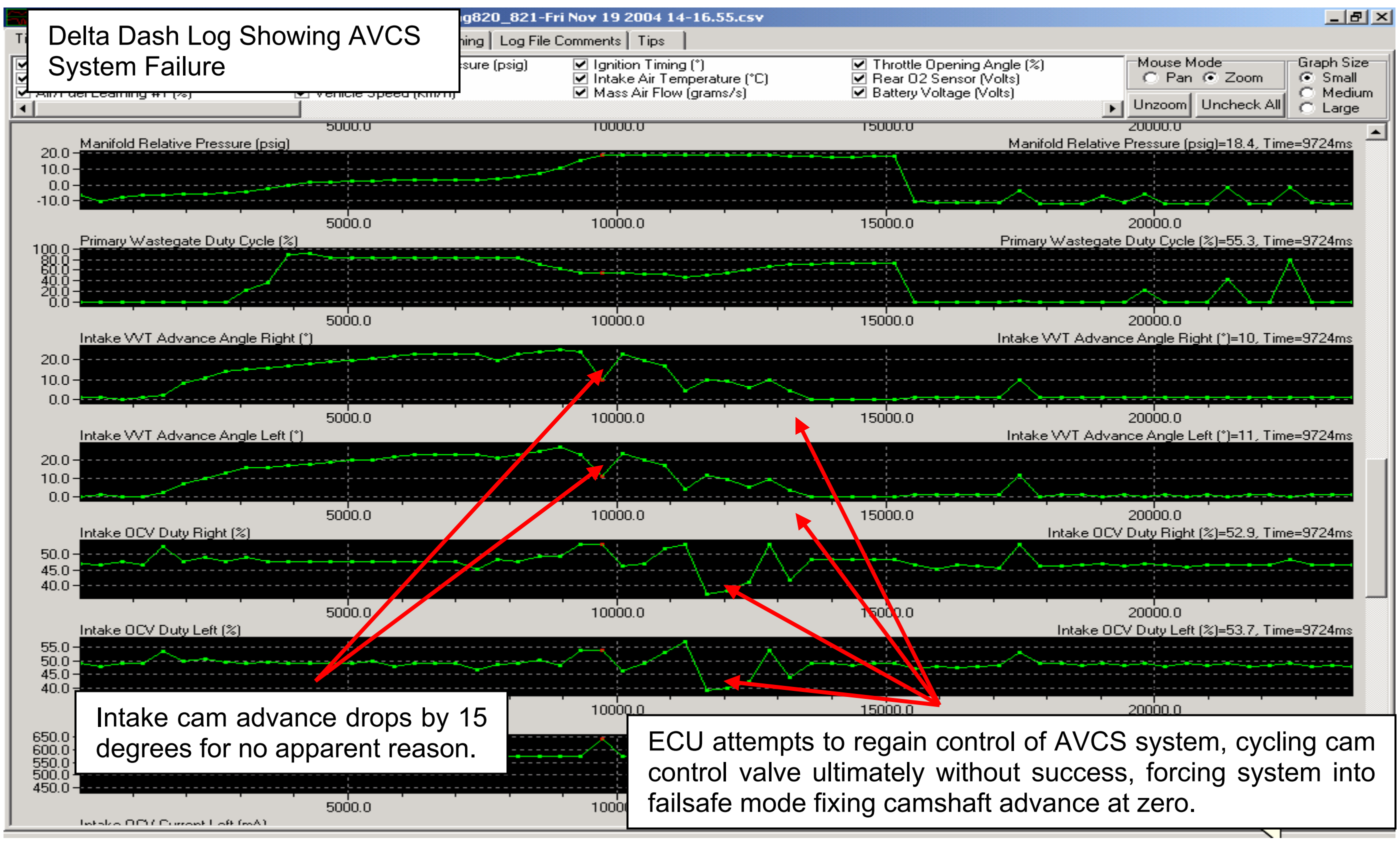
High Load



As engine load and RPM increases towards the top end of its operating range, the intake camshaft is progressively advanced to its maximum amount causing a significant amount of overlap between the intake and exhaust camshafts. This increases the amount of scavenging of exhaust gases from the combustion chamber by making better use of the inertia contained in the outgoing exhaust stream. Cylinder filling on the intake stroke is improved for greater engine power.

12.4.1 AVCS Problems

Some early build Version VII Sti's can have intermittent problems with camshaft control, manifesting itself by forcing the AVCS system into a failsafe mode. The problem was still evident in models up to the MY06, however was less common. An indication that Subaru Japan were aware of this issue was that obvious mechanical design changes were made as the model progressed. Notably AVCS cam control hardware and related software. Whilst not logging a fault code in the self-diagnosis system, power and driveability are effected. Where it does become a big issue is with modified cars, as power outputs can suffer quite dramatically as the system can no longer take advantage of the extra airflow generated by more efficient exhaust systems and higher boost pressures etc. Still very much a work in progress, as neither Subaru nor the aftermarket have a definitive solution to the puzzle. MRT have invested hundreds of hours in this problem and have narrowed it down to several areas. If you own an early model Bugeye STi (or later) and suspect that the AVCS system is not functioning properly, a quick check with Delta Dash (explained in more detail later in this chapter) will confirm system health. See your nearest EcuTeK agent for more information.



Subaru has subsequently ironed most of the bugs out of its cam control system in later model cars, to the point where the system will only shutdown in response to either one or more of the following:

- Low or high engine oil level causing a reduction in lubrication system pressure in the camshaft actuators;
- Aeration of the engine oil caused by too much engine oil in the sump;
- Incorrect viscosity grade or badly contaminated engine oil
- Fault as shown above (in some cases).

12.5 ECU Diagnosis

If all of this whiz-bang action is not enough, the ECU is programmed to reject information from any sensor reading outside of pre-set limits. In the event of a sensor failing totally, the ECU will ignore that particular sensor and will attempt to work around the problem operating in limp-home mode, while at the same time switching on the check engine light on the dashboard. All faults, both current and non-current are stored in the memory of the ECU for retrieval to assist with repairing the fault.

Of course there are limits. The ECU operates exclusively on what the engines sensors are telling it. If the ECU receives incorrect information, it will make changes that can adversely affect performance and driveability. Early model pre-flash ECU cars were especially prone to the ECU changing ignition timing curves in response to the knock sensor, and then being reluctant to change back to the original settings.

12.5.1 Manual ECU Diagnosis and Re-Set

Version I – VI ECU

Subaru Select Monitor

Using Subaru Select Monitor

Making use of the ECU's self-diagnosis system is relatively easy and whatever anyone may tell you, there is no need to purchase Subaru's very expensive "select monitor" computerised diagnosis machine. The self-diagnosis system has three separate modes: read memory, system test check and clear memory mode. Each mode can be activated by alternatively plugging and un-plugging the diagnosis connectors. These are located under the dashboard, between the heater box and the steering column. The green two pin male and female connectors make up the test mode connector, and the black male and female single pin connectors are the read memory mode connector.


Test Check and Clear Memory Connectors

Read Memory Mode

This allows the retrieval of stored faults in the memory of the ECU and is activated by connecting the black single pin male and female connector and then by switching the ignition to the on position. If all is well with the ECU, it will rhythmically flash the check engine light on and off in half-second intervals. Any other combination of flashes denotes a problem with engine sensors or actuators. In this case seek professional advice!

System Check Mode

This is a dynamic test of all of the accessories controlled by the engine ECU. Connecting the green male and female connectors and then switching the ignition to the on position activates it. The ECU will then begin to switch on and off the fuel pump, cooling fans, (alternating between high and low speeds), the A/C compressor clutch (if fitted) and the boost control solenoid. This is one way of verifying the operation of the boost control solenoid. You should hear a rapid clicking from the solenoid, which is fixed to the front of the RHS strut tower (seen from the driver's seat). If there is no clicking the solenoid is probably sticky, which will lead to low boost and performance. Get professional help to service the solenoid.


Version VII Boost Control Solenoid

Clear Memory Mode

Subaru has provided a means of re-setting the self-learning function of the ECU so that it is taken back to original factory settings without disconnecting the battery, handy in this day and age of security coded radios and monitored alarm systems. This allows the ECU to start from scratch, rather than saving any bad habits it might have “learned” along the way. If there were no such bad habits to begin with, this drill will make no difference.

The procedure to reset the engine ECU is as follows:

1. With the engine switched off and the gear selector in park (for auto transmission cars) connect together both the green and black connectors.
2. Switch on the ignition and ensure that the check engine light is illuminated. (If it does not, this denotes a serious system failure, and you should seek professional advice) For auto transmission cars shift the gear lever into neutral and then back to park.
3. Start the engine and then proceed to drive the car for at least one minute keeping road speed above 11km/h.
4. If the engine is not up to operating temperature, stop and warm up by holding the engine above 2000 RPM.
5. At this point the check engine light should start to flash the all-clear signal (half second flashes). If the check engine light flashes a sequence other than all clear, there is a fault present in the system, and it should be professionally checked and repaired as required.

The self diagnosis system is not perfect. It can only detect ECU-related problems. Thus it cannot tell if the fuel filter is blocked, or if the spark plugs are shagged. If all the above checks do not indicate a problem and the car still runs like a woolly goat, there is more than likely a problem elsewhere in the engine control system.

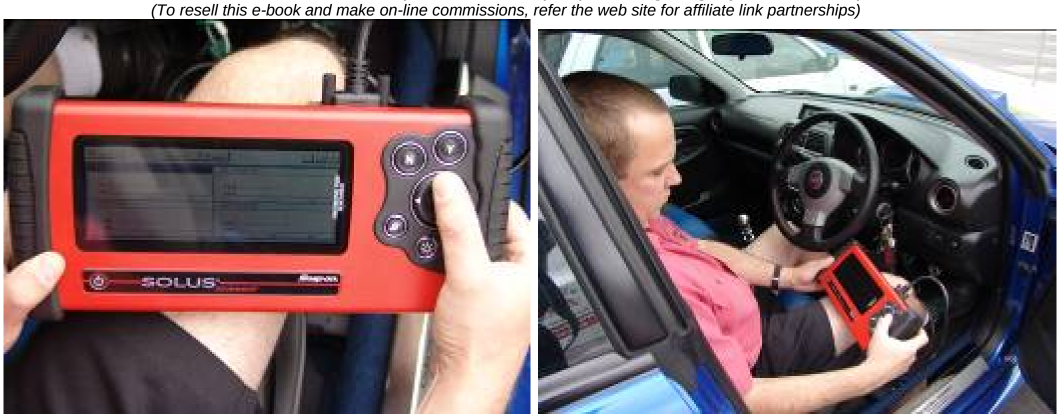
Version VII-VIII ECU

Manually resetting or reading any diagnostic fault codes is not possible on either Flash 02 or 04 equipped cars. Learned fuel and ignition corrections, or fault codes can only be cleared by either EcuTeK Delta Dash, an OBD-II compliant scan tool or by disconnecting the battery for a minimum of 30 seconds.

12.5.2 OBD-II and Subaru Data Stream

The advent of flash compatible ECU designs coincided with a couple of other fortunate developments of particular relevance to owners and tuners alike:

OBD-II – (On-Board Diagnostic system) describes a very specific set of self-diagnosis functions and communications protocol. This extends right down to the shape and layout of the interface plug in order to access this data. Originally devised by the Society of Automotive Engineers, and mandated by both CARB (California Air Resources Board) and the EPA (Environmental Protection Agency), it has subsequently been adopted not only throughout North America, but almost by default as a world standard amongst vehicle manufactures. OBD-II systems produce a generic data stream that as a minimum provides information regarding the status and health of emission control systems, and in particular Lambda sensor operation.



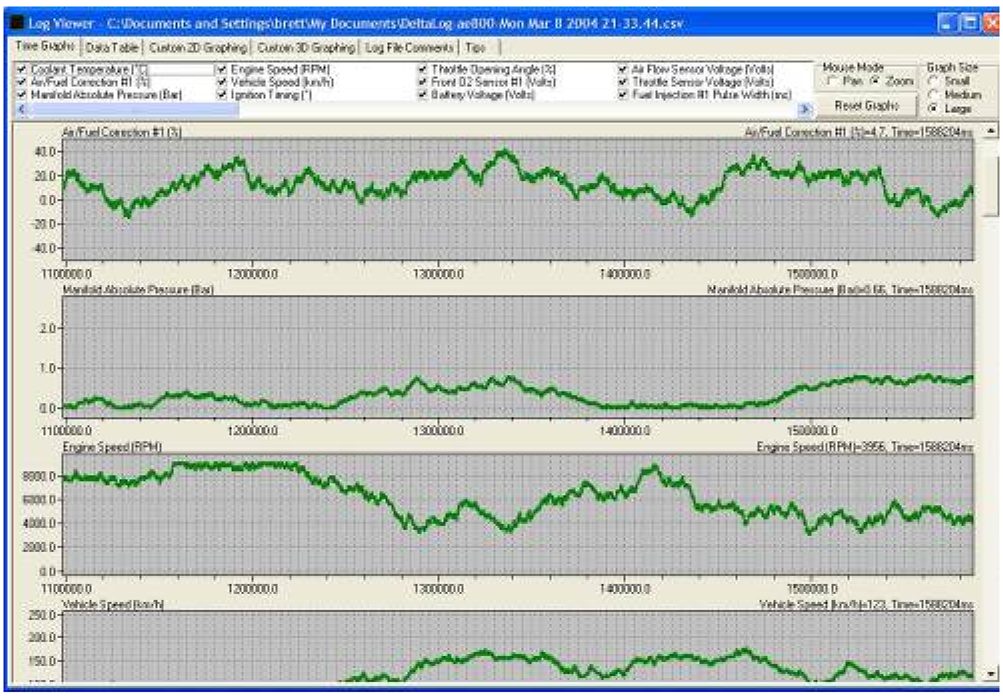
Pic OBD-II SnapOn Scan Unit

One big advantage of OBD-II being an industry standard is the availability of cheap code scanning tools, which provide a means of reading and clearing logged fault codes. Some units will also give access to other engine operational parameters. The actual functionality of these sorts of scan-tools are very dependant on both the cost of the scan tool and that of the OE ECU system. Scan tools start from as little as A$300 for a basic unit that will access all standard OBD-II mandated parameters on OBD-II compatible Subaru ECU systems, while one that accesses the greatly expanded data set provided by flash compatible Subaru systems can cost A$1500 dollars or more.

Subaru ECU Data Stream – late model flash compatible Subaru ECU systems produce a data stream that makes generic OBD-II information look childish in its simplicity. These ECUs produce operating information for just about every single sensor and actuator system connected to the OE ECU, including calculated operating conditions that are derived by combining two or more sensor inputs, engine load being an example of a calculated parameter. Not only does it provide a lot more data to assist with diagnosis and repair of system faults, it is of particular significance for performance tuners. Access to parameter such as knock, fuel injector duty cycle, turbo boost and camshaft control are an invaluable source of information, and opens a whole new window to actual real-time engine operation.

OBD-II Data Port

PC Based Data Collection - standing a whole head and shoulders above the rest when it comes to reading this sophisticated ECU generated data stream is EcuTeK's Delta Dash data acquisition software. Plugging into the OBD-II data port with Delta Dash software on a laptop makes available operational information that even Subaru dealers cannot access. Information can either be accessed real time or logged for replay when required. Logged data can be displayed in table form, or expressed as a run-time graph. Perhaps out of the realm of some users, as Delta Dash requires a large degree of assumed knowledge to extract maximum benefit, committed enthusiasts and tinkerers alike will find plenty of useable functionality. Delta Dash can also read and clear system fault codes, as well as performing ECU resets to clear learned fuel and ignition changes. Available in different options, Delta Dash starts at A$630 for a basic system that supports three different ECU models. Professional variants that can access all EcuTeK supported ECUs start from A$1,400. For information on EcuTeK's stand alone in dash data display see *Interior and Miscellaneous* chapter.



Delta Dash Graph Display

Japanese speciality electronics and software company Techtom offer a Subaru compatible variant of its MDM-100 data display console. It is a basic stand alone display that plugs into the OBD-II port and is self powered. Not capable of any sort of datalogging, it nevertheless can access and display the majority of engine operating parameters in a compact and easy to read unit costing around A$550.

Pic Techtom MDM-100

Dude, What's Happened to my Engine?
Recently a relatively new '04 build Version VIII WRX chugged into MRT's workshop sounding decidedly sickly. A cursory examination quickly revealed that the engine had suffered a major internal haemorrhage and was only running on three cylinders. A compression test confirmed the diagnosis reporting a distinct lack of compression on one cylinder. The owner was horrified when informed that the engine had failed as the car was completely standard and unmodified. Except for one very small detail, an aftermarket airfilter and air mass sensor intake tube had been fitted. Surely this could not cause a catastrophic failure? Think again. The replacement filter tube had an inner diameter 3.5mm bigger than stock, and was enough to fool the ECU into running too much ignition timing and not enough fuel, turning one of the pistons into a paperweight.

12.6 ECU Improvements

No matter how sophisticated the adaptive learning functions are in the OE ECU, mechanical tuning modifications such as exhausts and intakes very quickly push it past the limits of what it can compensate for, requiring some sort of engine management modifications in order to get the maximum benefit.

12.6.1 Mechanical Tuning and the OE ECU

Improving engine power through mechanical upgrades such as free-flowing exhausts, intakes, turbochargers and intercoolers will boost the amount of airflow into the engine over stock. Any increase in airflow is immediately picked up by the air mass sensor. This causes the following things to occur:

Subaru Air Mass Sensors

- Increased load forces the ECU to operate in areas of the fuel and ignition maps that it was not calibrated for, resulting in fuel mixtures that are too rich, eating up some of the power gains made by fitting the parts in the first place.
- Reductions in exhaust back pressure enables more ignition advance to be safely run in the mid range than the active ignition control system is programmed to allow, thus compromising peak potential power.

- Outside of the range of active timing control the ECU is effectively deaf and is programmed with a safe set of ignition timing values. These safe ignition values are for an unmodified engine. At high RPM and loads ignition timing needs to be retarded, especially after 6,000 RPM, or the engine can start to detonate.
- Normally as engine load and RPM increases, both fuel and ignition mapping changes progressively in reaction to this. After modifications, very quickly the ECU can reach the end of its scaling so that in essence fuel and timing becomes fixed at the last set values. This leads to driveability and reliability issues.
- The OE boost control is calibrated to suit a known set of exhaust and intake dynamics. More efficient parts can throw the boost control system to far out of sync for its closed loop boost control system to compensate for. Wild boost fluctuations, over boosting or even under boosting are all possible consequences.

Products that modify the way in which the engine management system works, in order to address the above issues are broken up into four broad groupings. They include re-flashing the OE ECU; fitting an interceptor type add-on controller; complete replacement ECU replacements; and finally plug-in chip upgrades. All of these upgrades have their place in the grand scheme of tuning things, each with their own pros and cons.

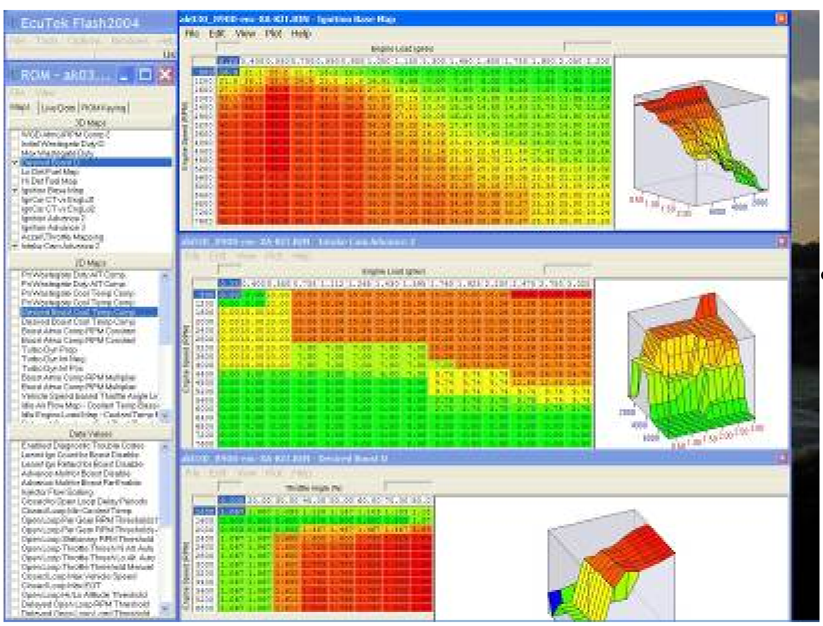
12.6.2 EcuTeK

In the past, even relatively simple performance parts exceeded the capacity of the OE ECU, to the point of becoming somewhat of a liability in terms of power and reliability. The advent of EcuTeK has changed this, as now the OE ECU can be sent back to school for some elocution lessons. Seasoned engine tuners that previously have had no experience with flash ECU tuning, can often be heard to exclaim “I see the light” over and over when using EcuTeK for the first time. In terms of sophistication and functionality, none of the aftermarket engine management products currently available come close to matching that of the OE ECU.

Subaru Flash 04 ECU

Reprogramming the OE ECU is by and far the best method for *correctly* compensating for the effects of mechanical tuning on engine operation. It is simply the quickest, easiest and safest way to come up with a tune to suit most modifications that are ever likely to be performed. Advantages of reprogramming the OE ECU include;

- No need for risky electronic boost clamps, bleed valves, add-on interceptors or boost controllers that otherwise dilute the functional simplicity of the OE management system.
- No modifications to wiring or sensors are required, eliminating the potential for system failures caused by badly cut or spliced wiring.
- Repair and diagnosis of a re-flashed ECU remains *exactly* the same as before. System fault tracing and diagnosis is unchanged simplifying maintenance operations, especially in remote areas away from "specialist" tuners.
- All the inbuilt refinements of the OE system are retained, such as civilised hot and cold starting, throttle response and idle quality.
- Tuning the engine does not have to start from scratch, as the process of optimising performance starts with a set of fuel and ignition maps that are very good to start with. Additionally, only areas of the OE mapping that need to be changed are adjusted, instead of having to start from a clean sheet of paper.
- All adaptive functions of the ECU are retained and can be improved in their operation to harmonise completely with mechanical tuning modifications. Closed loop to open loop fuel control transition points are adjusted to improve engine durability and driveability. Active ignition timing control parameters are modified to increase both engine power and driveability. While reliability is maintained by adjusting the system to react more appropriately in response to the increased intensity at which a modified engine will detonate at.
- Sophisticated safety features built into the OE ECU are maintained, such as sensor error checking, boost and RPM limiting. The ECU also has the ability to dynamically intervene in the event of detectable problems, and as it is still in full control of the boost control system, it can command boost reductions in an attempt to protect the engine from damage.



Flash O4 Software Screen Shot

Parameters that are adjustable via EcuTeK include:

- Base ignition mapping, active ignition parameters and compensations for temperature and pressures.
- Base fuel mapping, closed loop operational parameters and compensations for temperature and pressures.
- Desired boost pressure, overboost safety cut limit, turbo dynamics (to suit different turbos and exhaust characteristics), minimum and maximum wastegate duty cycles and boost pressure based speed limiting.
- Engine idle speed.
- Fuel injector scaling.
- Air mass sensor input scaling.
- And a whole lot more!

What does this mean? In the hands of a skilled engine tuner, substantial improvements to power and driveability are easily within reach without sacrificing any of good features that set the OE ECU apart from anything else available in the aftermarket. Power gains of up to 20kW can be made on otherwise un-modified late model WRX with a simple ECU reflash. When combined with parts such as an exhaust and intake, power increases of 40kW and more can be made over standard. In practice there seems to be really no effective power level at which the OE ECU cannot achieve, although it takes a very skilled operator and a lot more than just a passing familiarity with EcuTeK to extract really big power outputs.

Learning
Sounds weird but the factory ECU has some incredible features and one is its ability to learn. This can work for or against you. In some cases it can “zero” out the modification you just paid hard cash for. However on the other hand it can add some power when it sees the chance to do it!

Optional Parameters that can be added via EcuTeK include:

- Launch control.
- Map switching
- User tune

All these extra features are bonus options developed by the team at EcuTeK. However not all options are available on all ECU;s

EcuTeK reflash and tune costs vary depending on country of origin and level of tune, but as a rough guide a basic off-the-shelf reflash starts at around A$990 for Flash 99 and 02 systems. A basic tune for Flash 04 DBW equipped cars costs around A$1,500 more due to their increased complexity. Consult your nearest EcuTeK dealer for more information.

12.6.3 Chip Upgrades

Flash programmable ECUs have very much relegated plug-in chip upgrades to something of an anachronism these days. ECU functionality and sophistication has multiplied exponentially, greatly increasing the difficulty faced by chip tuners attempting to "hack" sections of the OE operating map in an attempt to find improvements. Additionally, long held attitudes of the chip tuning industry towards manufacturing "one size fits all" chip upgrades are simply out of step with the huge diversity of performance parts available on today's market. Owners of Version I-II stand to benefit the most from plug-in chips manufactured by well established tuners with a proven track record. Prices range from A$550-A$990.

Pic Version II Plug in Chip

12.6.4 Signal Interceptors

Still very much a large section of the performance engine management market and encompasses a wide range of products offering varying degrees of sophistication and ease of use. Without exception, the majority of these products intercept and modify input signal data, in essence "fooling" the OE ECU into doing something it normally would not do. Commonly, fuel corrections are made by bending air mass sensor input, reducing sensor output to lean mixtures, or to compensate for bigger injectors. Timing control is done by manipulating crankshaft position sensor output, either advancing or delaying this signal which in turn has an effect on the base ignition advance commanded by the ECU.

Products such as the Perfect Power SMT6, XEDE, E-manage by Greddy, Interceptor by Haltech and Dastek's Unichip are examples of intercept tuners. The Unichip is probably the least complicated of this group, having humble beginnings as an economy device in South Africa. More sophisticated are the Haltech and XEDE, especially in the area of user software and programming. Irrespective of manufacturer these units act as a "crutch" for the OE computer, coaxing it into doing something that it was not programmed for in the first place. Another popular unit, especially in the US is the UTEC, a sort of hybrid intercept unit that differs in one respect, in that it takes direct control of the ignition system, although this cancels out all the benefits of the OE active ignition and adaptive learning control systems.

Perfect Power SMT6

Haltech Interceptor

Interceptors are a quick and dirty way of making small changes to fuel and ignition mapping in response to changes brought on by mechanical tuning. This "trimming" function is handy when dialling in a new exhaust system or airfilter, but can very quickly get out it's depth when called on to perform major corrections in response to bigger turbochargers and high flow fuel injectors. Compensating for bigger fuel injectors requires the engine load signal (Mass Air Sensor) to be significantly re-scaled so as not to drown the engine in fuel. This fools the computer into thinking that there is a lot less engine load than there actually is, leading to issues with over advanced ignition timing, which then requires a re-scaling of the OE crankshaft position sensor output in order to retard ignition timing. A commonly overlooked by-product of this is the effect it has on injection timing, or the actual point at which the fuel is injected into the intake ports, often wasting fuel, increasing exhaust emissions and more importantly decreasing ultimate power gains.

Additionally, any increase in engine load (read boost pressure and power outputs) over stock has to be "compressed" in order to fit within the boundaries that the OE ECU was programmed to begin with, further compromising the end result. OE ECU functions such as active ignition timing and closed loop fuel control will also tend to compete with what is trying to be achieved with an interceptor. Tuners often have to resort to quite extreme measures such as grossly over-advanced timing and very lean fuel mixtures in order to make more power over stock.

12.6.5 Supplementary Controllers

These parts perform simple tasks and are fitted as an add-on to the OE ECU. Often sold as part of a performance power package such as an exhaust or air intake.

Fuel and Speed Cut Lifters

Fuel cut lifters will stop a MAP sensors signal from rising too far, thus preventing the ECU from going into an overboost safety fuel cut. This allows boost pressure to be increased above stock. A good quality fuel cut lifter will allow the user to very finely adjust (in lots of 0.1Volt) the actual upper voltage limit, in order to minimise interference with other OE ECU functions. Speed cut lifters function in a similar way, in that they change the speed signal that the ECU sees to a value which is under the point at which the ECU activates its speed limiting function. Fuel cut lifters start at A$160 through to A$350 for a speed cut lifter.
NOTE Data from EcuTeK tells us that the OEM ECU uses ignition and fuel trim against vehicle speed, so be wary when fitting such devices

Fuel Cut Lifter

Electronic Boost Controllers

Another popular gizmo is the electronic boost controller or EBC. An EBC is a stand alone unit that allows the driver to select a desired amount of boost from some sort of in-cabin head-unit. The level of sophistication varies greatly, ranging from a simple set of adjusting knobs to units featuring LCD displays. An EBC only controls boost pressure and does not interface with the OE ECU to modify fuel and ignition timing. This means if too much boost pressure is programmed into the EBC, it turns into an electronic self-destruct unit. Dial boost cautiously or dial an engine re-build. EBCs vary greatly in price from around A$500 right up to A$1500

Pic Electronic Boost Controller

Check Engine Light Defender

A simple electronic device used to prevent emission related faults form being logged by the ECU's self diagnosis system, after the removal of one or more of the catalytic converters. This includes the removal of the small cat converter and thermocouple in the turbocharger up-pipe, on those cars so equipped.

Cat Light Defender

12.6.6 Replacement ECUs

MoTeC OEM Style ECU

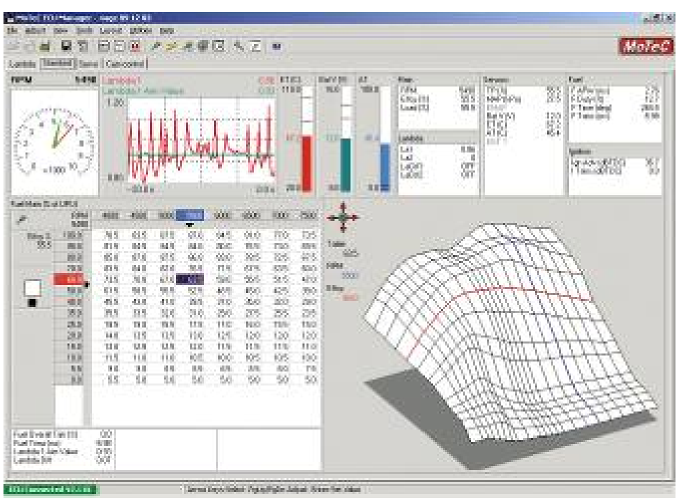
The advent of EcuTeK means that there is no longer such an imperative to junk the OE ECU when chasing big power outputs. This being said, there are still situations where changing to a fully programmable ECU will add functionality that cannot be achieved with stock management, even after a re-flash and complete re-program. Availability of flash tuning software can also be an issue for some applications, as it is not always possible to have a tuner well versed in ECU flash tuning standing by at all times. Mad scientist type operations working on mega-power projects often prefer to do all work including engine mapping in-house. While for race teams, direct access to fuel and ignition mapping, in response to changes in setup or conditions is mandatory. Or simply there are those that just want it all and have the bucks to spend.

Link Plug in ECU

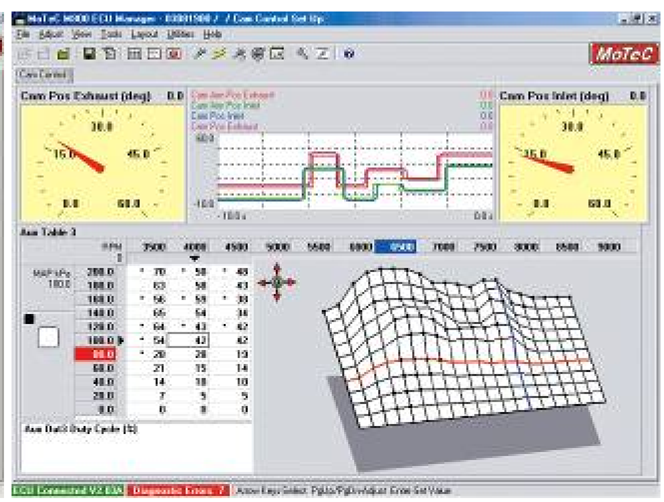
Recent advances in OE ECU technology has left all but the most expensive and sophisticated aftermarket engine management lagging a long way behind. Systems such as AVCS and drive by wire throttle control are notoriously difficult functions to duplicate. This has by and large forced out complete replacement ECUs from the lower end of the price scale, as most manufactures have problems supporting AVCS, let alone DBW. Included in this category are offerings from Link, Haltech, TEC, Wolf, EMS and Microtech. Only Hydra from the US currently advertise as offering an ECU that supports 04-05 STi with AVCS and DBW throttle control at slightly lower than stratospheric prices. This being said, there are reports of teething problems that are still to be ironed out with the Hydra STi ECU.

Haltech E6X

Of the high end of aftermarket management systems; Autronic and MoTeC, only the latter supports DBW throttle control and full closed loop AVCS. Such is the importance of getting DBW control right, MoTeC do not sell a DBW software upgrade for an ECU without the user first shipping their OE throttle pedal and sensor assembly, along with the DBW throttle body and wiring back to MoTeC for inspection!



MoTeC Fuel Table Screen Shot



MoTeC Cam Control Screen

Still very much the unit of choice for cashed-up enthusiasts or motorsport professionals the MoTeC M4/6/800 series of management systems comes the closest to matching OE ECU functionality. But this comes at a price, with a fully optioned MoTeC ECU to suit a late model STi with DBW costing upwards of A$3850 excluding installation.

Some of the goodies associated with higher end management systems include:

Turbocharger anti-lag boost enhancement – anti-lag is a nifty way of keeping the turbo spinning on trailing throttle and at idle. A properly setup system can generate in excess of 1.0bar of boost on a closed throttle, giving razor sharp throttle response. When the anti-lag engages, the ECU retards the ignition timing by up to 180% of normal, while at the same time randomly cutting spark to the cylinders. This results in a large amount of unburned fuel and air entering the exhaust system, where it ignites to give the characteristic popping and banging sound that rally cars exhibit. These explosions greatly increase the energy of the exhaust stream flowing through the exhaust turbine of the turbo, keeping it spinning at high RPM maintaining boost.

Anti-lag has its downsides; if improperly setup it will very quickly turn the exhaust headers into junk and can be a serious health risk for the turbocharger. Regular catalytic converters are not compatible with any form of anti-lag and will self destruct within seconds. Finally, the inefficient process of external combustion in the exhaust headers produces large amounts of toxic emissions. Still, it is a cool feature and gives rally cars that characteristic butch idle like a Rottweiler straining on a leash.

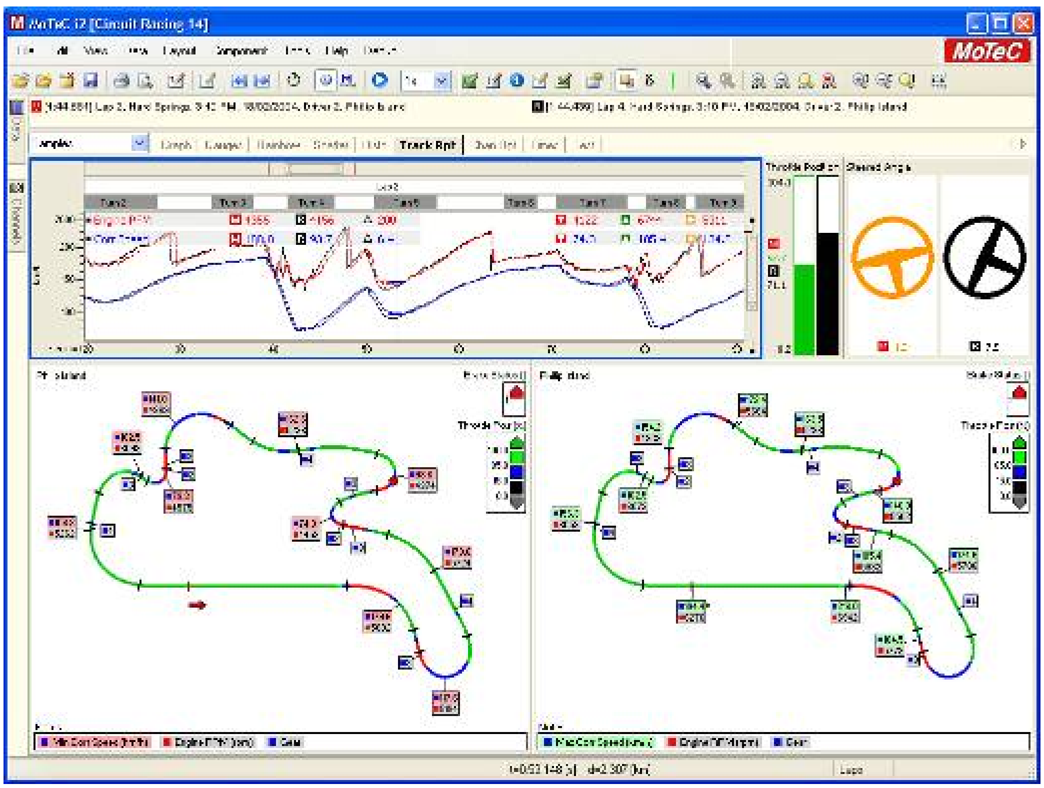
Launch control – not to be confused with traction control, which is very difficult to do with AWD. Launch control allows a user definable RPM point to be set in the computer. This functions as a secondary RPM limiter to make launching from a standing start easier. Launching cleanly can be tricky in an AWD vehicle like the WRX. Too little RPM and the engine bogs down and goes off boost, too many RPMs and engine power either disappears in a cloud of tyre smoke, or the drivetrain runs the risk of dropping it's bundle.

MoTeC Wire-In ECU

Gear change ignition cut – a special system that connects to either a clutch switch or gear shift switch, that momentarily cuts ignition to the engine on gear changes. This unloads the transmission shift mechanism allowing lightning fast gear shifts without the driver having to lift off the throttle. This also keeps the turbocharger spinning making turbo lag a thing of the past. Gear change ignition cut works the best on dog boxes, requiring specialist setup, so as not to turn even the strongest transmission into a pile of junk.

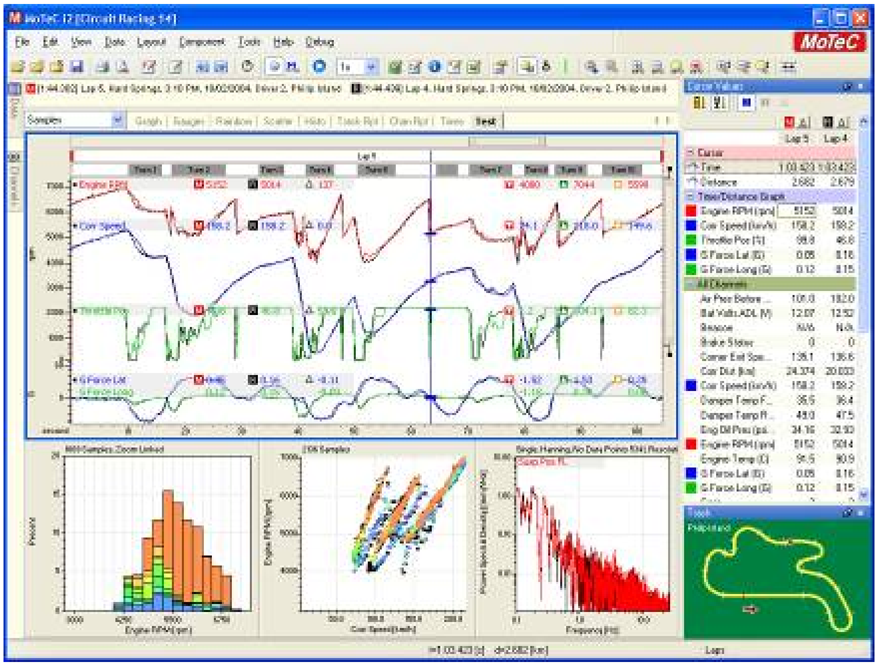
Gear shift lights – one of the more useful functions available with an aftermarket ECU. Can be either one or more lights setup to illuminate at a preset RPM point to signal when the driver should change gear. Some systems allow different RPM points to be programmed in to suit current gear position, taking into account the rate at which an engine accelerates in the lower gears.

Data logging – data logging is for the profoundly pointy-headed. Not that there's anything wrong with that. An aftermarket ECU will track all system inputs, calculated parameters and actuator outputs. This enables the deeply obsessed to closely scrutinise every engine operating variable, tracking their interactions in the quest for maximum power and reliability.



Pic MoTeC Data Logging Track Map

Used extensively by race teams, to ensure the engine is operating at maximum efficiency for a particular circuit and vehicle setup. It can also be used to keep an eye on the performance of the driver, as each gear change, every brake and clutch operation can be recorded and scrutinised. In motorsport, data logging is used to control the driver's ego, as it is no longer possible for the driver to lie to the crew about how brave he is.



MoTeC Data Logging Graphs

Reality Check

ECU replacement is like heart surgery, do it only once the original unit has outlived its purpose! Regardless of the type of engine management system to be used, they all require a significant amount of assumed knowledge in both the management system being used, and more importantly the art of engine tuning itself. This typically puts it out of the range of what an average customer might attempt on a DIY basis. The best engine management computer in the world will be worthless if it is not installed and tuned by a professional on a dynamometer. If you have made the decision to replace the standard ECU, do not penny pinch and make your choice on price alone, as many cheap systems have the intelligence of a digital watch, and will almost always be a huge step backwards in terms of sophistication and functionality.

12.7 Performance Engine Tuning

It may come as a surprise to many, but the theory behind performance engine tuning is not nearly as complicated as it is made out to be, especially when dealing with production based equipment. Engine tuning is neither a black art, nor is it a form of magic. Extracting power from a WRX engine is not difficult. It only requires roughly the correct ratio between fuel delivery, boost pressure and ignition advance to suit existing mechanical specifications and fuel quality. Where real genius comes into the picture, separating the men from the boys, is the speed at which a good tuner can instinctively arrive at the best possible *reliable* tune to suit a particular combination of parts. Another defining trait of the really talented includes an ability to quickly and efficiently diagnose problems with setup, communicating clearly and accurately what can done to improve engine operation. Does this sound like your engine tuner?

Engine Tuning the Modern Way

The Language of Engine Tuning

Every industry has its own catch phrases and descriptions to sum up in a few words, rather than a whole paragraph, a statement of fact. Some of my favourite terms describing engine tuners and builders include:

"*Jerry Rigging*" the slash and burn perpetrated by some individuals on a vehicles electrical system when installing an aftermarket ECU.

"*Smoke and Mirrors*" indicating that a rather large pinch of salt should be taken when describing some performance claims.

"*Twigs and Tape*" describes the act of fitting a new part to an engine in a less than durable manner.

"Playing up above their level" over-exaggerating a tuners ability. Commonly used to cast a competitor in a negative light, while singing their own praises.

All things being equal, regardless of the type of engine management system used, professional engine tuners will always pay a great deal of respect to certain key areas of importance when tuning a turbocharged engine. In this section we will take a bit of a look at some of the considerations made when tuning for maximum power.

12.7.1 Detonation

Without a doubt the single biggest barrier to high performance tuning is detonation. Also known as knocking, pre-ignition, pinking or pinging, these are all words describing a very serious engine condition. Detonation describes a situation where there is a sudden and *uncontrolled* increase in combustion pressure inside the cylinder and can take the form of:

Engine Block Damaged By Detonation

- The fuel/air mixture being lit-off too early in the engine cycle by over advanced ignition timing.
- Fuel with too low an octane rating causes spontaneous ignition of the fuel/air charge before the spark plug would normally initiate the combustion process.
- Excessive charge temperature and pressure causes a spontaneous ignition of the fuel/air charge before the spark plug would normally initiate the combustion process.
- Once the spark plug ignites the fuel air charge and begins to burn, a second unplanned ignition of the fuel/air charge occurs simultaneously in another area of the combustion chamber.

The first two types of detonation are easily fixed by adjusting engine mapping and by better quality fuel respectively. The last two are a tougher nut to crack, and ultimately far more dangerous to engine health. Whenever two competing flame fronts in the combustion chamber form, the point at which they collide causes a massive localised increase in combustion pressure. This produces both the rattling noise and mechanical damage associated with detonation. This localised pressure increase acts like a jackhammer producing not only huge shock loadings, but also a massive increase in heat focused in a localised area.


Long Term Detonation Damage


Short Term Catastrophic Detonation

Pistons and piston rings bear the brunt of detonation, but damage is not always confined to just these parts, as the constant hammering of detonation can result in; erosion of material from the combustion chamber around the valve seats, fatigue failure of connecting rods, blown headgaskets and damaged connecting rod bearings. If you haven't already worked it out, detonation must be avoided at all costs!

Detonation can be controlled by the following means:

- Efficient cylinder head, combustion chamber design and a corresponding static compression ratio;
- Sophisticated engine control electronics and matching fuel + ignition calibration;
- Sensible boost pressures;
- Controlling intake charge temperatures;
- Higher octane fuel, offering better resistance to detonation.

Subaru has done a good job designing an engine with a suitable compression ratio and base mechanical spec along with a highly advanced electronic management system. Unless considering major engine surgery (out of reach for most WRX owners), this leaves fuel quality, intake charge temp, boost pressure and engine management calibration as the easily attainable methods for keeping a lid on detonation. Juggling these changeable parameters, and translating it into a safe and powerful engine tune is the sign of a really good engine tuner. Again, does this sound like your guy?

Despite all the evidence to the contrary, some very curious attitudes towards detonation still persist. The following points on detonation are the real deal. Anything else falls into the category of old wives tales:

Note Detonation has Cleaned Carbon from Piston on Left Compared to Piston on Right

1) There is no such thing as minor or non-damaging detonation.
2) An engine that detonates only occasionally is still badly set-up.
3) Forged pistons and racing connecting rods are not detonation proof.
4) Each detonation event on a highly modified engine making large amounts of power, will be proportionally stronger and far more damaging compared to a detonation event on the same engine in un-modified standard trim.
5) Sophisticated closed-loop knock control is not a crutch on which to support a badly modified and tuned engine.
6) A knock sensor is only a glorified microphone, and in the case of highly modified engines, noisy engine parts and high RPMs, can make the ECUs job of listening for knock similar to trying to make out a flute at a heavy metal concert.

12.7.2 Detecting Detonation

Checking for detonation during the tuning process is not an easy task. Loud exhausts and noisy dyno rollers can easily drown out the tell-tale sounds of detonation. Professional engine tuners get around this issue by using acoustic probes clipped to the engine block, fed back through an amplifier and then into a set of headphones. Probably the best form of knock detection, it is also the hardest to master, as the operator has to be familiar with the way in which knock can sound subtly different depending on the type of engine being tuned..

Headphones and Knock box

There are other commercially available electronic knock detection boxes available. Typically they use a Bosch style knock sensor that is attached to the engine block. Sensor output is then sent back into a head unit inside the vehicles cabin. Once correctly calibrated and adjusted, knock events are displayed visually by means of different intensity LED lights. It is important to note though, these units cannot be depended on to detect detonation with 100% accuracy.

Knock Link

12.7.3 Fuel System

One of the keys to achieving power is the correct ratio of fuel for a given quantity of air. Either too much or too little fuel results in an engine that is down on power, delivers poor economy and has a big question mark against its long term durability. The primary job of the engine tuner is to ensure that the engine management system has been programmed to deliver fuel in the correct quantities at all times.

Insufficient Fuel Causing Piston Seizing on Crown

Fuel Mixture – measured in units of either Lambda or air fuel ratio (AFR). Also referred in tune-speak as either lean (small amounts of fuel to air) or rich (large amount of fuel to air). What is the correct mix of fuel and air? While there is no such thing as an absolute across the board setting, the generally agreed “golden rules” of fuel mixtures are:

1. At low power outputs (no boost) catalytic converter equipped cars require a fuel mixture of Lambda 0.99 (AFR 14.64) for best emissions, and is the target fuel mixture when the OE ECU is operating in closed loop. Improvements in fuel economy can be made by leaning fuel mixtures off to Lambda 1.05 (AFR 15.4 to 1), but this is done at the expense of cat converter operation and will increase exhaust temperatures when cruising.

2. Medium power outputs (the transition between on and off boost) sees best power achieved at around Lambda 0.89 (AFR 13.1 to 1).
3. At high power outputs things get interesting, as this is the area where the greatest potential for engine damage exists. Version I to VI engines with stock internals running around 1.2 bar boost typically make good power reliability at Lambda 0.78 (AFR 11.5 to 1). At the same boost pressure and with stock internals, Version VII and later models have redesigned cylinder head combustion chambers for a very different set of burn characteristics and fuel distribution compared to the previous model, dictating significantly richer fuel mixtures of around Lambda 0.75 (AFR 11.0 to 1) or lower to achieve best power safely.

Typically, air fuel ratios can be leaned slightly for a small increase in power on engines equipped with forged pistons, due to their strength and greater heat resistance when compared to OE cast pistons.

12.7.4 Measuring Fuel Mixtures

There are only two ways to check fuel mixtures accurately; the preferred method is to use a high quality aftermarket wide band air fuel ratio meter in conjunction with a five wire Bosch LSU type lambda sensor. This type of sensor and meter can accurately measure fuel mixtures from Lambda 0.69 (AFR 10.1 to 1) to Lambda 1.30 (AFR 19.1 to 1) and beyond. Hence the name wide band sensor. An alternative method for cars with flash compatible ECUs, fuel mixtures can be read directly from the ECU data stream using Delta Dash, with a few exceptions. The OE lambda sensor can "see" lean mixtures well, but cannot measure fuel mixtures richer than Lambda 0.76 (AFR 11.2). Additionally, at power outputs higher than stock, sensor placement is an issue, as exhaust back pressure between the engine and turbocharger causes a significant reduction in sensor accuracy. Any other method of measuring fuel mixtures such as cheap DIY meters, reading tea leaves or consulting a psychic have no place in modern high performance engine tuning.

Professional Lambda Meter

12.8 Fuel System Setup and Testing

A surprising number of both tuners and owners seem to get this piece of the engine tuning puzzle consistently wrong. Take for instance the frequency at which tuners will setup a WRX engine to well in excess of fuel injector and pump capacity. A dangerous and totally unnecessary practice, given the availability of heavy duty fuel pumps and bigger injectors for not a lot of cash.

Fuel Flow and Pressure Tester

12.8.1 Fuel Pump

In order for the WRX engine to make power safely, its fuel injection system must be supplied with a constant supply of high pressure fuel with enough flow volume to meet intended power outputs. Insufficient flow will cause the engine to starve for fuel, resulting in:

- Reduced or unstable power outputs;
- Surging and power loss as engine load increases;
- Elevated exhaust temperatures and early onset of detonation.

For engine power outputs in the 160 to 270kW ATW range, a fuel pump with a minimum of rate of 3.5 litres per minute (LPM) is required at a minimum of 4.0 bar rated pressure; This is an important point, as delivered volume decreases significantly as fuel pressure increases. An OE pump might deliver 5 or more LPM at zero pressure (ie straight out of the pump and into a bucket), but the same pump will struggle to flow 2.0 LPM at 4.0 bar of fuel pressure. Temperature is another important factor when it comes to fuel pump operation. On very hot days, with a tank full of hot fuel, delivered fuel volume can drop by as much as 25%. Fuel pump performance is not like good wine, and does not improve with age. Pumps that may have been borderline when new, have no capacity to spare as fuel system components wear and age. A high performance pump that might seem as overkill in terms of flow initially, very quickly becomes a no-brainer for even lightly modified WRX and STi. Heavy duty 3.5 LPM pumps that bolt straight into the OE fuel pickup start from A$250.

500Hp Fuel Pump

Subaru Fuel Sender unit

As a basic rule of thumb, any performance modification that is more than a rear muffler on a Version VII or later model WRX / STi will need a higher flow fuel pump in order to maintain adequate delivered volume. Earlier model turbo Subaru's are better served in this respect, featuring from standard a pump that has plenty of excess volume to spare, but it must be remembered that with the ravages of time, this may no longer be the case.

Very high power applications (350 kW ATW +) will require two pumps connected in parallel and not in series. This includes engines running nitrous oxide.

12.8.2 Injector Duty Cycle

An important term used to describe how much of injector theoretical flow capacity is being used during engine operation. At low power levels the ECU opens and closes the injectors quickly, holding them open for only short periods of time (low duty cycle) as engine fuel requirements are low. At high power levels the ECU has to open and close the injectors faster and faster as RPMs rise, while at the same time attempting to keep the injectors open for longer (high duty cycle) in order to deliver sufficient fuel. Duty cycle cannot keep increasing indefinitely, as mechanical considerations such as the time it takes to open and close the injector makes operation above around 95% unsustainable. In industry jargon, this is known imaginatively as going over “max injector duty cycle” and can only be remedied by switching to bigger injectors. Symptoms of injectors that are too small include:

- Noticeable lean-outs of the fuel mixture at high RPM;
- Unstable or erratic power outputs at high engine loads;
- Increased occurrence of detonation;
- Mechanical damage to engine parts.

Duty cycle is one component of the data stream generated by Flash compatible Subaru ECU systems, and is easily accessed by Delta Dash or a Subaru compatible OBD-II scan tool. Alternatively, duty cycle can be measured directly at the fuel injector by using a good quality multi-meter that includes a duty cycle function.

12.8.3 Fuel Injectors

Fuel injectors must be big enough to either meet or exceed intended engine power outputs. Injector flow rates are measured in either cc per minute or lbs per hour at 100% injector flow and at a nominal fuel pressure of 4.0 bar. Flow equates to theoretical power rating by the following conversion:

- 500cc per minute @ 3 bar fuel pressure = approx 74kW (100 HP) per injector. For those metrically challenged, this equates to 49 lbs per hour injector in the old money.

NOTE.
Its imperative that you check with the supplier as different brands use different pressures to rate their sizes.

Version VII and later 2.0ltr WRX use 380cc top-feed fuel injectors. Low compression engines without AVCS normally can handle exhaust and intake mods, along with a minor boost increase to 1.1 bar and still have a small amount of spare injector capacity in hand. Later 2.0ltr engines with AVCS and increased compression ratio are much more efficient and run out of injector capacity even at 1.0bar if fitted with a good exhaust and intake system.

Sard 650cc Fuel Injectors

STi Pink Injectors

Big increases in boost pressure and turbo upgrades all require a big increase in injector capacity. Fitting 500cc STi “pink” injectors are a quick and easy way to boost fuel flow on Version VII and later WRX and cost around A$1240 for a set of four.

Version VII and later 2.0ltr STi have much larger 500cc injectors fitted, although, it is possible to run very close to max injector duty cycle with an efficient intake and exhaust system running around 1.4 bar of boost through the stock turbocharger. For 2.0ltr STi, 650cc top feed injectors are available and cost around A$285 each. These are an aftermarket part, and are slightly taller than the OE injectors, requiring spacers to be fitted.

For really big power outputs, OE style 850cc high flow plug and play injectors are available for both top feed and side feed applications starting at A$300 per injector.

12.8.4 De-Capped or Drilled Injectors

A popular low cost alternative to bigger injectors, especially for the 2.0ltr WRX is to modify the injector end cap, which serves a flow calibration purpose on the OE part. This is done by either enlarging the four small holes in the end cap, or simply cutting it off completely. A bit of a crude way of increasing injector capacity, it nevertheless works; up to a point that is. Cutting the end cap off completely results in a set of four injectors that can theoretically flow enough fuel to produce 450kW (that’s 600+ HP in the old money!) which is a real case of overkill for a mildly modified street car. It also requires some very significant engine management re-mapping to scale back fuel delivery enough so that the engine does not drown in fuel. Injector spray pattern can also be a problem, requiring a large increase in fuel pressure over stock to try and improve fuel spray pattern, further complicating engine management issues.

De-Capping WRX Injector

De-Capped Fuel Injectors

Herein lies the problem with these modified injectors. At low power outputs, injector duration is so small that the actual timing of each injector event becomes a serious issue. Fuel is no longer injected at exactly the right point in the engine cycle, resulting in large quantities of fuel sitting on the back of the intake valve. This can lead to rough and unstable idle quality and fuel wastage at low to medium loads. For most applications, saving money by using modified injectors is a false economy and is no substitute for correctly matched high-flow items.

12.8.5 Fuel Rail Kits

The boxer layout of the WRX engine means that high pressure fuel must travel through a long and torturous path from one side of the engine to the other. The fuel inlet is on one side of the engine, with the fuel pressure regulator on the other side. This can lead to a situation where at high RPMs and high boost, the pulsing of the fuel injectors is enough to create funny harmonics in fuel delivery rails and feed pipes. This then creates the situation where one cylinder will run a little leaner than the others, and is bad news for a highly stressed engine.

Billet Fuel Rails

Modified OE Rails

Easily fixed, a fuel rail kit is strongly recommended for WRX engines with bigger turbochargers and boost levels above 1.1 bar. Kits are available to separate LH and RH fuel rails into two separate symmetrical fuel systems each with their own fuel pressure regulator. This can be in the form of either complete replacement billet alloy fuel rails, or modified OE fuel rails done on an exchange basis. Each kit comes with an extra fuel pressure regulator, high pressure fuel hose and clamps to suit, and cost around A$475 for a set of billet alloy items.

12.8.6 Fuel Pressure

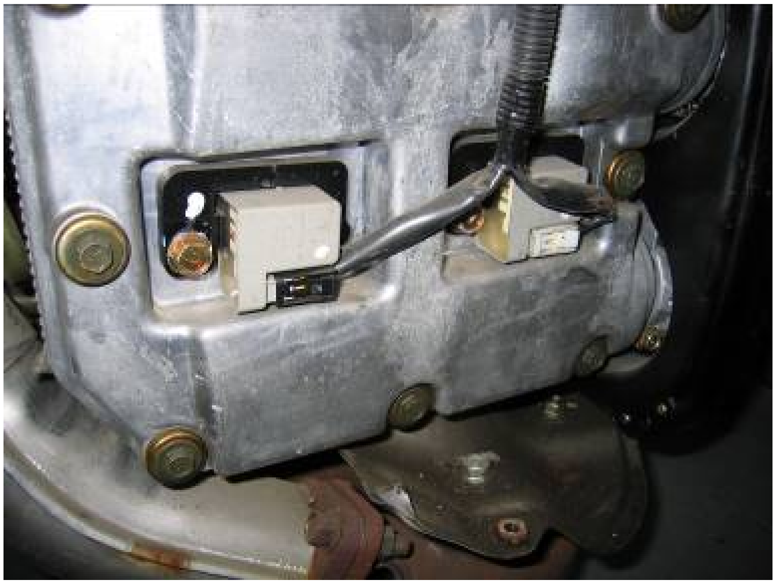
Increasing fuel system pressure is a method used by some tuners as a way of boosting injector flow rates. While this does achieve an increase in peak fuel flow, there are some important caveats:

- Increasing the fuel pressure decreases significantly delivered volume from the fuel pump, and is dangerous for fuel systems with borderline pump capacity.
- Most OE fuel pumps have a safety relief valve built into the pump which opens above a preset output pressure. This further reduces delivered volume.
- Increased fuel pressure can improve fuelling at high load, but will result in significant over fuelling at low to medium loads, unless changes are made to engine management mapping.
- Rising rate fuel pressure regulators that raise fuel pressure by anything more than a straight linear ratio against boost pressure tend to be unreliable and erratic in operation.
- Actual fuel flow increase at the injector is not proportional to the actual increase in fuel pressure. For example, doubling fuel system pressure (unlikely to be achievable) will only result in an increase of around 40% in fuel flow. This is due to fuel system flow restrictions and injector operating mechanics. A more realistic increase of 25% in fuel pressure will result in a flow increase of approximately 10% over stock.

Adjustable Fuel Pressure Regulator

For the majority of engine applications, keeping fuel pressure at a ratio of 3.0 bar above manifold air pressure is sufficient. That is, if there is 1.0 bar of manifold pressure, fuel system pressure should be a minimum of 4.0 bar, something the OE fuel pressure regulator is more than capable of doing, until such stage as boost pressures in excess of 1.6 bar are used.

12.9 Ignition System



Version VII and later WRX and STi use coil-on-plug ignition coils. These units have proved to be both reliable and capable of supporting high power outputs. Version III to VI ignition systems uses a wasted spark type double ended ignition coil. In practice these systems operate well, but can run out of ignition energy at very high power levels when compared to coil-on-plug.

Version VIII Ignition Coils

Spark Plugs – The standard spark plugs give excellent performance and are reliable in normal service. They are also the spark plug with which the vehicles engine management and electrical system was designed to operate with, something of an imperative these days with the number of electronic control units in modern cars these days. There are many aftermarket spark plugs out on the market with fancy electrode designs claiming to boost power and improve economy. If they actually are an improvement over standard is harder to quantify. In stock form the WRX engine comes equipped with PFR6B-9 dual tipped plugs; that is both the centre and ground electrodes are platinum tipped, while replacement BKR6EVX-11 plugs have a platinum tipped centre electrode only.

The most that needs to be done to improve spark plug operation is to swap out the stock No6 heat range plugs for a set of colder No 7 units. This is normally adequate for all but very high power outputs or engines on nitrous oxide. Spark plug gaps will need to be decreased from the Subaru recommend setting for engines running high boost levels. Consult your workshop for advice on this.

12.10 Performance Fuels

Oil companies advertise exhaustively the merits of their product over another. Then there are the exotic and hugely expensive racing type fuels used by motorsport professionals and weekend warriors alike. As discussed a little earlier in this chapter, using better quality fuel can help reduce detonation, but what about engine power?

Performance Fuels

Fuel effects engine power in two ways, the first being an issue of density, or its energy potential. Density differences between pump and race fuels contribute to a small but measurable increase in engine power if taken in isolation. Where really significant increases in power can be made is in the area of a fuel's octane rating. Increasing the octane rating of a fuel improves resistance to detonation caused by high combustion temperatures and pressures. This allows engine power to be increased in three ways; 1) Additional fuel/air charge can be jammed into the cylinder (in the form of higher boost pressures). 2) The cylinder charge can be squeezed together harder (in the form of a higher static compression ratio). 3) More ignition advance can be used to "light-off" the fuel/air mixture at precisely the right time.

In this section we will have a look at some fuel testing done carried out by MRT on both commercially available "pump" fuel and racing fuel. All testing was completed in house on their Dynapack hub dyno, on the same day and with the same vehicle. Results have been checked and tabulated by the Formula SAE team from Sydney University.

Fuels tested included (All numbers are expressed in RON):

Pump fuel – Caltex (Havoline) 95 and 98; BP Ultimate 98; Mobil Synergy 98; Shell Optimax 98; 10% Ethanol Blend 95 and 98.

Race fuel – ET 102; Elf Turboplus; Elf Turbomax; Elf LMS; Sunoco GT; Sunoco Sun Euro; Martini Racing;

Pic Test Car On Dyno

12.10.1 Test Vehicle

The test vehicle consisted of a late production Version VIII Australian spec 2.0ltr STi with the following modifications:

- MRT three inch diameter stainless steel mandrel bend turbo back exhaust with a high flow cat and rear muffler.
- External (control) fuel tank,
    - Standard Subaru sender
    - 3.5 LPM heavy duty fuel pump
- EcuTeK ECU Reflash

12.10.2 Dyno Test Procedure

1. Allow vehicle to idle for five minutes with fuel to be tested in the external tank;
2. When temperature and humidity are in correct range, the first power dyno run is commenced;
3. Wait 30 seconds and then commence the second dyno power run;
4. Wait 30 seconds and then commence the final dynopower run;
5. Save logged data;
6. Every fourth fuel test, three dyno power runs on a control fuel (Caltex 98) are performed to check calibration and consistency of both the dyno and vehicle.

12.10.3 Fuel Changeover Procedure

1. Switch off external fuel pump;
2. Run vehicle until fuel lines are dry;
3. Drain external fuel tank;
4. Evacuate all lines of and residual fuel and reassemble;
5. Blow-dry external fuel tank and rinse with control fuel;
6. Blow-dry again and remove any residue from external tank with lint-free cloth;
7. Fill tank with next fuel to be tested;
8. Set ECU active ignition timing parameters for new fuel category, if required.

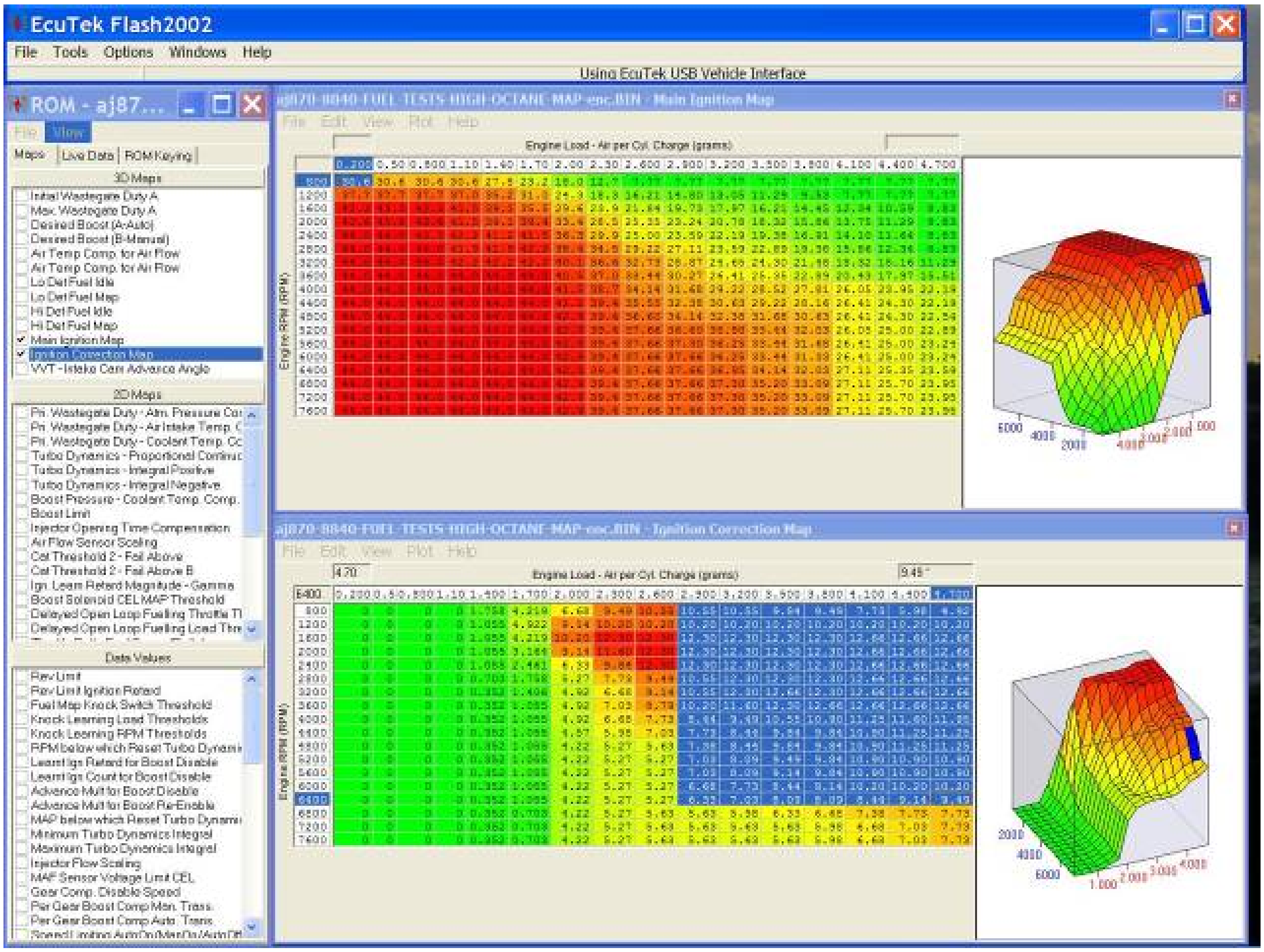
External Fuel Tank Test Rig

12.10.4 ECU Tune

The STi ECU was run with the OE active ignition timing control system fully enabled. Depending on the fuel to be tested, an overall plus or minus of ignition advance was programmed into the base ignition timing map. This allows the ECU greater freedom to use its active ignition control in order to find the optimum amount of ignition advance for best possible power. The amount of timing added or subtracted to the base advance map is as follows:

- Race fuels: + 8 degrees;
- 98 octane fuels: 0 degrees (standard);
- 95 octane fuels: - 5 degrees.

It is important to note that at no time was there any other changes made to other operating parameters such as boost pressure or fuel mixtures. The EcuTeK software interface remained connected at all times to the vehicle during testing for the purpose of data acquisition and to monitor actual ignition advance numbers.



EcuTeK Screen Shot

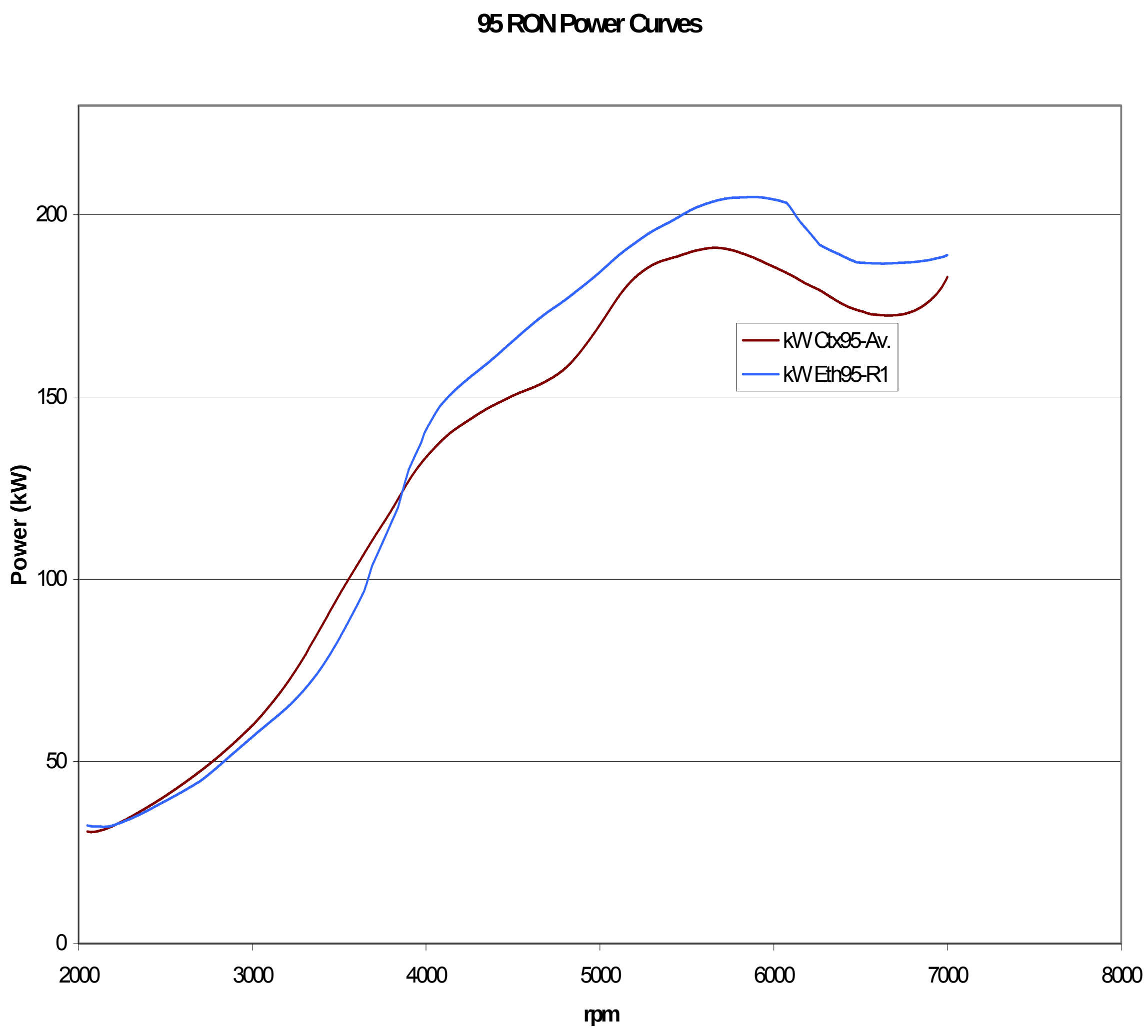
12.10.5 Fuel Test Results

95 Octane Fuel

As only two 95 octane fuels were tested, potential sample errors dictates the results of this particular test more of an interesting comparison, rather than a definitive result. What is relevant is the effect on engine power when running on 95 octane fuel considering Subaru recommend 98 octane fuel as a minimum for this model car.

The 95 octane 10% Ethanol blend outperformed Caltex 95;

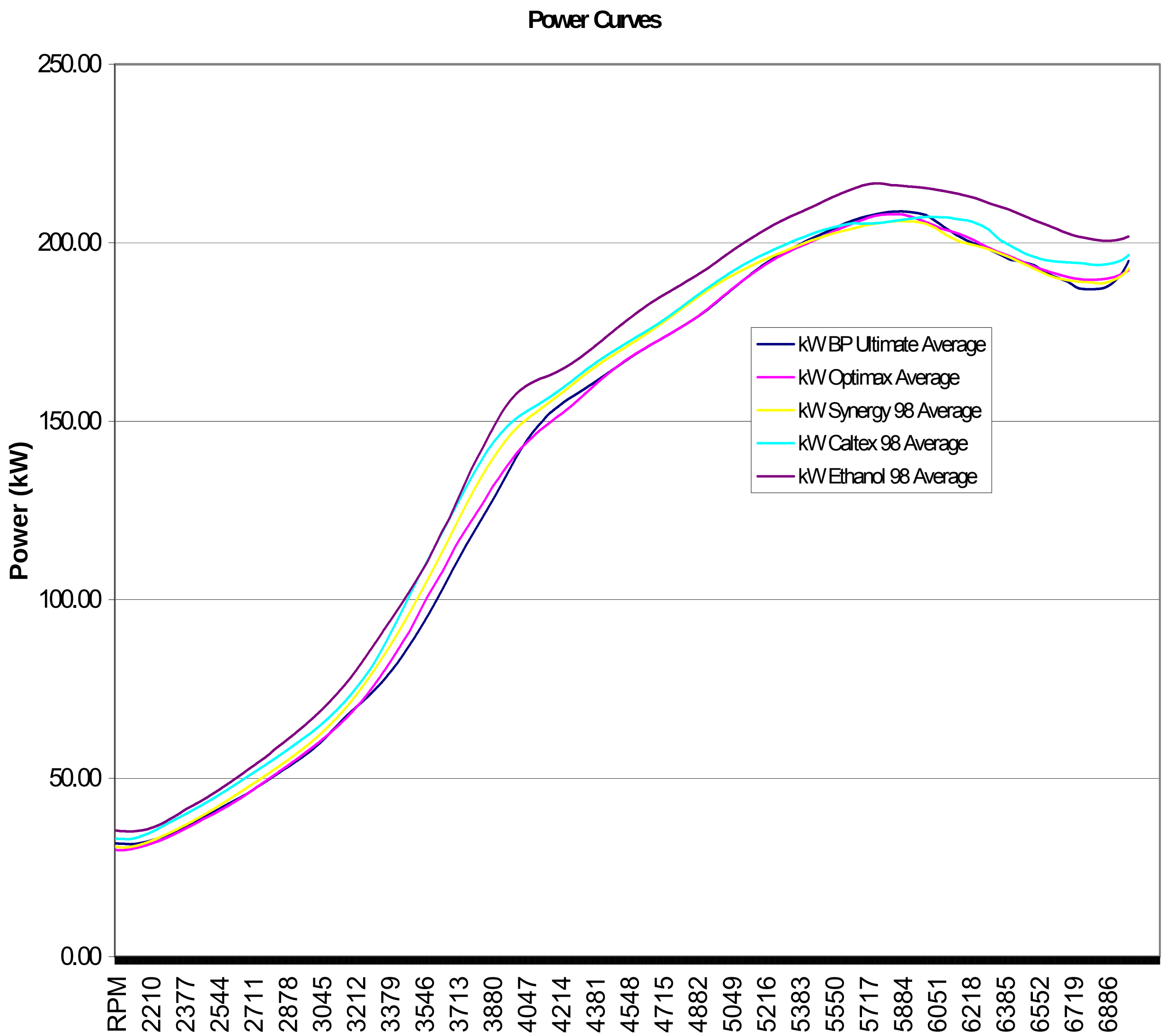
- Peak Power difference: 204kW – 190kW = 6kW



98 Octane Pump Fuel

Originally this test was intended for comparing conventional 98 octane fuels only, but an Ethanol blend was added to the test as it was considered that this fuel was reasonably available to consumers in Sydney suburban petrol stations.

- 10% Ethanol Blend 98 outperformed all the other fuels;
- Of the conventional fuels, Caltex 98 was second;
- Peak Power difference between highest and lowest: Ethanol 98 216kW compared to BP Ultimate 208kW = 8kW.

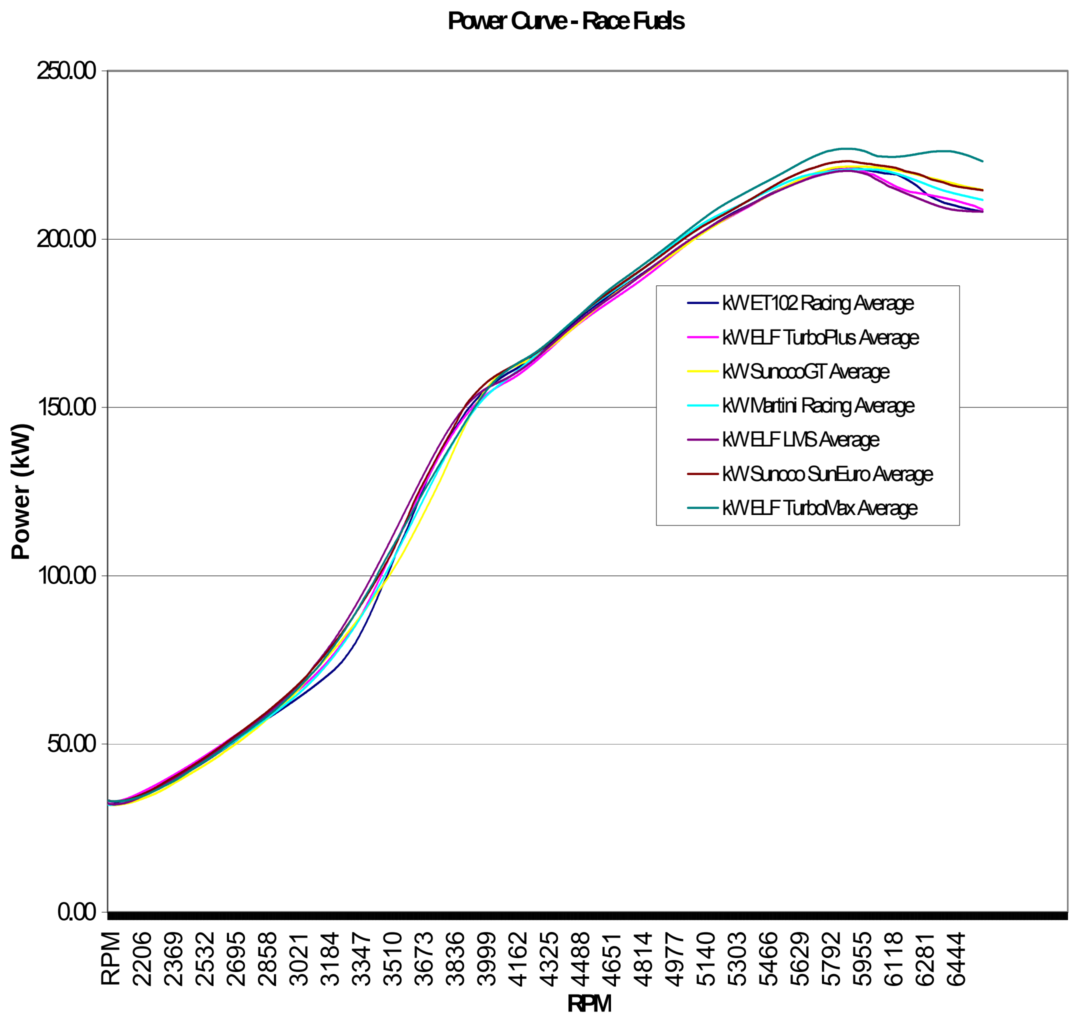


Race Fuels

Power outputs were all extremely close, indicating tight product quality control, a desirable quality indicative of race fuels. Elf Turbomax was clearly better above 5000 rpm, as power did not taper off as quickly.

It is important to note that specialist race fuels (such as Sunoco and Elf) can be made to make significantly more power *when tuned specifically to suit*. However for the purpose of this test, ignition advance was not increased beyond the base adjustment of an additional +8 degrees of ignition advance. Peak Power difference:

- 227kW (Elf Turbomax) – 223kW (Sunoco Sun Euro) = 4kW



Elf Turbomax Race Fuel

12.10.6 Overall Comparison

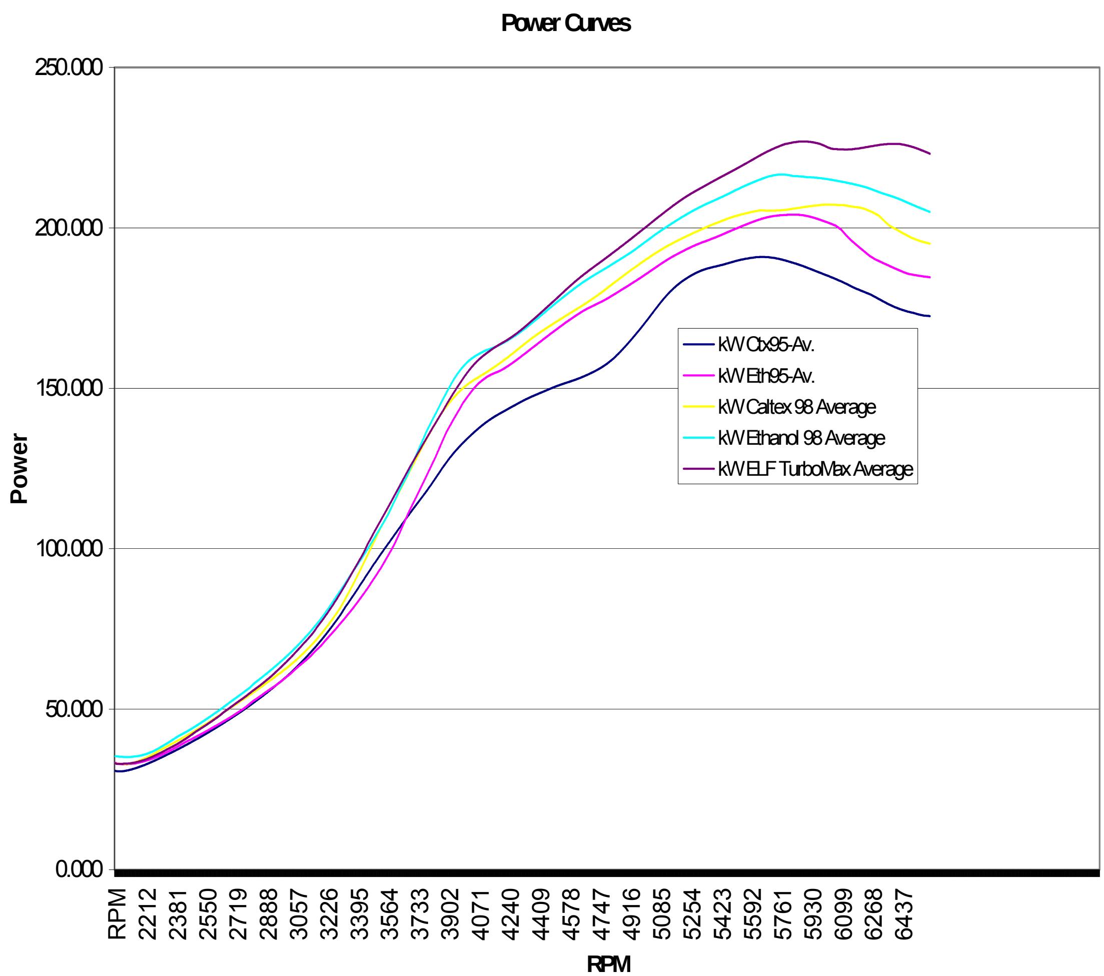
When measured on pure results only, Elf Turbomax was the standout winner recording the highest power reading. Another interesting point was that of all the fuels tested, Turbomax exhibited impressive consistency over the set of three dyno power runs, resisting the affects of heat soak extremely well. This is not surprising given that Turbomax is an approved fuel for Group N rally cars in the World Rally Championship, and is blended specifically to suit highly stressed turbocharged applications.

If measured on a cost vs performance ratio, the surprise winner of the fuel test was the 98 octane 10% Ethanol blend, especially considering the huge price difference between Turbomax at between A$7-8 per litre, and Ethanol 98 which can be purchased easily for around A$1.25 per litre. (At time of writing)

- Peak Power diff: 227kW (Elf Turbomax) – 216kW (Ethanol 98) = 11kW

The comparison between the best and worst performing pump fuel on performance terms was also interesting, graphically illustrating the difference in power potential between 95 and 98 octane pump fuels.

- Peak Power difference: 216kW (Ethanol 98) – 190kW (Caltex 95) = 26kW



12.10.6 Ethanol Blended Fuels

With fuel prices rising to all time highs, one issue that has come to a head, especially here in Australia is the controversial topic of pump fuel blended with Ethanol. From an economic point of view it makes sense as mixing in locally produced Ethanol as it reduces the amount of expensive foreign crude oil required. Blended fuels are not a new development, as Sweden and the US have been using 10% mixes for many years successfully. In Brazil, it is illegal to sell pump fuel that has less than 20% ethanol content. Granted, Brazil was the last country in the world to finish producing the original Volkswagen Beetle, in itself not exactly a paradigm of high performance or modern technology, it is plainly evident high levels of Ethanol doesn't seem to create too many issues. And certainly not the sorts of wild predictions of doom and gloom for your motorcar as portrayed by the Australian media.

In actual fact, ignoring the hype, there are four main areas of concern with 10% Ethanol blends:

Water – Ethanol has a great affinity with water. Most metal components in fuel systems will corrode or rust in the presence of water. Fuel blended with 10% Ethanol will increase the quantity of water it can absorb without separating out. It is important to note that the addition of Ethanol doesn't suddenly create water out of no where, but tends to "pick" up water more easily throughout the transportation and storage phase of its distribution to end users. It is generally accepted that 10% blends do not pose a significant risk of fuel system corrosion in everyday use, as Ethanol blends have increased quantities of anti-corrosion additives found in normal un-blended fuels.

Fuel System Contaminants – 10% Ethanol blends can cause problems with cars that already have a heavily contaminated fuel system *to begin with*. Ethanol can act like a solvent, scouring gum, varnish, dirt and water from the insides of fuel tanks and fuel lines, leading to clogging of fuel filters etc. Easily fixed by increased preventative fuel system maintenance, such as changing fuel filters more regularly until contaminants are cleaned from the system.

Material Incompatibility - Older cars can be at risk of accelerated wear of rubber, cork and certain plastic fuel system components, but these very same components are equally at risk when used with fuels containing high levels of toluene, the additive primarily responsible for improving the octane rating of unleaded fuel.

Fuel Consumption – Ethanol has a lower energy content when compared to petrol, requiring a slightly higher volume of fuel to be burned in order to provide the same amount of power. In theory, an engine using a 10% blend should consume 3.8% more fuel. So there is a downside in fuel economy. This is somewhat offset by a slight improvement in efficiency, but is very much dependant on the type of engine.

Now for the good news. As demonstrated by the fuel testing result, significant performance gains can be made by using a 10% Ethanol blend. This is because Ethanol is an oxygen rich fuel, and this assists with improving the combustion process. Most importantly the addition of Ethanol improves resistance to detonation, which is good news in a turbocharged car such as the WRX. The ECU in the WRX will respond to improved fuel quality and will increase the maximum amount of ignition advance generating more power. As a general rule of thumb, 95 RON unleaded fuel blended with 10% Ethanol will achieve an octane rating of between 97.5 and 98.5 RON.

Performance Tuning For Ethanol Blends – highly stressed WRX engines would benefit from a dyno tune and check if switching to an Ethanol blend. Typically airfuel ratios will go slightly leaner, somewhere in the vicinity of 3-4%, requiring slightly more fuel so as not to compromise engine safety.

NOTE
At the time of print, early data with regard to Ethanol fuel economy was limited. However what was evident on the cars tested (one was a MY03 WRX Wagon) that it did not like the Ethanol mix when checked for economy.
Such was the result that the owner wanted to revert back to "normal" 98 Pulp as soon as possible to save on his wallet!

12.11 Nitrous Oxide

Pic Boot Mounted Nitrous Tank

Bottle fed, laughing gas, N_2O or just "on the bottle" are a few of the amusing terms used to describe the use of nitrous oxide in automotive applications. The power boosting properties of nitrous oxide for internal combustion engines first came into serious use towards the end of World War II, used by the Germans in order to improve the performance of their piston-engined fighter planes at high attitude where air density is low. German engineers didn't have access to high octane aviation fuel that allied engine manufacturers did, and couldn't run supercharging boost pressures high enough to provide the power required for combat operations. Nitrous oxide was used to increase power.

For some time now nitrous has been mostly the domain of the drag racing fraternity, V8 engines and Saturday night specials. This paradigm is changing, as tuners and enthusiasts alike are coming to appreciate really how well a properly engineered nitrous system and turbocharging can work out on the road.

It's History Time!
Nitrous oxide or laughing gas as it is more colloquially known as was first discovered in 1793 by English scientist and man of the cloth Joseph Priestley. After initial testing, Priestley believed that N_2O could be used as a preserving agent, but this was to prove incorrect. Very quickly though, the physiological effects of the gas were noted, and was studied in some detail. Despite all best intentions, over the proceeding 40 years N_2O's primary use was for recreational use and public shows. *Nitrous Oxide capers* as they were called took place in travelling medicine shows and carnivals, where the public would pay a small price to inhale a minute's worth of gas and enjoy all the laughter and silliness it brought on. English poet Robert Southey wrote "*I am sure the air in heaven must be this wonder working gas of delight*" Safe to say it's a sure bet what he had just inhaled! It wasn't until 1840 that N_2O's anaesthetic properties were noticed. This occurred purely by accident, as a user of Nitrous was observed to stagger around, injuring his leg, but was blissfully un-aware of any pain until such time the gas wore off. A light bulb illuminated over the head of local Connecticut dentist Horace Wells, launching N_2O as an anaesthetic. It's not a happy ending though, as initially derided by the medical profession and ultimately resulting in Dr Wells committing suicide, N_2O took some time to be accepted by the medical profession.

12.11.1 Nitrous Oxide Basics

First and foremost, a solid grasp of the reality lever is required here. Laughing gas has almost miraculous properties for increasing power outputs, but your basic mechanical package must be capable of handling the additional grunt. Tacking on a 250kW nitrous kit onto a bog stock 65kW Corolla is an extreme example, with the poor little Toyota engine more than likely exploding under all that extra load. Jokes aside, three main areas should be considered carefully before putting your WRX on the bottle if you want good achieve good results and keep heartache to a minimum.

It must be clearly understood that not only must the basic engine package be strong enough, but it must have sufficient margin built into its tuning in order to absorb increases in power safely and without initiating a self-destruct sequence. A very strong engine that is already tuned and stressed to its limits will be pushed well past what it can handle given a whiff of gas.

Fuel systems are commonly overlooked. The same principles that govern mechanicals apply; a badly over-taxed or under engineered fuel systems simply won't cut it when called on to feed a nitrous engines appetite for fuel, and is a great way to turn pistons into ashtrays.

Another commonly overlooked issue is the affect of nitrous bottle temperature on the performance of a nitrous system. Nitrous kits normally have a recommended bottle operating pressure (which is determined by bottle temperature) and is the pressure at which tuning and operating should be done at. Lower than operating pressure (due to a cold NOS bottle) will result in less power and an overly rich mixture, which is not so much of an issue. Serious nitrous operators will use thermostatically controlled heating blankets to regulate bottle temp in cool weather to overcome this.

Problems really start when higher than recommended bottle pressures are used. Worst case scenario would have to be the situation where a car has been parked outside in direct sunlight for several hours, superheating the interior of the car and NOS bottle, boosting its operating pressure by anything up to 25% over standard. Delivered volume of NOS increases, but without any proportional increase in fuel, severely leaning the fuel mixture. Taking the car out in this situation and giving it a big serve almost always never has a happy ending! Nitrous professionals, again in consultation with the nitrous bottle's pressure gauge will carefully cool an overheated tank to bring operating pressure back down to normal levels.

Some form of ignition timing retard is the final piece in the nitrous puzzle. The rate at which nitrous augmented fuel/air charge ignites and burns is much faster than before, leading to the possibility of detonation raising its ugly head. Not so much of a problem in lightly stressed NA street motors, but is a real imperative on a turbocharged engine that already has high combustion temperatures, pressures and fuel burn rates. Most aftermarket engine management systems such as MoTeC and Autronic will feature a NOS mode, where a switch input can be configured to bring into paly a set of specific laughing gas maps used while the car is on the bottle. Nitrous oxide kit manufactures and re-sellers normally include a scale for suggested ignition retard rates for a specific shot of gas, but in practice may not bear much resemblance for the WRX being calculated predominately for NA motors.

12.56 Insert Pic

For Pointy Heads

Its time for a chemistry lesson on why nitrous works the way it does. N_2O is a colourless and almost odourless gas and is quite un-reactive with most other substances at room temperature. However, the fun starts when nitrous is heated sufficiently, as it breaks down, decomposing exothermically into its base constituent elements. Through the heat of combustion, the following chemical reaction takes place: Two molecules of nitrous oxide ($2N_2O$) decompose producing two Nitrogen molecules ($2N_2$) and one Oxygen molecule (O_2). This benefits the WRX engine (or any turbocharged engine) in four ways: Firstly the additional Oxygen available makes it possible to burn a lot more fuel efficiently liberating more engine power. Those free molecules of Nitrogen left over when nitrous breaks down have a cushioning effect on the burn process, stabilising the speed of combustion, controlling the flame-front as it travels across the combustion chamber. Effectively chemical supercharging, N_2O boosts exhaust energy greatly at low RPM where spooling the turbocharger much earlier than before. Lastly another physical property of nitrous comes into play. Injected into the engines intake airstream in the form of a liquid under high pressure, it immediately flashes into a gas absorbing large quantities of latent heat from the intake charge, boosting its density, while helping to protect against detonation. *Knowledge is power!*

Nos Nozzle In Intake Pipe

12.11.2 Nitrous Oxide and the STi

Now we will investigate in detail what sort of results can be achieved with a properly engineered and installed nitrous kit on an Australian spec Version VIII STi. Although sporting quite a few existing modifications such as a bigger turbo, exhaust system and FMIC, it still has plenty of strength left in the engine package. Aussie delivered STi come standard from the factory with forged pistons and is a big help when going on the gas. The fuel system was upgraded sporting a 3.5 LPM pump to boost delivered fuel volume. Engine management was taken care of by custom EcuTeK programming custom tuned to suit on a Dynapack hub chassis dyno. MRT's resident gas guru had already crunched the numbers and had settled on a 55kW wet NOS kit as being a sensible and realistic upgrade.

Pic Nitrous and Fuel Solenoid Box

Several hours later and after multiple ECU re-flashes and fiddling with nitrous and fuel jet sizing, the final results were in. Already no slouch due to its existing modifications the STi returned some spectacular results on the dyno. Peak power increased by a big margin *everywhere* over stock, as was torque, which probably was the most impressive gain of all. Previously the STi made peak torque at around 5,000 RPM but while under the gas, its torque peak dropped to 3,000 RPM transforming the engines characteristics completely. It was almost as if while we were not looking, somebody dropped a big-block V8 under the bonnet of the STi.

Power gains aside, actual technical details were interesting. Total ignition advance was in places up to 10 degrees less than before when on the gas, with the new lower turbo spool point requiring a large amount of re-mapping to prevent detonation.

Dyno graph Nitrous Charged STi

Fuel supply remained adequate at all times thanks to the bigger pump, but MRT's tuner did stress the point that any additional power increases above its current level would require an even bigger fuel pump.

Now for the best bit, out on the road the STi's behaviour was totally transformed, undergoing a massive hike in power and torque with the flick of a switch, in true Jekyll and Hyde proportions. Simply saying that the car now felt like it had a big block under the bonnet doesn't do justice to how strong it felt.

In summary, nitrous can liberate fantastic amounts of power from a WRX's engine, and works extremely well when combined with turbocharging. But it is serious business, as for every success story there are countless others that end in failure due to poor planning and execution. Seek professional advice from those with experience in nitrous systems *and* turbocharging. Nitrous is a demanding baby, and requires constant attention and supervision, and is a lot of stuffing around in order to do it properly. A professionally installed nitrous kit will cost around A$2,200 fitted and tuned, but does not include things like ECU reflash license costs or heavy duty fuel pumps etc. And finally be prepared for the addictive properties of nitrous, which is one thing they never mention in chemistry or medical text books. This we cannot help you with. One day perhaps the pharmaceutical industry will produce nitrous substitute patches for reforming NOS junkies.

12.12 Conclusion

By now it should be very apparent that engine management is easily the most complicated part of the Subaru WRX performance puzzle. Unfortunately it can be the least understood part, even by so-called professionals. Subaru invests a huge amount of time and effort in programming the OE ECU to operate perfectly in a wide variety of environmental conditions and on different grades of fuel, maximising fuel efficiency, as well as being suitably green. Engines are literally run to death on dynamometers testing different combinations in order to achieve the best possible power, torque and reliability. Badly chosen or poorly tuned engine management products can be tantamount to throwing away literally millions of dollars of testing and development. Choose wisely and use a balanced approach for an informed decision on what engine management modifications suit you.

Chapter 13

The Turbocharger

The Turbocharger

Subaru Turbo Truths Part 1

In true form for an industry that from time to time doesn't let truth get in the way of a good story, the capabilities of the stock TD04L turbo fitted to the WRX are often overstated. Since its introduction in '97 with the Version III, turbocharger spec has remained essentially unchanged on 2.0ltr models right up until current. Manufactured by Mitsubishi (the irony of this not lost on the author!) boost characteristics are skewed more towards mid-range torque rather than out and out top-end grunt, courtesy of it's comparatively small size. Peak power is achieved at around 6,000 RPM, or a full 1,500 RPM short of redline, pointing towards a degree of breathlessness at high RPM. Small stature aside, the TD04L turbo is a plucky performer nevertheless, responding well to all the normal tweaks – as long as end goals are kept in perspective.

Improvements to air intake, exhaust, top mount intercoolers and engine management all reap useful power gains, but don't expect much of a change of the point at which max power is achieved, remaining fixed at around 6,000 RPM. Happily whistling away at peak boost pressures of 1.1-1.2bar the TD04 is in its optimum efficiency range. Increasing boost by more than this only generates more intake charge heat and turbo exhaust backpressure creating a net negative gain. FMICs, exhaust headers, etc are a waste of time unless a bigger turbo is planned in the future. Well modified 2.0ltr engines with stock turbos are capable of around 170kW ATW – watch out for injector capacity though, as at this power output the stock top-feed injectors will be completely out of flow on some later models.

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14 The Turbocharger

Turbocharging and all-wheel drive are the two standout from the crowd features that make the Subaru WRX the car it is. Take either or both of these attributes away, and the WRX suddenly becomes just another nicely made import econo-box. In this chapter we will investigate the WRX's turbocharger.

Mine's Bigger than Yours

Air Flow

The power of any internal combustion engine is determined by the amount of fuel that can be burned efficiently – this being the key factor, as simply doubling the amount of fuel supplied to an engine will not lead to a doubling in power. The reverse applies in fact, with so much additional fuel entering an engine, it's highly unlikely it would run in the first place. The amount of fuel that can be burnt is determined according to a very specific ratio of air and fuel (see chapter on Engine Management for more detail on this). The first order of the day when attempting to make power is to have an engine that can flow a lot of air.

Engines without a turbocharger or supercharger are known as "naturally aspirated" engines. An NA engine depends on the action of atmospheric pressure to force air into the cylinder as the piston descends on its intake stroke. The amount of air that actually makes it into the cylinder is known as the "intake charge" Things that affect the size of the charge in a NA engine are:
The displacement or "swept volume" of an engine.

- Ambient air pressure and temperature.
- Restrictions that atmospheric pressure has to overcome in order to fills the cylinder with a charge of air. These take the form of things such as air filter size and type, intake plumbing, throttle body diameters, intake manifold size and design, cylinder port size, valve diameters and camshaft profiles among other things.

With NA engines substantial increases in power can only be made by adding extra cylinders or increasing engine capacity (swept volume – no substitute for cubic inches and all that stuff), expensive modifications to cylinder heads, camshafts and manifolding, or simply revving the damn thing harder to squeeze in more firing cycles per minute. Most of which are an impossible dream for the average WRX punter, although imagine the kudo's of roaring down the street in a 600kW 18,500 Rpm BMW formula one engine! On a more practical (and economical) level, Subaru has chosen the path of forced induction for the WRX.

Pic Bolt-On Turbocharger

Forced Induction

Even with supercharging or turbocharging the above points regarding increasing power are still valid, but with one important exception. Using an impeller to increase the amount of air forced into an engine will lift engine power immediately from a base engine without any of the other mechanical modifications mentioned previously. A simple example illustrates this - If a NA engine makes 100KW at sea-level (approx 1.0bar of pressure), raising intake pressure by 1.0bar above atmospheric (2.0bar absolute – in other words allowing twice the amount of air to enter the cylinder on each stroke) should, in theory, double the power to 200kW! In reality, the multiple is between 1.5 and 1.8 times its NA power rating due to such things as density reduction, flow restrictions etc. This is partially demonstrated by the way a NA 2.0ltr Impreza is rated at 92kW while its high performance Turbocharged cousin the WRX makes 165kW at just under 1.0bar of intake pressure over atmospheric. This aside, the potential for increased power through forced induction is undeniable.

Pic OE WRX TD04 Turbo

Subaru Turbo Truths Part 2

The STi is not immune to over-enthusiastic power claims or the laws of physics either, but the fact remains, it produces substantially more grunt than the WRX. Why is it so? Detail mechanical differences aside, basically it boils down to the STi being a couple of shoe sizes bigger in the turbo department than the WRX. Being bigger the STi puffer moves more air generating more urge. It comes at a cost, as low-end performance suffers noticeably when compared to its less well endowed sibling. The Australian model STi in particular is roundly criticised for doughy low-rpm performance and a relatively large amount of turbo lag. Subaru North America solved this issue, using the V8 brigade's motto "there's no substitute for cubic inches" by specifying a "big-block" 2.5ltr engine for its STi go-fast model. Additional "cubes" makes it possible to run a turbo for good top-end performance on lower-octane fuel, without all the penalties of lag etc faced by the 2.0ltr engines. As with the WRX, STi's respond well to intake changes, exhaust and engine management upgrades. This time though, the larger turbo gives a better return on dollars spent fitting items such as FMICs and exhaust headers.

A well sorted 2.0ltr STi will make around 190-200kW ATW, on 98 Octane pump fuel running 1.4 bar of boost. USDM STi's with the right combo of bolt-ons punch out around 380Hp (US numbers at the flywheel) running a touch less boost owing to the lower octane rating of Yankee gasoline. Better served by bigger stock injectors, at these power levels the stock fuel pump will be struggling to keep up – have your fuel system checked!

In a forced induction engine, an impeller is used to boost cylinder intake charge. This impeller is no more than a highly efficient and powerful fan that through rotation compresses air in excess of prevailing atmospheric pressure. In order to drive this fan, a powerful source of energy is required to “drive” it. This can be supplied in two ways. A superchargers impeller is driven off the engine by a belt or gears, whereas the turbocharger uses a second exhaust driven turbine or fan that makes use of fast moving exhaust gas (containing kinetic energy) which is normally wasted. Turbocharging boosts engine efficiency as it makes use of this wasted energy. There is no such thing as a free lunch, as often at low RPM there is not enough exhaust energy in order to drive the turbo, making performance “lazy” at low speed or after gear changes, until such time as intake pressure or “boost” rises.

Superchargers on the other hand are connected to the engine directly and produce positive pressure even from low RPM’s or immediately the throttle is floored. Problem is, driving the impeller requires considerable power itself. This is known as “parasitic” power loss. Although a supercharger creates more power than it uses, overall efficiency is reduced by these losses, while fuel consumption increases. At this point though, we leave supercharging there, and concentrate on Turbocharging, as fitted to the WRX.

As an interesting aside, a NA engine that makes around 140kW, wastes approximately 50kW worth of raw energy out the tailpipe in the form of exhaust. 50kW is enough energy to meet the air conditioning requirements of a five story apartment building. This gives you an idea of the turbocharger’s incredible potential for moving air.

The turbocharger consists of three major parts: The compressor wheel and compressor housing, exhaust turbine and turbine housing, interconnected by a common shaft running through the CHRA (centre housing rotating assembly).

13.1 Turbocharger Problems

As touched on before, the benefits of turbocharging don’t come for free, but any WRX owner understands that it’s more than worth all the trouble. In this section we will describe the most obvious problems associated with turbocharging, how they have been fixed, or at least minimised, by Subaru and most importantly, what can be done to increase power!

13.1.2 Turbo Lag

Easily the most well known and discussed problem associated with turbocharging, and certainly the issue harped on by proponents of other forms of power adding. Lag is literally the delay felt between pressing the throttle pedal and feeling the greatly increased power and torque that the turbo provides. This is due to the time needed to accelerate the turbos inlet compressor and exhaust turbine up to a high enough speed to make boost. Commonly known as "spooling up" it is particularly noticeable when accelerating from very low engine RPM's (read exhaust gas velocity). Other factors such as compressor wheel size, turbine wheel size, housing sizes and shaft bearings and rotating inertia also contribute to more or less amounts of turbo lag. A turbo with a large flow capacity with big diameter heavy impellers will take a lot longer to spool and make boost compared to more modest smaller, lighter and responsive ones. Likewise low friction roller or ball bearing raced CHRAs will permit the turbo to spool faster than one fitted with plain metal floating bearings.

Tiny Turbos

Ever wanted to know why the 2.0ltr Forester GT just doesn't cut it with the WRX? Obviously its rated flywheel power output of 125kW versus 160kW for the WRX immediately springs to mind, but why is it so? Subaru use a much smaller TD035 Mitsubishi turbo in the GT, compared to a more muscular TD04L for the WRX. So child-like is the GT turbo, mothers have to resist the urge to stand around and make comments like "ooohhh isn't he such a cute little thing". With all the turbo swapping going on, a cheap and cheerful modification is to transplant a second hand TD04 from big brother WRX onto the Forester. It's a straight bolt on and add a pinch of engine management, a bit of boost and shazam - A Forester with a lot more grunt and a whole lot more maturity! But why stop there when an IHI VF30 or 400Hp Garrett turbo bolts straight on….. Mmmmm powerrrrrrr…..

Pic Garrett Ball Bearing Cut-away Turbo

Subaru has done a good job matching turbo compressor and exhaust turbine wheel sizes and housings to suit the standard WRX engine, giving an excellent compromise between outright power, response and torque delivery. They have even seen fit to leave enough additional capacity for tuners and enthusiasts alike to have some fun.

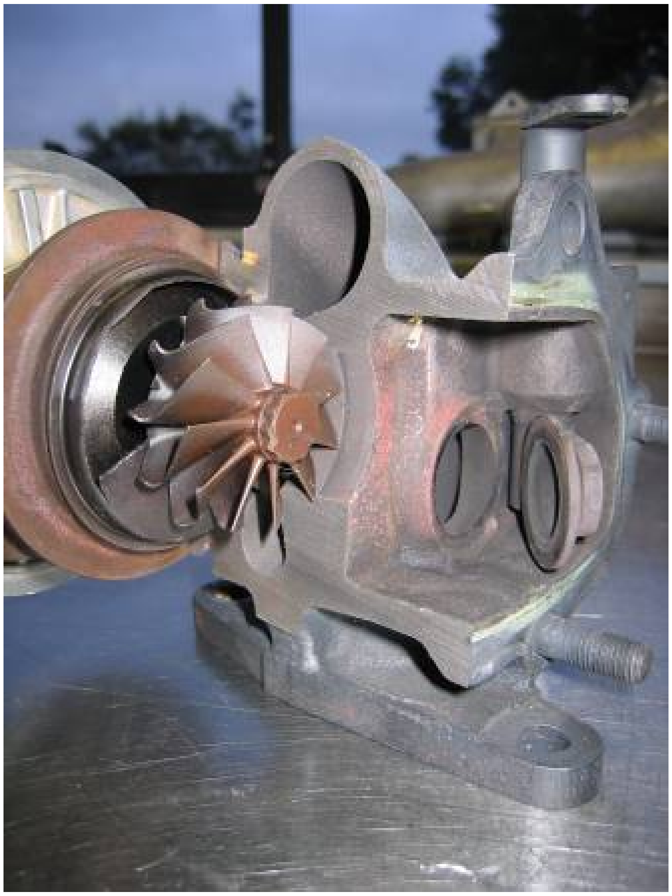
13.1.3 Intake Charge Temperatures

Wastegate Porting

Normally the boost control system in your WRX works automatically, without the driver aware of all the associated activity taking place under the bonnet. In the case of the VF39 turbo fitted to the North American model 2.5ltr STi, the turbine wastegate outlet can become overloaded. Improvements to the intake and exhaust systems increases the amount of exhaust energy passing through the turbocharger, up to the point where even fully open, the original wastegate by-pass hole can no-longer divert enough exhaust energy in order to accurately control boost pressure. Often called "boost creep" it manifests itself in higher gears where the engine is accelerating relatively slowly allowing more time for the turbocharger to make boost. Left unchecked, boost creep will often trigger an ECU overboost protection or "boost cut" to prevent serious engine damage. Carefully porting (read grinding) the wastegate orifice fixes boost creep as it adds flow capacity to the wastegate. Talk to your tuner for more advice on this. Porting the turbocharger is a specialist job, and if done badly will negatively impact on turbo performance.

It is an inescapable physical property that when air (or any gas for that matter) is compressed, its temperature will rise. The amount of heat generated by the turbochargers compressor is affected by size, desired boost pressure and how hard it has to work to achieve desired boost pressure. A very simple rule of thumb is a small turbocharger that works flat-out in order to make its target boost, will heat the air more than a bigger low-taxed unit, and ultimately have a lower power making potential.

Elevated charge air temperatures are the enemy of forced induction, as a 10 DegC increase in temperature decreases charge density by approx 3.3%. This in essence is counteracting the effort of compressing the intake charge in the first place! Subaru offset this by fitting the WRX with an intercooler, effectively a radiator for the intake system. See the *Intercooler* chapter for more information.



Pic Turbine Housing Wastegate Flap Valve

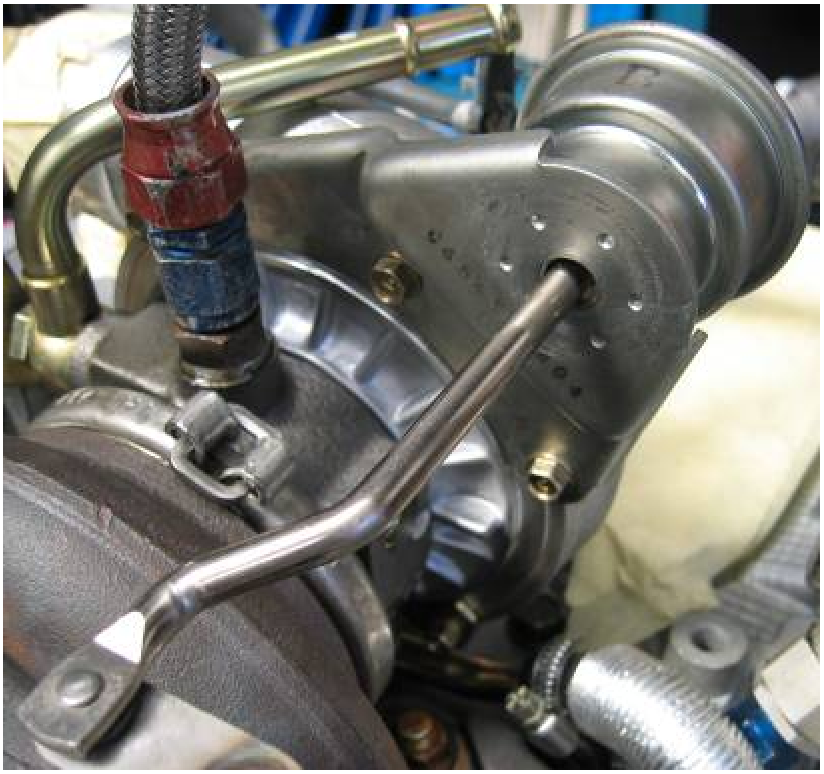
13.1.4 Boost Control

Now that we have established that the turbocharger fitted to the WRX is capable of compressing large amounts of air, we will investigate ways of accurately controlling intake charge pressure within precise limits. A device incorporated into the WRX turbocharger called a wastegate does this. A by-pass (or flap-valve) is built into the turbine housing, allowing a percentage of exhaust energy to be diverted (or “wasted” hence the term wastegate), that would otherwise flow through the exhaust turbine. This directly controls turbocharger RPM and charge pressure by managing exhaust energy, which is the power source that drives the turbocharger.

A spring loaded pneumatic diaphragm (actuator) operates the wastegate. Boost pressure is applied to the wastegate actuator from the turbo compressor outlet. Once boost pressure reaches a pre-set level, actuator spring pressure is overcome and the wastegate flap valve lifts off its seat reducing boost. This is known as actuator pressure.

Boost Control Solenoid

On the WRX this simple mechanical system is enhanced by electronic control of the wastegate circuit by the ECU via a solenoid bleed valve. (See *Engine Management* section) When the ECU begins to pulse the boost solenoid, the amount of boost pressure the wastegate actuator sees is reduced, causing boost to increase. Once target boost pressure is reached, the ECU will progressively slow the rate at which the boost solenoid is pulsed, which increases air pressure in the wastegate circuit. In response to this the actuator extends, opening the wastegate valve, regulating boost pressure. In extreme circumstances, the ECU will stop energising the boost control solenoid completely, causing the system to revert back to its mechanically determined actuator pressure (ie the spring tension inside the actuator).



Wastegate Actuator

Sometimes, in very high performance applications, or where a non-standard turbocharger is used, another form of mechanical boost control is used. Called an external wastegate, as its name suggests is an independent unit that is not integral with the turbo. They still perform the same task as an internal wastegate, diverting exhaust energy from the exhaust turbine, but potentially have a much higher flow capacity compared to even an enlarged internal wastegate. External wastegates use a poppet type valve (similar design to engine valves) operated by a two stage pneumatic diaphragm and spring. It is possible to control an external wastegate via an ECU driven boost solenoid in a similar manner to an internal one.

Installation is not an easy task, as additional exhaust plumbing has to be fabricated and installed to integrate with existing manifolding. The WRX's engine bay is tight, and can be a bit of a headache to package the whole system.

XT Forester Capers

Subaru's 2.5 XT Forester, to use a well worn cliché is a killer application. It's a WRX but with more interior space, a bigger cargo area and higher ground clearance. It also does without all the somewhat naff bits found on the WRX that scream "boy racer, look at me!" Traffic light drag race kill quotients are high, as other less well schooled motorists have problems spotting the Forester's wolf in sheep's clothing persona. One thing that spoils the show is turbocharger spec. Subaru lifted the TD04L turbo directly from the 2.0Ltr WRX and bolted it up to the Forester's 2.5 donk. Maybe Subaru was just looking for torque, but the end result is a car that just doesn't feel quite right. Off the mark the XT jackrabbits nicely, but then goes off the boil in the upper RPM ranges. Adding extra boost, exhausts, filters and intercoolers merely magnifies this feeling. Call up to the operating theatre and have the transplant team stand by I say! As with its smaller engined sibling, the XT takes to the whip incredibly well. An IHI VF30 swap in particular works a treat when dosed with a course of engine management changes. Owners and tuners alike remark how fantastic the XT Forester feels with this turbo, at a modest boost level of only 1.1bar. Many owners insist this is the way it should have come from the factory in the first place! All the other normal WRX hot-up stuff also applies such as exhausts, intercoolers, fuel injectors and pumps for those who want more, more, MORE!
Oh, and watch out for that pesky cat converter in the turbocharger up-pipe

External Wastegate

External Wastegate Internals

13.1.5 Thermal Management

Extra power cannot be produced without making large amounts of extra heat. Subaru deal with elevated intake charge temperatures using an intercooler, but heat management does not stop there. The WRX has a highly efficient cooling system with a high flow coolant pump and radiator and has excess cooling capacity to spare. In addition to this, an elaborate set of heat shields are fitted to all exhaust pipes, manifolds and turbocharger exhaust housings to protect engine bay components from radiated heat damage.
Subaru also fits an oil/water heat exchanger on its turbo engines. It serves a dual purpose, increasing the speed at which engine lubricating oil gets up to operating temperature, and as a cooler once oil temp exceeds coolant temperature. Although finely engineered with capacity to spare, big power increases, front mount intercoolers/oil coolers all stress the factory cooling system to the point where it will no longer cope. See the *Cooling System* chapter for more information.

13.1.6 Detonation and Related Problems

The seemingly simple act of raising intake charge pressure starts a new set of engine management requirements that are very different from a NA engine. Increasing the amount of air in the cylinder requires a proportional increase in fuel delivery according to a strict ratio of air to fuel. Explained in more detail in the *Engine Management* Chapter, in essence, not enough fuel and too much air causes a lean mixture. Lean fuel mixtures burn extremely hot and can damage pistons, valves and head gaskets. Too much fuel and not enough air is a rich mixture, which burns at a much lower temperature but with much less efficiency hurting power output and exhaust emissions.

In addition to fuel metering, increased cylinder charge also requires adjustments to ignition timing. As the molecules of air and fuel are more tightly squeezed together it takes far less time to ignite and burn the cylinder charge. Spark timing needs to occur slightly later in the cycle, otherwise premature ignition can occur. Referred to as pinging, knocking, pre-ignition or simply detonation must be carefully avoided to protect against serious engine damage. Relatively rich fuel mixtures, high octane fuel (96-98 RON) and good engine management contribute to reliable running by minimising detonation, but only within strict limits and are not infallible, especially if over-enthusiastically modified.

13.1.7 Engine Management Conflicts

Explained in further detail in the *Engine Management* chapter, factory ECU mapping is very finely matched to suit stock boost levels and air flows. Even seemingly small changes in boost pressure and exhaust/inlet efficiency will lead to the engine operating in different parts of the factory fuel and spark timing maps, areas that are not always optimum in terms of power and economy.

13.1.8 Mechanical Weaknesses

Turbochargers are not indestructible, and like engines and transmissions suffer from the effects of mis-use, abuse and poor servicing. Turbo failures normally can be traced back to one or more root causes, and almost always result from any or a combination of the following issues:

Mechanical Damage

Turbos run tight internal tolerances, and rotate at fantastic speeds, making them susceptible to FOD (foreign object damage). FOD is dangerous to both the intake compressor and exhaust turbines. Common points of entry on the intake side are in-frequently serviced, poor quality or non-existent air filters, rusty intake pipes/and or badly finished internal welds on intake plumbing. Even high quality intake systems will by-pass FOD if incorrectly fitted or if they have loose hose clamps.

On the exhaust side, sources of FOD include badly finished or rusty exhaust manifolds (this includes poor quality cast manifolds in which the actual manifold material flakes off and enters the exhaust stream). Even poor quality spark plugs that shed electrodes or insulators can by-pass particles that end up going through the exhaust turbine like a dose of prune juice. Small diameter FOD slowly erodes the turbo compressor or turbine over a period of time, with the sandblasting action of these particles reducing compressor efficiency as its sharp edges are worn down. Large diameter FOD tends to have a more immediate and catastrophic effect, often totally destroying a turbo compressor/turbine in short order.

Compressor Damage

Turbine Damage

Refer to the chapter on *Blow Off Valves* for more information on the final mode of mechanical turbo damaged known as "backspin"; caused by an inadequate blow off valve.

Misuse / Abuse

Driving a turbocharger past its operating capacity (Overboosting) results in peak Turbine speeds often in excess of design limits. As with most things there is a significant operating margin built in when it comes to maximum turbine RPMs, and while these can be exceeded for short periods of time, there is an inevitable limit. As shaft speed increases, centrifugal force climbs as a square root of shaft speed and if left to increase unchecked, shaft bearings begin to fail, and compressor wheels "burst" or fly apart, as do turbine wheels, often simply parting company with the bearing shaft ending up in the exhaust system.

Poorly fitted intercooler plumbing is another potential source of compressor over-speeding. If an intercooler or turbo hose "blows" off at full load, almost immediately the turbocharger can gain up to 30% more RPMs as load is instantaneously removed from the compressor wheel, often pushing shaft RPMs well past its safe operating range. Every time this occurs, fatigue damage builds up and manifests itself in compressor and turbine failures along with premature shaft bearing failure. In extreme circumstances shaft breakage can occur.


Turbine shaft breakage

Hardening Arteries

Subaru used to fit a little sticker to the drivers door on turbo Impreza's recommending that the engine should be allowed to idle for one minute, prior to shut-down if used for extended periods at high speeds. Perhaps they don't consider it to be a problem any more, or simply got tired of trying to explain the theory behind this to owners. I don't know. What remains is working the turbocharger to the point that its red hot, and then shutting it down immediately is not a good idea. It is an equivalent of force feeding your turbo on a high cholesterol diet of deep-fried chicken 'n chips, and all of the health risks associated with it. Fit a turbo timer if you don't have time to sit in an idling car for a minute or two.

Lubrication

Constant oil flow is absolutely essential for correct turbo operation. Engine oil both lubricates turbocharger bearings and also cools them. Even water cooled turbochargers still use engine oil for the majority of their cooling requirements. Engine oil pressure and volume is particularly important with older style plain bearing turbos. The turbo shaft only becomes centralised and starts to "float" on a film of oil once enough pressure and volume has been achieved through the turbo.

Newer style roller or ball bearing type turbos require less oil volume and pressure than the other type, and too much oil pressure can prematurely "burst" the plastic cages that locate the bearings around the circumference of the bearing shaft.

What both turbos have in common is the way they can suffer equally from the effect of carbon build up around turbo oil galleries and shaft bearings through heat soak. Heat soak occurs after sustained hard use when the engine is switched off and the supply of engine oil to the turbo ceases. This causes what oil is remaining in the CHRA assembly to "cook" as heat continues to migrate from the exhaust side of the turbo into the CHRA. As turbo bearings become progressively more and more clogged with sludge and carbon, friction increases making turbos lazy to spool, while ultimately restricting oil flow to such a degree that bearings starve for oil, leading to complete failure. Grossly exceeding oil and filter change intervals, or simply using cheap grade engine oil is another contributing factor towards carbon and sludge build up inside the CHRA.

Turbo Timer

Thankfully modern high grade synthetic oils are very temperature tolerant and resist the formation of carbon deposits, while water cooling of the core really comes into its own as the cooling system is designed to thermosiphon even with the engine switched off. Coolant continues to flow through the WRX's CHRA under the action of convection cutting the peak temperature reached by the CHRA on shut-down. These two features have pretty much made turbo clogging a thing of the past, but of late, with the emergence of many low cost replacement turbo combinations for the WRX that don't feature water cooled CHRAs, this problem could be set for a resurgence.

13.2 Turbocharger Upgrade Options (Version III and Onwards)

Turbochargers are another area where explosive growth has taken place. In the not so distant past, upgrades for the WRX's puffer were limited pretty much to the domain of mad scientist type turbo specialists, hidden away from public view in dimly lit and grubby workshops. Even these scary individuals could only perform relatively basic techniques, such as fitting bigger compressor wheels and high-flowed turbine wheels, limited ultimately by what could be done to the stock turbo CHRA. Other more adventurous types experimented with special one-off Frankenstein-type combos featuring bits 'n pieces taken from up to three different turbo manufactures and melded into one unit! The cost and complexity of fitting these "creations" often put it out of reach of most owners and tuners. For a time, the only realistic alternative available was the range of IHI VF series roller bearing turbos taken from JDM STi models. In the next section we will go into a bit more detail on turbocharger combinations readily available.

13.2.1 IHI Turbochargers

IHI VF Turbocharger

Still undiminished in popularity is the expanded range of IHI bolt-on turbos readily available to suit anywhere from mild to wild power increases:

Note, unless mentioned otherwise, all power figures quoted are measured as at the hubs using a Dynapack type hub dyno, and are achievable using a package of basic supporting mods including exhaust and intake changes with associated upgrades to engine management.

Early Model IHI

VF24 and VF28 - Still the turbocharger of choice for 2.0ltr Automatic transmission WRXs and GT Foresters, especially if only mild increases in power are the desired target. Producing good boost pressure from as little as 2,900 RPM it gives strong bottom end and mid-range at the expense of top end performance. 1.1Bar at around 6,000 RPM is about the maximum amount of boost pressure the VF24 will happily produce on a 2.0ltr engine. Less desirable is its relatively expensive price. For what ever reason the VF24 has remained an expensive choice, costing around A$2,000 each.

VF23 - another perennial favourite for middle-of-the-road power increases for the 2.0ltr engine. Boost delivery starts strongly from around 3,200 RPM, and efficiently makes up to 1.2 Bar of boost pressure at around 6,500 RPM. Power outputs in the region of 180kW ATW are possible with the right combination of bolt-ons and engine management. Lag is still pretty minimal, a strong point of its advanced roller bearing CHRA design. The VF23 costs around A$1,575.

VF22 – The old undisputed king of easy bolt-on turbo power. Still popular due to its low price, easy availability and good power potential on 2.0ltr engines. Boosting strongly from around 3,800 RPM and is capable of running up to 1.4Bar of boost pressure at around 7,000 RPM. Advisable only with supporting engine and engine management mods, with outputs of up to 200-205kW ATW possible. Some users report a degree of unreliability with the VF22, suffering compressor blade and bearing failures, but that is offset to a degree by a lower purchase price. VF22s are around A$1,375.

IHI Bolt-On turbo

Late Model IHI

VF30 – Relatively new, having appeared first on JDM model Version VII STi. It features an exhaust housing of equivalent size to the VF24, while sporting a compressor sized between a VF23 and VF22. Although being a plain bearing type design, this does not seem to detract from its performance, and has become an immediate hit with Group N and Group A Rally cars. A popular alternative to those previously using VF23 Turbos, it is a major departure from IHI's roller bearing range in that the VF30 can be rebuilt with new seals and bearings. Up to 185-190kW ATW with supporting mods is achievable, as are boost levels of 1.3Bar @ 7,000 RPM on a 2.0ltr engine. VF30 Turbos start at A$1,470.
VF34 – Very specialised JDM turbo fitted to the Spec C Version VII STi, equivalent in size to the VF30 but uses a roller bearing type CHRA. Favourites of rally teams with money to burn, they have a reputation amongst competitors for being relatively fragile, and require regular replacement as they are non rebuildable. Very responsive by nature, this can sometimes lead to problems with overboosting and poor boost control when coupled with high flow exhausts, intercoolers and intakes. Requires supporting engine managements to solve these issues. Capable of making up to 1.4bar @ 7,000 RPM efficiently, power outputs of 195-200kW ATW are possible. VF34 Turbos start at A$1,575.

VF35 – As fitted to Version VII and onwards Australian spec STi's. Slightly smaller than the VF30, with power outputs marginally down over the VF30. Still possible to make up to 185kW ATW without too much fuss, VF35s start at A$1,400.
VF39 – USDM 2.5ltr STi turbocharger. Roughly equivalent in size to the VF30 and with the right modifications can make around 380Hp (US numbers at the flywheel) @ 6,000 RPM and 18psi boost.

Late Model IHI Twin Scroll

Finally taking a leaf out of the Mitsubishi EVO series of turbochargers that have had this feature since the EVO 4, Subaru have fitted as standard equipment to Version VIII and onwards JDM Spec C STi and the 2.0Ltr Liberty/Legacy GT range what is referred to as a twin scroll turbo. Twin scroll turbos use an exhaust system that has four into two exhaust secondaries that remain split right up to the turbocharger, using a specially designed turbine housing with two inlets keeping the two exhaust streams separate as it flows through the turbine housings "snail". It is a technique used to more efficiently combine the exhaust pulses from the individual cylinders, boosting available exhaust energy and low-rpm performance. Relatively easy to do with an in-line engine like Mitsubishi's EVO, but a real headache on the WRX, given its widely spaced boxer configuration.

Twin Scroll Exhaust Manifold

VF36 – Fitted to JDM Version VIII Spec C STi. Extremely well matched to suit the STi's engine specification, it offers good low to mid range power and an excellent top end. Again, particularly susceptible to boost control issues if higher flow exhausts and intakes are used without matching engine management mods. This aside, the VF36 is an excellent all-round performer with outputs approaching 200+ kW ATW at a boost pressure of around 1.4bar. Cost is a real bugger though, with just the turbocharger assembly costing A$3,500, not including any of the also required manifolding, turbo dump pipe, and replacement sump that are required to complete the changeover. Easily the same amount could be spent again on top of the turbo cost purchasing all of the associated paraphernalia in order to upgrade a WRX to twin scroll spec.

Turbo Tuning Liberty/Legacy Style

Just about anyone that either owns or has driven one of the new BP model 2.0Ltr GT, fall over themselves to explain how good they are. For good reason, it is an excellent car, except when it comes to ahem, err, umm, well grunt. A nicely responsive, smooth and torquey engine are fine attributes, but wears thin when compared to big brother STi. Replacing the GT's little puffer is the key to boosting output, as when compared on basic engine specs, the 2.0Ltr GT engine is significantly more advanced than its WRX/STi brothers, featuring variable valve timing for both exhaust and inlet cams, electronic throttle control and more. At the time of this book going to press, MRT was hard at work testing several new IHI turbocharger combinations, with some very encouraging results. The quest for power continues. Stay tuned!

Twin Scroll Turbo

VF38 – Fitted to Australian and JDM model Liberty/Legacy 2.0ltr GT's. Significantly smaller than the VF36, it's a solid performer nevertheless, delivering nicely spaced power and torque curves very much in keeping with the Liberty/Legacy GTs gentlemen's conveyance type image. Peak power numbers are down compared to its larger IHI brothers, with power outputs around 155-160kW ATW possible. This turbocharger is not interchangeable with USDM spec Legacy GT due to major differences in turbine housing and compressor cover.

13.2.2 Bolt-On Garrett Ball Bearing Turbos

The new king of bolt-on turbochargers is Garrett. AVO Australia led the charge being the first to the market with its own custom designed and manufactured Subaru compatible compressor and turbine housings to suit Garrett's GT range of performance turbochargers. This was soon followed suit by APS, releasing their own range of custom made bolt on Garrett turbos. Still very much state of the art in the world of turbochargers, the Garrett GT series features twin ball-raced shaft bearings for very low friction levels compared to conventional style bearings and are extremely strong to boot. Compressor and turbine wheels feature advanced aerodynamics for maximum efficiency over a wide range of operating conditions.

Superior genetics aside, the GT series also boasts a large range of compressor and turbine wheel size combinations, making it possible to finely tune and match a Turbocharger for a given set of engine modifications. Less applicable for stock or lightly modified engines, they really come into their own at high power levels with 2.2ltr and 2.5ltr engines, while retaining the functionality of a bolt on part. Each turbocharger comes complete with oil and water fittings enabling it to fit up to standard hardware. Garrett bolt on turbos come in four basic power/modification categories:

320Hp – Marketed by AVO only, this is an entry level Garrett turbo. Designed specifically for lightly modified 2.0ltr engines and is roughly equivalent in flow capacity to the IHI VF30. This turbo boosts strongly from 3,100 RPM and is capable of up to 190kW and 1.3bar @ 7,000 RPM, with excellent spool and throttle response courtesy of its ball-raced CHRA. Features 0.6 A/R comp housing and 0.64 A/R turbine housing. Not recommended for 2.5ltr engines unless used at boost levels less than 0.85bar.

Green with Envy

Almost too late to be included in Training WRX Mark 3 was the arrival in Australia (and subsequent testing) of a new bolt on turbocharger combination supplied by U.S based Turbo supplier FP Green. Bit of a strange creation to look at on the bench, it features a TD05 style turbine housing machined out to fit a non-ball bearing non-watercooled Mitsubishi CHRA. On pure wheel sizes, the FP Green unit compares favourably with either AVO's 450Hp or the APS SR55, featuring a comparatively large 76x54mm compressor, and a 65x55.2mm turbine wheel. Curiously, it uses a very small A/R compressor housing compared to the Garrett bolt-ons.

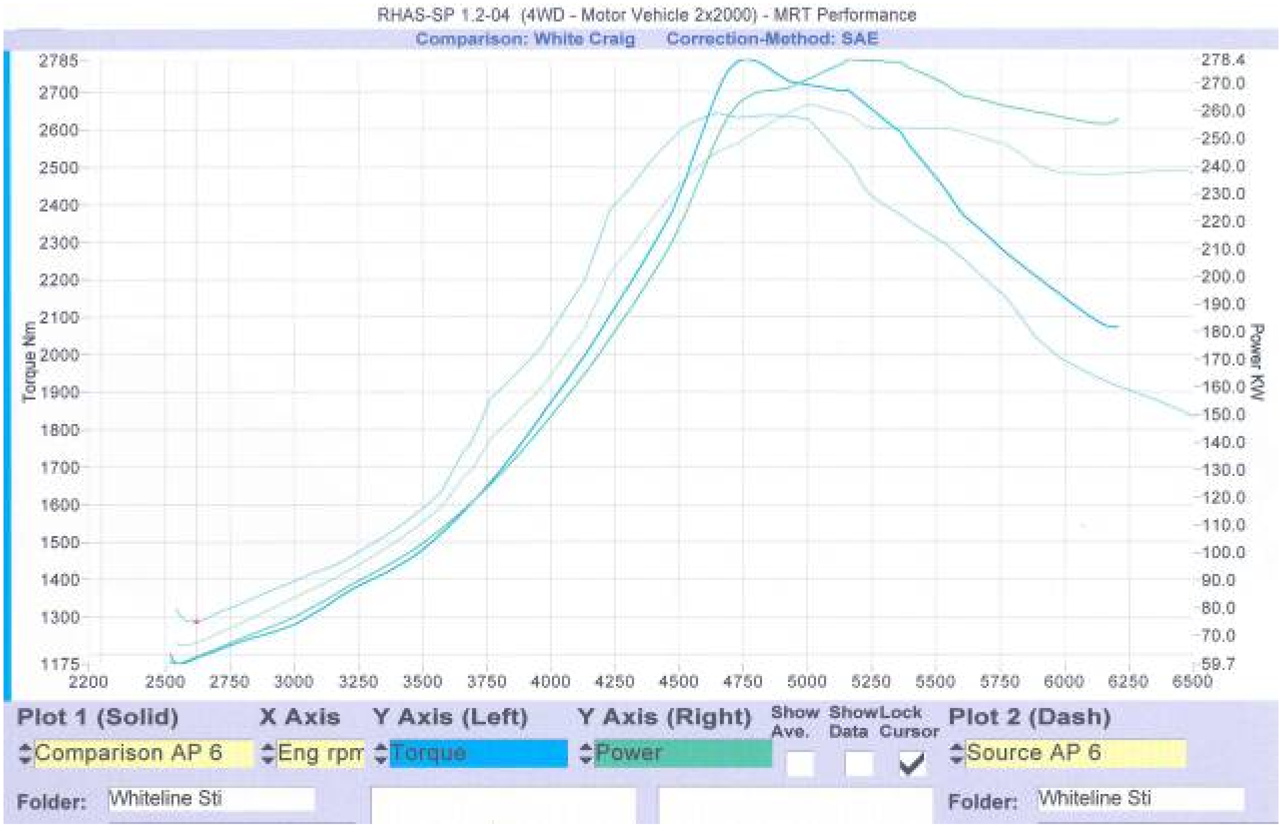
Fitting the FP unit was relatively pain free, needing only some minor tweaking of the oil feed line to the turbo. A small hose joiner was supplied for the redundant turbo coolant hoses.

Dyno results were surprising to say the least. The FP turbo fitted up to a worked 2.5ltr with ported heads and cams, immediately punching out some very healthy power and torque numbers. On the road its old-tech turbo bearing design didn't seem to hurt it, spooling quite nicely. Question marks do remain regarding turbo thrust bearing strength at high boost, the longevity of its non-watercooled core, and peak power potential in the real world (at time of print testing was still taking place). Pricing is around A$2,500 depending on exchange rates.


AVO Garrett Bolt-On Turbo *SR55 Turbocharger*

400Hp – AVO market a couple of different models within this power category, the 400S and 400L. Both feature the same sized compressor and exhaust wheels, but the 400L uses a slightly larger turbine housing, up from 0.64 to 0.86A/R. The compressor housing remains unchanged at 0.60A/R. The APS equivalent to the AVO 400Hp range is the SR40. All three of these bolt on Garrett's suit heavily modified 2.0ltr, 2.2ltr and some 2.5ltr engines with plenty of supporting modifications. There is not much between the 400S and the 400L, with the primary difference being a slightly sharper spool up time for the unit with the smaller exhaust turbine housings, with a corresponding decrease in top end power. The 400S is capable of around 220kW ATW, the 400L around 240kW ATW, and the SR40 marginally higher again.

450Hp – The heavy-hitting end of the bolt-on turbo market. Both AVO's 450Hp and SR55 from APS are capable of producing prodigious amounts of horsepower given the right supporting modifications. A specialist turbocharger suited to highly modified 2.0ltr engines with increased RPM limits over stock. When used on a properly modified 2.5ltr engine, power outputs of up to 270-280kW and 1.45bar @ 7,000 RPM are achievable. There is not much separating either model turbocharger at these sorts of power outputs, except that it seems that APS use compressor and turbine housings that are slightly better finished than the AVO ones offering improved spool characteristics without hurting top end power.



AVO 450Hp vs SR55 Turbo Dyno Graph

500Hp – Special order only AVO turbocharger. Features the biggest possible Garrett GT series CHRA that can be squeezed into their Subaru compatible compressor and turbine housings. Wheel sizes are huge, featuring a 62x82mm compressor wheel with a 53.6x56.5mm turbine wheel. Somewhat compromised by the fact that this model turbocharger still uses the same sized compressor cover and turbine housings as the 400Hp models, restricting peak airflow, it is still an impressive turbo nevertheless. Capable of cracking the magic 300kW ATW holy grail with a properly prepared 2.5ltr engine, along with boost pressures up to 1.55bar @ 7,000 RPM. Due to the large size of the 500Hp turbine wheel, some serious amount of machining of the turbine housing is required to make it fit, potentially weakening its structure along with a commensurate reduction in turbine housing lifespan.

Bolt on style Garrett turbos are an easy answer for those seeking high power outputs without the trouble of reinventing the wheel in order to fit a new turbo. This does not mean that they are a set and forget type part. They still require a small amount of "massaging" to make them fit, and adjustments to base actuator preload can be time consuming, as can be the task of interfacing them properly with an OE or aftermarket boost controller. This comes at a cost, being somewhat of a hand-made part, these turbos don't come cheap. Most of the Garrett range mentioned above are priced from between A$2,200 and A$3,500+ depending on final specification.

13.2.3 Angle Mounted Turbochargers

Eventually the quest for maximum power gets to a point where even the biggest bolt-on turbocharger is simply not up to the task. This is when we really get into lock-up-your-daughters type territory. At approximately 340kW ATW the stock turbocharger location makes it impossible to use large enough compressor covers and turbine housings in order to flow the required quantities of air. The stock inlet pipe (under the intake manifold in standard location) also begins to become a serious liability.

Angle Mount Turbo vs Stock Turbo

In order to fit such monster compressor and turbine combinations, physical space limitations dictates off-set mounting the new turbocharger at an angle compared to the stock item. This gives plenty of space for larger units, while offering a straight shot from the air filter and into the turbocharger. This configuration also opens up a completely mind-numbing array of compressor and turbine wheel and housing size configurations, which when properly matched to supporting mods are capable of pushing power outputs approaching 400kW ATW at boost pressures of 1.8bar and higher.

Locating the turbocharger in a non-standard location also opens the field up to a mind-boggling array for makes and models of turbochargers, as you are no longer confined to units that bolt-up. The inevitable downside is the huge cost and complexity of such a job. New turbocharger up-pipe, down-pipe, oil, and coolant fittings require fabrication. In addition, top-mount intercoolers cannot be used, requiring a FMIC with custom made piping. Most applications will also require the use of an external wastegate and associated plumbing for stable boost control as the regular internal type wastegate found on the bolt on turbochargers is simply not large enough.

Angle Mounted Turbocharger

Very much a specialist conversion requiring large amounts of metal fabrication to get it all fitted and working, along with a long list of supporting modifications. These include engine internals, engine management, fuel system, clutch and transmissions; its hard to quote an exact cost. Expect to pay up to A$5,500-6,000 excluding FMIC or other modifications just mentioned.

Angle Mounted Turbocharger Installed

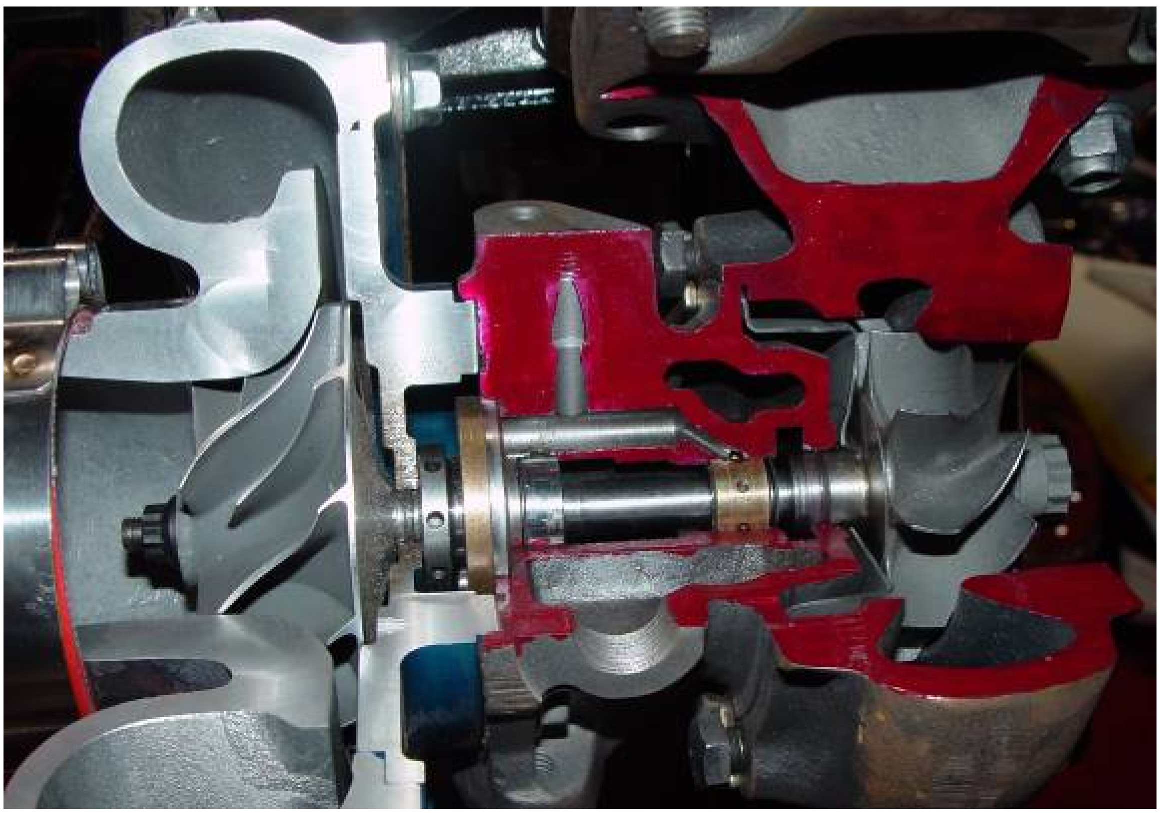
13.3 Turbocharger Upgrade Options (Version I-II)

TD05 Turbocharger

94-96 model WRXs came standard with a much bigger TD05 Turbocharger more in keeping with the prevailing Group A rally regulations of the day, dictating the use of a larger than ideal turbo in the humble road-going version in order to have the right equipment on the race car. As a consequence, these early model cars can achieve healthy power outputs without swapping out the stock turbo, going some way to compensating for doughy off-boost performance, and the general laggy behaviour these cars exhibit at low RPM. Early model WRXs can achieve around 185kW ATW and upwards with the right mix of bolt ons at safe boost levels, before requiring augmentation in the turbocharger department.

As these cars are starting to get a bit long in the tooth, owners of early model cars should consider the following items prior to turning up the wick:

- Give the turbo a medical and have its health checked. Increased power outputs mean increased turbo RPMs. A unit that is a bit sickly and only just hanging on will quickly fail when push comes to shove.
- If your turbo does need overhauling, specify a heavy duty thrust bearing set for the CHRA. High boost levels causes the turbo to try and “wind” it’s way out of the bearing housing placing extra load on the thrust bearing.



Cutaway Plain Bearing Turbocharger

- If your stock turbo is knackered, and are considering an upgrade to one of the more modern late-model turbos, be sure to specify an adaptor kit to enable the curved air-intake "snorkel" to be retro-fitted in order to maintain the early model behind the manifold turbo intake. Otherwise, expensive and complex modifications are required in order to space the intake manifold and power steering pump to allow enough clearance for an under the manifold intake.
- One last item to remember, the standard TD05 turbo is capable of producing more boost than the standard engine can handle by a big margin. Seek specialist advice before tinkering.

Group A Carbon Turbo Intake Pipe

13.4 Conclusion

The turbocharger, when it's all said and done is a powerful tool when it comes to dramatically changing the nature of your WRX. What is the perfect turbocharger for your WRX or STi? That is a difficult question, as one man's ideal turbo is another's nightmare. Treat it with the respect that it demands, and seek professional advice from your tuner. Possibly the best advice is to benefit from the experience of others. Refer back to *Why This Book Was Written* chapter and save having to re-invent the wheel. Sound advice beats a good price every time.

Reality Check

Remember that a turbo swap can upset the delicate balance of boost, ignition timing and fuel mapping controlled by the factory ECU. Although a new turbo can pin your ears back, it is not something to be done casually. If you want to spend only a limited amount of money, there are probably better ways of using this cash. On the other hand, if you want to make your WRX into a bit of a project, capable of sucking the doors off just about everything else on the road, a turbo swap is the best foundation for serious performance tuning.

Consider the implications of changing the OE turbocharger on the drivability vs performance compromise that exists on a stock car. As a turbocharger becomes more and more slanted in the favour of performance, generally the poorer it is for everyday street use. A 450kW monster punches out an impressive Dyno graph, but can be a dog and/or downright dangerous/illegal to drive on the street. Cost vs benefit ratios also become somewhat compressed, with your car turning into a cash consuming monster as costs spiral upwards faster than resultant power gains when at the pointy end of things. *Don't* even ask about new car warranty implications!

Homemade Angle Mount

Chapter 14

The Intercooler

The Intercooler

On a WRX, the intercooler is that thing that looks like a small radiator, mounted horizontally at the rear of the engine bay, sitting underneath the scoop in the bonnet. Its job is to cool compressed air discharged from the turbo. Why is cooling the intake charge necessary? The hotter the intake charge, the less dense it is, reducing the power potential of the air/fuel mix. The act of compressing air, as discussed in the *Turbocharger* chapter, raises its temperature and is an inescapable physical property. Friction within the turbo itself will also contribute towards heating the intake charge by a small amount, as does radiated heat off the hot side of the turbo in addition to heat conducted through the bearing housing of the turbo. The intercooler recovers lost density by cooling the intake charge prior to it entering the engine.

Once cylinder filling of the intake charge is complete, the piston rises, further compressing the fuel/air mixture, thus heating it by a further amount. If charge temperature rises too high, detonation or spontaneous ignition of the cylinder charge can occur. Covered in more detail in the *Engine Management* chapter, detonation of any severity or duration is serious and constitutes one of the single biggest barriers in the quest for more power, and must be avoided at all costs. In this chapter we will investigate available intercooler options and the part it plays keeping detonation at bay while at the same time boosting engine power.

14.1 Intercooler Categories

Intercoolers fall into two basic categories: Air to Water and Air to Air

Air to water intercoolers are effectively an engine radiator in reverse. That is to say it consists of a radiator core filled with air, submerged in coolant. Hot compressed air from the turbocharger flows through the radiator and is cooled through a process of heat transfer into the coolant via the intercooler core. The warmed coolant is pumped to a second radiator mounted in the frontal air stream of the vehicle, where heat is transferred back out of the coolant and into the surrounding air.

Water to Air Cooler

Subaru is no stranger to Air/Water intercooler, having used one in the '89-'93 Series RS Liberty/Legacy for all markets except for North America, where the same model car had a non-intercooled Turbocharged 2.2ltr engine. Water is an excellent medium for heat transfer, as it is capable of handling large amounts of heat lending itself well to intercooling. This efficiency is somewhat offset by the need to have a complex and relatively heavy system of coolant lines, an electric pump to circulate coolant throughout the system and additional front-mounted radiator to make the system work. Water to air intercooler systems have good thermal stability, and are very good at clipping big spikes in charge temp, but can work against itself once hot, taking a long time of time to cool back down. Not a maintenance free item either, as intercooler coolant requires change intervals similar to engine coolant.

Air to air intercoolers on the other hand are simplicity personified. It still can be considered as a radiator for compressed air, the major difference is that heat is transferred out of the intake charge via the core into a stream of ambient air passing through the outside of the intercooler.

When Subaru originally designed the first evolution of the WRX, considerations were made in respect to use in the World Rally Championship. Final intercooler spec was influenced by input from Prodrive, the company responsible for the preparation and running of Subaru's World Rally Championship programme. Prodrive extensively tested the performance of both water to air and air to air 'coolers on the outgoing RS Liberty/Legacy and found that, with water spray, an air to air intercooler was equally as efficient, far less complex, lighter and maintenance free to boot. Downsides of the OE WRX intercooler centre around its underbonnet engine bay location. Only when the car is travelling at speed does the bonnet mounted scoop begin to deliver sufficient quantities of ambient air to the intercooler in order to cool the engine's intake charge. In slow stop-start traffic the engine bay intercooler can act as an intake charge heater!

Intercoolers and Engine Management

Most performance parts for the WRX work reasonably well in isolation, but really deliver when combined with one or more products. Intercooling is no different. Modest power gains can be achieved by bolting on an intercooler onto an otherwise stock engine through improvements in flow and increased air density. But when combined with some engine management some really impressive gains can be had. Typically, the engine management system can be tweaked to run more boost and ignition timing without fear of detonation. Consistency improves as well, with less power loss due to hot weather or extended heavy loads.

Version II Group Engine Bay

Interestingly enough, the driving force behind Subaru placing the intercooler above the engine in the WRX (and related models) was simply through cost vs packaging constraints. The boxer engine provides a convenient space behind the engine. Very early naturally aspirated models had the spare wheel situated there. A large amount of powertrain overhang forward of the front axle, courtesy of a north south engine/transmission arrangement, contributes to frontal space being at a premium for packaging cooling systems and deformable impact protection structures. It is simply cheaper and easier to mount the intercooler in the engine bay. Being stationary for long periods of time in traffic is not a consideration for rally cars, but for us mere mortals and regular players in the traffic light grand prix, an important consideration. It is worth remembering that after your WRX has been idling for long periods of time, the intercooler will be fully heat soaked by the engine and will not begin to operate efficiently until the car starts to move and sufficient ambient cooling air becomes available.

14.2 Intercooler Improvements

First order of the day is to remove bonnet protectors and car bras as some designs will significantly reduce the amount of airflow to the top mounted intercooler. Certain car bras feature a strip situated in front of the intercooler scoop that stops bugs and other nasties from entering the intercooler. Unfortunately as a consequence it also stops just about all airflow. Owners of Version IV or later WRXs can upgrade to a copy of the much larger Version VIII STi intercooler bonnet scoop. (Available in fibreglass and carbon fibre) Taking another cue from the STi are splitter kits for the intercooler scoop. These are simple to fit and divide the intercooler scoop into two sections greatly improving the distribution of cooling air across the face of the intercooler core. Reproduction Fibreglass STi Bonnet scoops start at A$210 excluding painting and fitting, while an intercooler scoop splitter will cost around A$500. A cheap and cheerful upgrade for the budget conscious or tight-of-wallet, is to tilt the rear of the OE intercooler upwards slightly. This improves cooling air distribution across the face of the core.

Pic Version VIII STi Bonnet Scoop

These simple things aside, for those seeking large improvements in power, while keeping the bug-bear of detonation at bay, there are three options for improving the heat transfer capabilities of the WRX intercooler system:

- A larger and more efficient unit situated in the OE location.
- A larger and more efficient unit mounted at the front of the car.
- Water spray system for either the OE or upgraded intercooler irrespective of location.

OE Intercooler Spray Nozzles

14.2.1 Intercooler Waterspray

The easiest and cheapest option is to fit an intercooler water spray. Due to the incredibly high latent heat of evaporation of good old H_2O, spraying water directly onto the intercooler core will improve the operating efficiency of the system by 10-14%. Subaru caught onto this very early on in the piece, offering STi and RA models in certain markets with waterspray as standard equipment. These genuine systems consist of a couple of nozzles mounted in the intercooler seal under the bonnet, linked to a water pump and reservoir. STi models use an auto button that activates the water spray for a pre-set time only, at which point it switches off, until the driver next triggers the system. A manual override exists, that activates the waterspray only while the driver holds down the manual button. STi and RA competition models Version I-VI use an Underbonnet water reservoir located behind the RHS headlight, normally where the ABS unit is situated on cooking model WRXs. This is not an important consideration for race cars, but a tad useful out on the road. Australian spec Version VII STi and later cars have the waterspray reservoir in the boot and out of the way. JDM spec C Version VIII STis have a large capacity plastic tank that bolts between the rear strut towers inside the boot area.

Spray Away

For whatever reason, Intercooler spray kits seem to have fallen out of fashion with the WRX performance crowd of late. Somewhat curious considering it really is performance for a pittance, especially in the case of DIY kits. Perhaps it was due to some very poorly put-together Waterspray kits available early on that left a bit of a sour taste. These kits sometimes required almost as much time spent diagnosing why they are not working, as opposed to actually operating. Parts such as badly selected pressure switches and $1.50 screen wash pumps drove owners to pulling out great clumps of hair in frustration. Times have changed, and in general the aftermarket has got its act together and are now offering well made quality waterspray kits at the right price.

Version VII I/C Spray Reservoir

Aftermarket waterspray kits vary enormously in price and sophistication. Many are sufficiently straight forward that DIY construction is practical. They achieve that same aim as OE systems and contribute towards reducing charge temperatures. The main issues are efficient management of the limited amount of water able to be carried in the reservoir, and getting a nice, neat result.

Basic Waterspray Systems

Those of you with green thumbs, or have ever plumbed up a remote watering system for your garden will have no problem mastering the skills required to fit a spray kit to your car. These waterspray systems commonly feature regular garden irrigation fittings and lines to deliver the water, fed by an automotive windscreen type electric pump. Water is usually supplied by tapping into the windscreen washer reservoir, although larger remotely mounted tanks are available. Switching of the pump is accomplished via a few different ways, most preferable being an adjustable pressure switch fitted to the inlet manifold, or alternatively a throttle activated micro-switch. Even a simple in cabin on-off switch can be used. These kits do work, but they lack a certain amount of finesse. Systems using an on-off switch waste a lot of water, and tend to be ineffective if you don't remember to turn them on! Those making use of a manifold pressure or throttle switch are much better in this respect, but need constant attention and tinkering with to keep everything adjusted and working correctly.

Electronically Controlled Systems

A properly setup, electronically controlled waterspray kit is functionally more elegant than a manual system. It will offer the most economical and efficient use of the water it delivers to the intercooler. Really good electronic systems will monitor operating conditions such as engine boost pressure, throttle position and inlet temperature before pumping water. In certain situations such as extremely cold weather, or during engine warm up spraying the intercooler is unnecessary. An electronic spray controller will hold its water. The very best systems include a manual override mode so the intercooler can be soaked while engine is idling prior to a fast getaway. Very important when it is a roasting 38DegC outside and you feel the need to shutdown the V8 lining up next to you at the traffic lights. Not that we condone such childish behaviour.

Electronic Waterspray Controller

Spray kits range in price starting from as little as A$80 for a homemade system right up to A$400 for a whizzo, all-singing and dancing number. Some aftermarket ECU's such as MoTeC, Link, Haltech and Autronic can be configured to provide a user defined Waterspray function. Many aftermarket boost controllers such as E-boost by Turbosmart and EcuTeK's in car dash have a waterspray function. Large capacity alloy boot mounted reservoirs start from around A$320.

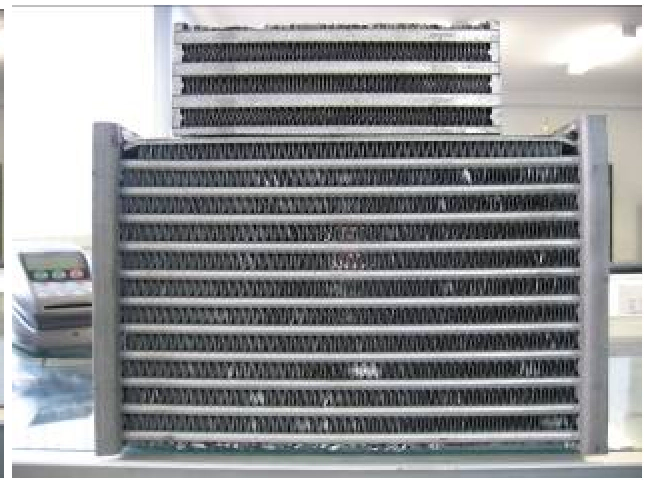
Large Capacity Intercooler Water Spray Tank

The Great Intercooler Debate
Which is better? Bar and plate or tube and fin? A stoush of mega proportions has existed between the devotees of these different styles of intercooler core for a long time. An almost indeterminable amount of text has also been written in magazines and forums alike debating this very question. As a consequence I will attempt to keep my ramblings on this subject to a minimum. The easy answer is that there is really no real difference in performance between the two different construction cores, as long as they are properly matched to a specific application, end of story. It is true that tube and fin has a significant weight advantage, often up to 60% over bar and plate, and is cheaper, while in applications short on installation space a bar and plate core will out perform a tube and fin of the same size by a small margin, and will be worth the additional weight and cost. In addition, a good quality tube and fin core will comprehensively beat the stuffing out of a cheap and nasty bar and plate unit and vice-versa. Intercooler cores should be judged on actual merits, with supporting data such as pressure loss numbers and heat rejection properties taken into account. Vague performance claims and a lack of technical information very quickly sort the good from the bad.

14.2.2 Intercooler Core Types

Intercooler cores come in two distinctly different types of constructions: They are tube and fin and bar and plate. Tube and fin intercoolers are popular with OE manufacturers as they are cheaper to manufacture, and have a distinct weight advantage over the latter. In keeping with the thrifty nature of manufacturers, Subaru use tube and fin construction for the OE intercooler core. Easy to spot, both externally and internally the OE intercooler is almost identical in construction to an engine radiator.

Tube and Fin vs Bar and Plate Core Side View



Tube and Fin vs Bar and Plate Top View

Bar and plate cores look quite different, using large rectangular shaped passages stacked symmetrically one on top of each other, with fins in both the charge air and ambient air passages. This increases the amount of material used and makes construction tougher resulting in a finished product that costs more to purchase.

Intercoolers are measured in terms of their efficiency. Theoretically a 100% efficient intercooler would reduce the temperature of the compressed air passing through it back to ambient. A more realistic efficiency rating is around 70%, resulting in a charge temperature of approximately 30% more than ambient. Pressure drop is another means by rating an intercooler. Pressure drop can be considered the amount of “drag” exerted on the intake charge as it flows through the core, and is measured by comparing intercooler inlet pressure vs outlet pressure. Some decrease in pressure is inescapable, as the Intake charge flows through the intercooler at high speed and must be slowed slightly in order to facilitate heat transfer. Keeping pressure drop to a minimum, to around 0.14Bar or less, while retaining good cooling efficiency at peak airflow rates is a sure sign of a finely made intercooler core.

14.3.1 Top Mounted Intercooler (TMIC)

Upgrading the Intercooler by fitting a larger unit in the OE location is a worthy option, especially for early model Version I-II's, which had a very small unit fitted, and for those seeking large power increases while keeping the spectre of detonation at bay. A TMIC is an easy way of bolting on a big increase in intercooling capacity quickly and keeps the distance between the turbo and engine short, benefiting throttle response. It is also somewhat low-key, with the car looking standard from the exterior, while keeping front area unobstructed for radiator cooling air flow, and plenty of space to spare for oil coolers. Spark plug changes and other routine maintenance operations also remain unaffected with a TMIC.

WRX TMIC

Liberty/Legacy GT TMIC

Somewhat underestimated by tuners and owners alike the TMIC is routinely overshadowed by its more glamorous brother the FMIC. This is often more to do with the forces of automotive fashion, rather than any glaring technical deficiency. Ultimately space limitations within the engine bay, along with the physical size of the intercooler bonnet scoop duct ultimately restrict how big a TMIC core can be squeezed in behind the engine and under the bonnet. Nevertheless, due its inherent efficient heat rejection properties, power outputs approaching 260kW ATW are achievable with a good quality TMIC and supporting mods. TMICs with fabricated/machined alloy tanks start at around A$1,500 for Version V to current cars, while units to suit earlier models use cast alloy tanks and are slightly cheaper starting at A$1,300

14.3.2 Front Mount Intercooler (FMIC)


WRX STi FMIC

When chasing absolute maximum power, an FMIC is a better option, albeit at a higher cost. Situating the intercooler core at the front of the vehicle is simply the best place for it. This location provides the intercooler with maximum airflow whenever the car is in motion, while when stationary the intercooler remains insulated from engine bay heat. In one stroke the two biggest shortcomings with the OE location are solved. Testing and data logging reveals a reduction in intake temperatures of up to 25DegC over an upgraded TMIC. This sounds great, but as ever there is a catch or two; namely cost, complexity, an increase in turbo lag and a reduction in airflow to the radiator.

Tanked Up

An intercooler tank is the part fitted at either end of the core, and has the job of feeding the incoming intake charge into, and then out of the core through into the inlet manifold. Tank design is important, having a great bearing on flow restriction and air distribution across the core. Normally tanks are fabricated from sheet alloy, machined out of solid billets, or cast from moulds. Which is the superior type? A difficult one to answer, there are the obvious advantages in favour of fabricated or machined billet tanks as they take the cake presentation wise, while cast alloy are cheaper to manufacture and buy. The biggest defining factor is mass, cast alloy is much heavier, and increases thermal mass of the Intercooler system. While this slows the rate at which it heats up, heavy intercoolers will be tardy in cooling back down again. Somewhat of a liability in the traffic light grand prix!

High Impact Value

Fitting a FMIC to a Version VII or later WRX is not an easy task. In the quest for improved frontal impact protection, Subaru fitted a substantially upgraded front crash bar that also serves as a bumper bar support. A big heavy lump of metal, this assembly has to be removed before fitting a new FMIC. Most intercooler kits now come with mounting points incorporated into the intercooler to attach the top edge of the bumper bar to adequately support the bumper. What is harder to establish is the effect in the event of a major accident. Without sounding like a press release from the Grim Reaper's PR department, it is a valid consideration, as airbag deployment, performance and rate of frontal crush are all finely calibrated parameters set by the manufacturer. Fooling around with these parameters could mean the difference between walking away from an accident, doing a stretch in hospital, or even worse. Who knows? What is for sure, fitting a FMIC to a WRX will change the cars behaviour in an accident. Repair costs for low speed nose to tail bingles will skyrocket, as will tangling with Betty, the supermarket carpark demolition derby queen.

Basic hardware costs increase, as big intercooler cores are expensive, taking more labour to install and requires a complicated set of metal and flexible connecting pipes between the turbocharger and intake manifold. Some trimming and massaging of the front bumper bar is also required in order to fit the bigger core, while on the earlier model cars some FMIC kits require the removal of the spot lights to make room for intercooler piping. Space requirements also force the use of an aftermarket cone type air filter as the factory air filter box has to make way for intercooler plumbing. This additional equipment in the engine bay can make servicing and other maintenance operations harder. Turbo lag becomes more noticeable, as the added capacity of the intercooler and connecting pipes greatly increases intake system volume, taking longer to become pressurised before making boost. Large FMICs also decrease the amount of cooling air flowing through the radiator, normally not much of a concern for street use, this can lead to problems with overheating at high power outputs, high ambient temperatures and heavy loads such as track work. Quality FMIC kits with all of the required fixtures and fittings start at around A$2,000

WRX Front Crash Bar

14.4 Water Injection

Sometimes confused with water spraying of the intercooler, water injection is very different, but shares the common aim of reducing charge temperature. Water injected under high pressure as a fine mist through a nozzle directly into the engine intake manifold pulls heat out of the intake charge due to its high latent heat of evaporation. Very useful for turbocharged engines, as in the right situations large power and torque gains can be made through a combination of higher compression ratios and boost pressures. Good examples of this are the current generation of WRC rally cars running compression ratios of 10.1 to 1 with peak boost pressures exceeding 2.0Bar on control racing unleaded fuel, due to the additional benefits of water injection. WRC water injection systems are incredibly sophisticated and are built to a very high standard. In addition a team of highly skilled technicians constantly check and recheck system health, tinkering as required.

Aquamist Water Injection Pump

For road use the benefits of water injection are still valid, but a few things must be considered. Water injection on its own will *decrease* engine power unless adjustments are made to boost pressure or ignition timing to take advantage of the cooler intake charge. Engines that are set-up to depend 100% on water injection to prevent detonation will be toast if for some reason the system runs out of water or simply stops running. Water by nature is an extremely corrosive solvent, and even the very best water injection system is by no means maintenance free. Filters, pumps and nozzles require regular servicing to keep in top condition.

In short, water injection can serve a useful purpose for highly stressed engines for added safety margin, but for most street applications is no substitute for a good intercooler. High quality race spec Aquamist water injection systems start at A$910

14.5 Conclusion

An intercooler upgrade remains a key element in the quest for power, and the resultant gains far outweigh the pains, as long as you can make room in your budget. While the TMIC is cheaper and has no negative effect on lag, it is limited by size and position. FMICs offer ultimate performance, but at a greater cost and with certain drawbacks. Some FMIC kits on the market reside purely in the realm of automotive fashion, often comparing unfavourably with a high quality TMIC in terms of performance and turbo lag. The choice remains difficult, and will depend very much on your eventual goals balanced with the amount of cash you have to spend. Again, if on a very limited budget, other modifications may offer better value for money.

Reality Check

Heavy competition within the performance industry has driven down the costs of intercooler kits greatly since the publication of the 1st and 2nd editions of Training WRX. On the whole this has been a good thing, as in general intercooler kits have far better fit and finish than any time in the past. What is less encouraging is the emergence of bargain basement priced intercoolers. Some FMIC kits are now available at incredibly low prices including pipe work and fittings. These intercoolers use highly restrictive cores that are nothing more than a bad copy of the real thing with pressure drops of up to 0.8bar! In this situation, in order for you to have 1.0 bar of boost pressure at the engine, your turbocharger will have to make approximately 1.8bar, stressing it unnecessarily! Unless the decision to upgrade your OE intercooler is on purely cosmetic grounds, shop around and make an informed decision on the type of intercooler upgrade that best suits you.

Pressure Drop

Is a term used extensively when describing intercooler performance, and is the measurement of intercooler inlet pressure compared to outlet pressure. A slightly lower pressure reading at the intercooler outlet over the inlet is normal, as the airstream has to be slowed slightly when travelling through the intercooler for the exchange of heat to take place. It is the magnitude of this difference that is important. Good quality intercoolers typically keep pressure drop to under 0.14 bar at high flow levels. Some poor quality intercooler cores can record up to 0.5 bar of pressure drop and are a serious power liability.

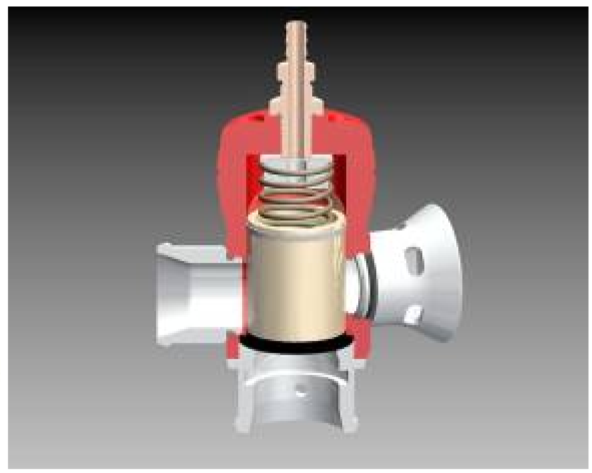
Chapter 15

Blow-Off Valves

Blow-Off Valves

Blow off valves (BOV) are fitted to turbocharged engines with the purpose of maintaining turbo shaft RPMs and preventing “back-spin”. Picture the engine of your car under heavy load, the turbo pumping large quantities of air, and is running near maximum RPM. The driver lifts off the loud pedal to change gears or slow down and suddenly all that air has no where to go. Closing the throttle is not unlike turning off a water tap quickly. We have all experienced “water hammer” or the racket from the pipes as water pressure backs up. What happens inside a turbo when air backs up in the system is a little more serious than knocking water pipes due to the speeds and pressures involved.

GFB Deceptor pro BOV External View



GFB Hybrid BOV Exploded View

When the throttle is lifted, thermal load or the driving force on the exhaust turbine is reduced, meaning there is no longer anything driving the compressor. Two things happen; first turbocharger rotational speed decreases rapidly and secondly, pressurised air starts to buildup in the intercooler system, right back up to the turbocharger, causing it to stall. High pressure air begins to fight its way past the compressor wheel and back out to atmosphere, attempting to reverse the rotational direction of the turbine shaft. This is commonly known as turbo back-spin. In certain situations this is very damaging to the health of your turbocharger. IHI VF22 turbos often exhibit compressor blades that have been literally turned inside-out from the force of back-spin due to insufficient BOV capacity. This condition is also particularly hard on the thrust bearings inside a turbocharger, a major weakness of non-ball bearing turbos. See *Turbocharger* chapter for more information.

The BOV works by detecting a vacuum condition on the engine side of the throttle butterfly, and opens in response to “dump” excess pressure back into the intake system upstream from the turbocharger. As manifold pressure increases, the BOV begins to close, becoming fully closed once there is positive manifold pressure. Thus the BOV prevents pressurised air from backing up in the system, reducing the amount of drag on the turbo and allowing it to free-wheel and maintain rotational speed for longer. As a result when you put your foot back down on the loud pedal, the turbo will have conserved shaft RPMs, taking less time to build boost back up thus reducing lag. BOVs do not increase power or control boost pressure. Their purpose is to protect the turbo from dangerous backspin, as well as improving on/off throttle response.

Version I-II WRX BOV

Version I-II WRXs used a very small BOV that quickly became overloaded at higher than stock boost levels, contributing to a very noticeable whoosh on gear change. The Version III came with a larger capacity BOV and redesigned plumbing in line with changes to the turbocharger. Somewhat troublesome, this was subsequently redesigned for the Version V, where the BOV was mounted directly onto the intercooler. In all subsequent models right up to current the BOV has remained in this location, but has received some detail changes to construction and plumbing.

Version V BOV

Version VIII BOV

15.1 Replacement Blow Off Valves

The main benefits of aftermarket BOVs are higher flow capacities, stronger spring rates to better resist leakage at high boost levels, and adjustment to fine tune the point at which it opens and dumps pressure. Replacement BOVs are available with the following features;

- Externally venting, where all dumped air exits out into the atmosphere. Extremely popular due to the whipcrack or sneezing sound they make on gear changes or throttle lift-off. This type has engine management implications, and very few vendors take the time to fully explain this. Externally venting BOVs can present a false picture of engine operation to the ECU. When the BOV opens and dumps air to atmosphere, the air mass meter sees a large increase in airflow, but it is air that is not entering the engine. This can lead to excessively rich fuel mixtures, backfiring and general rough running. Installers will often adjust the valve so that it stops venting soon after the throttle is backed off, which alleviates ECU problems, but actually reduces BOV performance.
- Fully recirculating in the same manner as the OE unit, operating without any engine management issues. Somewhat low-key as noise levels are not much higher than stock.
- Hybrid type BOVs that offer the user the choice between fully recirculating or externally venting for those days when the teenager inside us all is trying to get out. Somewhat of a good compromise, as a fixed percentage of airflow is recirculated at all stages minimising engine management issues.
- Manufacturers such as Turbosmart offer “sleeper series” BOVs that feature matt black finish for a low key OE look.

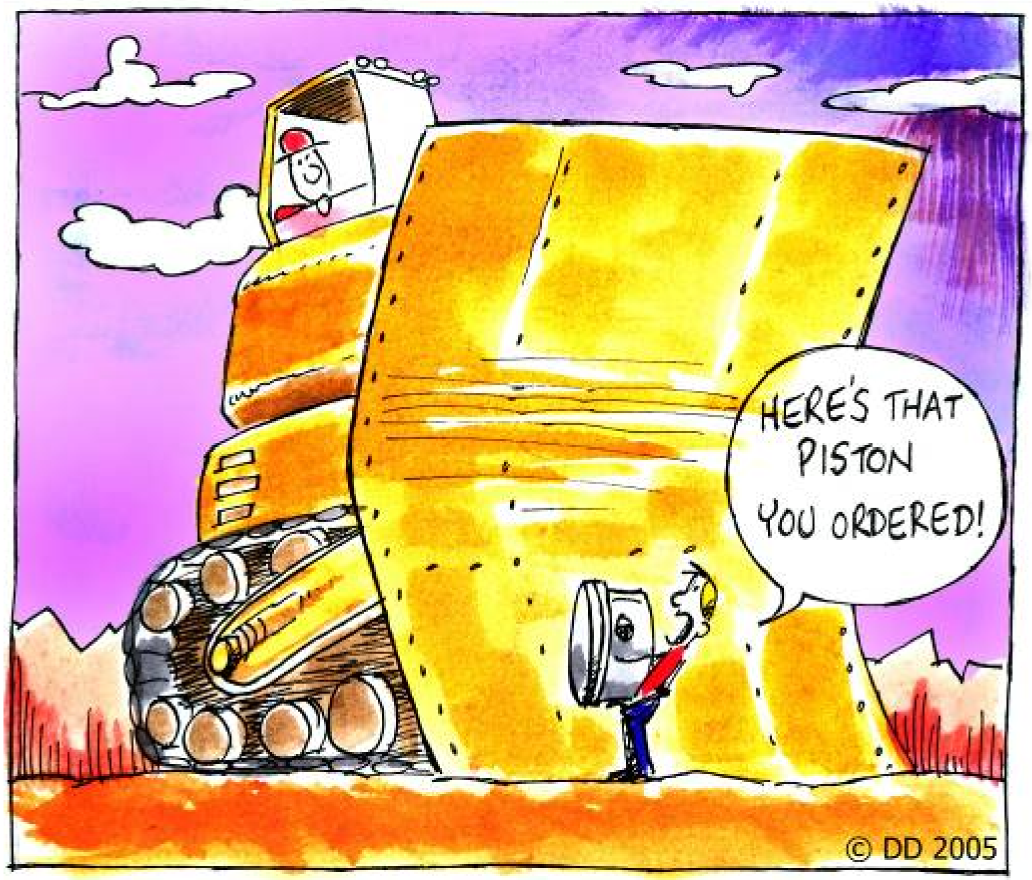
Turbo smart Dual Port BOV

Early model Version I-II cars should have the poorly performing OE BOV replaced even if only lightly modified. Version III cars have issues with annoying BOV noise on part throttle, something an aftermarket BOV can be adjusted in order to cancel this out. These two cases excepted, the majority of BOVs are fitted for their characteristic noise, and as an automotive fashion item. This being said, very highly modified engines that are running big boost pressures and oversized turbos will require a matching increase in BOV capacity. A Hybrid BOV start at A$300

Hybrid BOV

GFB Stealth adjustable BOV

Chapter 16



Engine Mechanical

Engine Mechanical

The engine fitted to the current model WRX can easily trace its family tree right back through the range to the engine fitted to the '89-92 RS Liberty / Legacy, without resorting to the services of a genealogist. A well proven tried and tested configuration, a properly cared for and driven WRX engine can easily crack 200,000kms without needing much more than routine servicing, so obviously the basic Fuji Heavy Industries product is no cheap 'n nasty. Barring the unthinkable, such as a major engine malfunction (politically correct term for bearing one's internals for all to view), or just plain wearing out, confusion reins supreme on how to decide when is the right time to put your WRX's engine innards under the knife, and thus embarking on the process known affectionately as the "monster tune". Upgrading the rotating bits stuffed inside the WRX engine is expensive, time consuming and often painful, but if done right, loads of fun and very satisfying. In this chapter we will shed some light on this very question and investigate what powers the WRX.

16.1 Subaru EJ Engine Series Overview

As touched on, the WRX engine has remained in essence unchanged in configuration throughout its entire model life. Although it has been the subject of a number of evolutions, basic specifications remain the same. The two piece engine block is constructed of aluminium with cast iron integral cylinder liners, arranged in a horizontally opposed or "boxer" layout. The term boxer was coined by means of this unique layout, as the pistons operate in an opposing "boxing" motion. The crankshaft is made from cast iron and has five main bearing journals integral with the cylinder block halves. Pistons are cast alloy (for most WRX and STi applications). Pistons use floating piston pins (a.k.a gudgeon pins) retained by circlips accessible through threaded plugs in the cylinder block. Cylinder heads feature direct actuation of the four valves per cylinder via a shim and bucket arrangement (Version IV to current). Spark plugs are centrally located in a highly efficient pent-roof combustion chamber. Double overhead camshafts are driven by a toothed camshaft drive belt. Engine lubrication system consists of a wet sump, full flow oil filter and an oil/water heat exchanger to cool engine oil.

Version VIII WRC Engine

These elements combine together to produce a very light, efficient and powerful engine package. Courtesy of its flat four configuration, the engine has a very low centre of gravity and is compact in length, compared to conventionally laid out inline four cylinder engines.

16.1.1 Version I-II

Essentially an evolution of the previous model RS Liberty/Legacy engine, the one major difference being valve actuation. Camshafts now directly actuated the valves via bucket type hydraulic lash adjusters. This replaced the troublesome combination of hydraulic lash adjuster and rocker valve actuation on the outgoing Liberty/Legacy engine. Camshaft pulleys changed from metal to plastic items to reduce noise and valve train inertia.

Direct actuation of the valves improved reliability, but was prone to valve and lifter problems at sustained high RPMs, while at the same time as is the nature of hydraulic lifters, restrictions on the use of aggressive cam profiles apply. RA competition models differed in this respect, as it used shim adjustable solid tappets fitted between the valve and the camshaft bucket, avoiding the possibility of shim spitting at high rpm.

Another desirable feature of RA models was a specially constructed cylinder block covered in more detail later in this chapter.

16.1.2 Version III-IV

Piston specifications changed for this model, adopting a new low friction piston skirt and piston ring pack. Piston crowns are ceramic coated for better thermal management, while the skirts are molybdenum coated reducing friction and aiding with running-in.

Valve actuation is another major change, with hydraulic lifters discarded and replaced with shim in bucket adjustable tappets. The adjusting shim sits between the camshaft and the bucket. This opens up the potential for a wider range of aggressive camshaft profiles, and allows the engine to rev harder and longer without the fear of lifter failure. Multi layer metal headgaskets are fitted as standard, previously regarded as a desirable upgrade.

The intake manifold and intake system were revised completely to suit the change in turbocharger spec, with a new throttle body, smaller plenum and longer smaller diameter inlet runners.

16.1.3 Version V-VI

Probably the most desirable engine incarnation of the EJ20 engine for Subaru performance specialists. Cylinder heads, combustion chambers and camshafts were all heavily revised for this model, and provide an excellent base for those attempting a monster tune due to favourable air flow potential. Detail changes were made to the cam belt tensioner for improved operation and reduced noise.

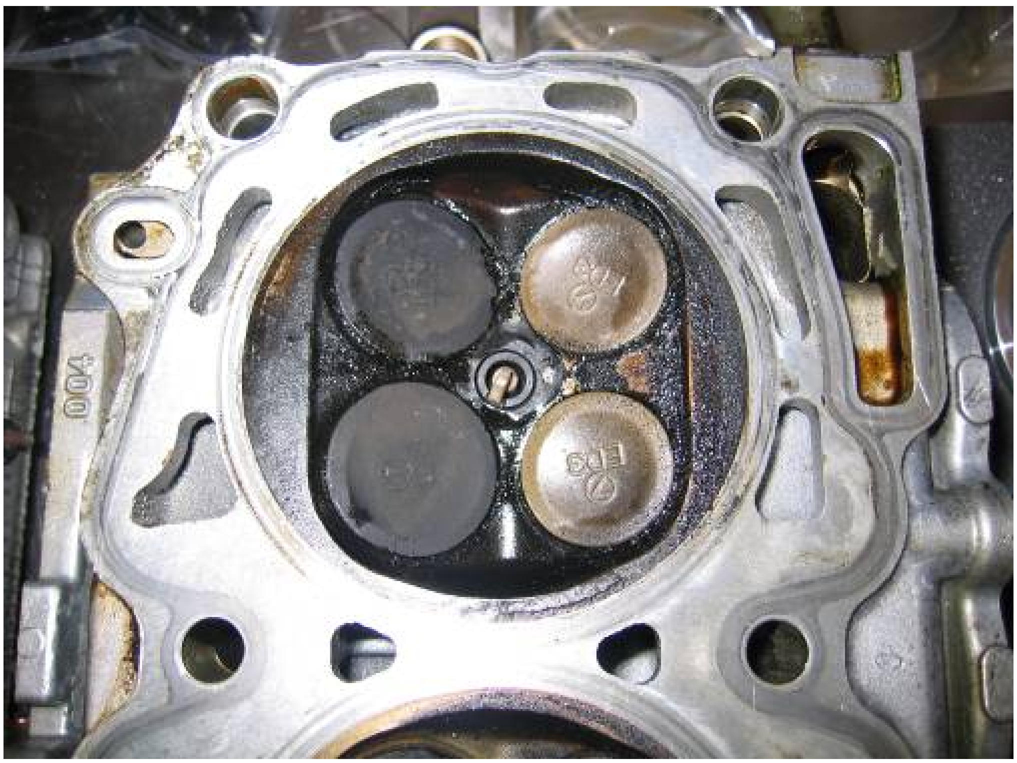
Version V-VI Cylinder Heads

In line with revised cylinder heads the intake manifold was further refined and modified with a new throttle body, plenum shape and intake runners.

16.1.4 Version VII

A bit of a letdown compared to the outgoing engine, stemming mainly from heavily redesigned cylinder heads, port dimensions and combustion chambers with the release of the Version VII here in Australia. These modifications seem to be more for emissions compliance, and when combined with a low compression ratio of 8.0:1 made the face lifted WRX a lacklustre performer.

Of greater relevance to the performance industry was some very different combustion chamber fuel distribution and burn characteristics when compared to the outgoing engine configuration, especially at high power levels. This took the aftermarket some time to come to grips with the tuning implications of changes to the cylinder heads. See *Engine Management* for more details.



Version VII Cylinder Heads

The valve train came in for some major modifications, including graded size cam shaft buckets replacing separate valve adjusting shims thus eliminating the possibility of the adjusting shims parting company with the cam follower at high RPMs. Exhaust valve cooling is improved through the use of sodium filled valve stems. Intake valves also feature a hollow cavity in the valve stem to reduce weight and valve train inertia.

Another major revision of the Intake manifold, with a new throttle body, totally redesigned plenum and longer intake runners. Of particular note was the adoption of tumble valve generators in the intake manifold. Consisting of small butterflies situated just up stream from the fuel injectors, they operate at idle speed only. When activated the tumble generators partially close off the intake manifold greatly increasing turbulence into the manifold improving fuel distribution and mixing for easier cold starts, smoother and cleaner idling.

Version VII STis for the Australian market come standard with 8.0:1 compression ratio forged pistons as standard equipment. This engine was the first to feature Subaru's AVCS (Active Valve Control System) intake camshaft control system on Australian models.

16.1.5 Version VIII

Major changes to base mechanical spec included a big jump in compression ratio from 8.0:1 to 9.0:1 for WRX models. New pistons and re-profiled piston crowns were fitted in order to achieve such a large gain in compression. A slight redesign was made to the combustion chambers, cylinder head ports and camshaft profiles, improving performance potential, although still not in the same league as Version V-VI engines. AVCS intake camshaft control became standard equipment on the WRX, and this along with detail mechanical changes, deletion of the tumble valves and turbo up-pipe catalytic converter boosted power and torque. Oddly enough, the significant performance difference noted both on the road and on the dyno don't do justice to the tiny gain in flywheel power (3 kW) claimed by Subaru for the current crop of WRXs.

Cutaway WRX Engine

USDM STis in comparison use an 8.2:1 compression ratio 2.5Ltr “big block” version of the WRX flat four engine, in deference to the lower quality pump fuel in the US compared to Japan or Australia. Also featuring AVCS intake camshaft control as found on Australian spec models, throttle control is different, and is done electronically without any mechanical connection to the driver.

Engine specifications for the Australian spec STi remained unchanged from the previous model.

Subaru Factory Performance Engines

Early model STi and RA competition variant engines were much sought after and highly desirable for use as the base for a Monster Tune project, due to differences in valve actuation, camshafts and cylinder block construction when compared to the stock engine.

STi Factory Engine

In practice there is no longer such a big gap between the base WRX mechanical package and the go-fast STi variants, although differences still remain in the areas of cylinder block, camshafts and compression ratio. The most immediate differences exist in bolt on items such as intercooler and turbo specifications, and revised engine management calibration.

STi factory engines are generally identified by a red painted intake manifold. It is important to note that even in Japan, forged pistons are not standard equipment and are a special order item, requested by the customer by ticking an options box. This means the vast majority of imported second hand Japanese STi engines have cast pistons only. Australian delivered Version VII-VIII models with the 195 kW engine is the only one in the world delivered from the factory with forged pistons.

16.2 Deciding When to Upgrade Engine Internals

Unfortunately, what should be a relatively straight forward decision, turns out to be a very contentious and divisive issue. Just about everybody has an opinion on what can and cannot be done with the standard bottom end. Internet forums and pub-talk alike abound with a lot of people claiming an amazing range of power outputs and turbo boost levels. In practice it boils down to how you intend to drive and use your car and how much of a risk you wish to take by exceeding safety margins that exist within the OE engine.

Street use is very flattering towards engine durability, and can hide a multitude of tuning sins. An over enthusiastically or badly modified engine running borderline fuel quality will last a surprising length of time out on the street. This is due to WOT rarely being held for more than a handful of seconds at a time and confined mainly to the lower gears, leaving little time for heat soak, combustion temperatures, detonation and other nasties to raise their ugly head. Short fast dyno pulls or even trips to the track for a run down the dragstrip, rarely see an engine stressed for more than a handful of seconds at a time, in any one gear.

Serious use on the other hand is a completely different set of conditions, good examples being circuit racing, tarmac rallies, sustained high speed driving, and high ambient temperatures. An engine described in the previous paragraph that has happily survived for some time on the street, might in all probability turn up its toes and suffer a catastrophic failure within a handful of laps on the circuit, or the very first time it is held at high load in top gear.

Pic Engine On Stand

In standard form, late model WRX 2.0ltr engines, with the right mix of bolt-ons and engine management tuning, are capable of producing around 180kW ATW with little or no loss in reliability, while keeping things conservative, erring on the side of safety. In practice, a 2.0ltr engine fitted with a larger IHI series VF (or similar) turbocharger should be limited to around 1.2Bar boost on 98 octane pump unleaded, if still running standard internals. This is especially important for current spec WRXs and their relatively high static compression ratio. If you wish to create (and keep!) a "monster tune", up to and well beyond 200kW ATW, internal modifications are mandatory.

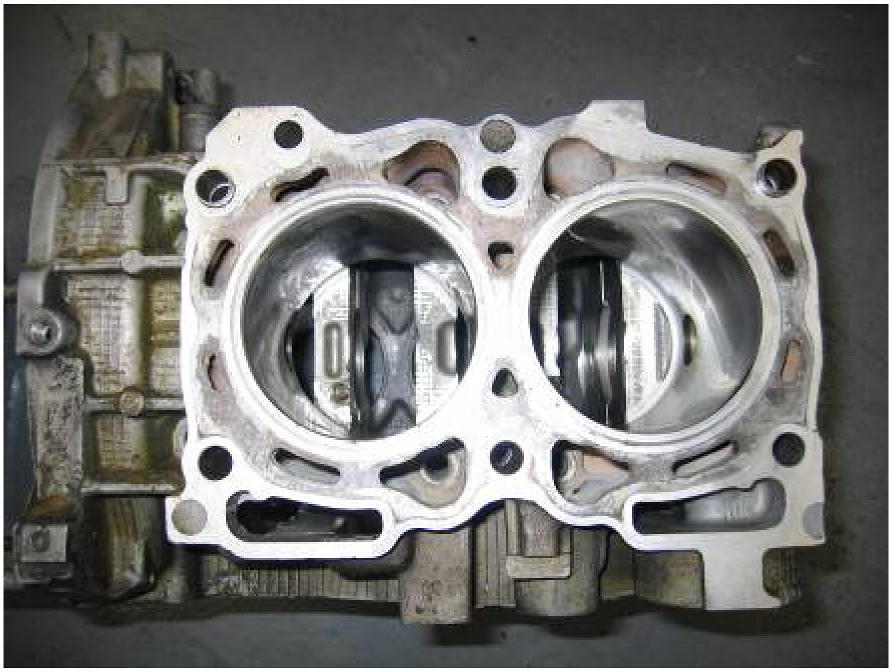
16.3 Internal Engine Rebuilds

If you have got to the stage of considering building a monster engine, take note of the following suggestions:

- Don't fall into the trap of taking the mindset of "I'll fit the good stuff once my standard engine goes bang". A curious, but popular philosophy, given that unplanned failures often results in serious damage to the engine block, cylinder head and crankshaft. This pushes the ultimate repair cost up, eating up hard earned cash that didn't need to be spent in the first place. Plan ahead and do the job when it suits you and your engine builder and don't leave it up to fate.
- Second hand OE parts can be turned into cash on eBay or Internet chat forums etc.
- Never lose sight of the fact that even the world's best and most expensive engine internals are still not indestructible. Stronger, better quality parts merely postpone the inevitable failure if ham-fistedly modified. Again, take the balanced approach, and appreciate that a strong engine on its own is useless and a waste of money without supporting modifications.
- Shop around so that you can benefit for the experience of others, get second and third opinions. If possible, talk to owners that already have had major engine work done.
- Ask plenty of questions, see if you can find a common thread to the answers you are getting, generally this means you should be taking note of that advice.
- Settle on a compression ratio for your engine early on. Compression ratio choice is determined by such things as maximum boost pressure, fuel quality and the degree of engine management system sophistication. Calculation of the right compression ratio for your application is a complex task, and requires specialist attention.
- Deal only with reputable companies with a proven track record.
- Do not base your decision on price alone; indeed, be suspicious of very cheap quotes. Good quality engine internals are at all time rock-bottom prices, making major engine work more affordable than ever, so use this to your advantage and investigate other areas in order to "value add" the whole engine build process.
- Once you have decided on the company to complete the job, get the exact specification in writing. Firmly fix limits to your budget, and set in place regular communication between you and the engine builder, so that you can be kept up to date with progress, any cost overruns and changes to specification. This safeguards not only your hip-pocket, but also ensures you get what you want, at the highest level of quality.

Building-Blocks

A word on cylinder blocks is the use of closed deck or semi-closed deck blocks. Open deck cylinder blocks are cheap to manufacture and use an open style casting, which depends on the structural strength of the cylinder liner to maintain integrity. Closed deck blocks as used on early model STi and RA competition models have a fully enclosed "deck" that completely surrounds and supports the upper regions of the cylinder liners. Semi closed deck blocks fall neatly in between the two. A stronger, stiffer cylinder block, especially in the upper areas of the cylinder liners increases an engines power potential, as it reduces bore distortion and improves cylinder head gasket and piston sealing. Version VII and later STi 2.0ltr and 2.5ltr engines use a cheaper to produce but still reasonably strong semi-closed deck block. Early WRX tuning theory was that a STi closed deck block (around A$1,500-2,000 second hand if you can find one) was mandatory for monster tune engines. Thanks to continual improvement of the factory items, these, though still desirable, are no longer as important as they were. A closed deck block weighs in at 25.6Kg while an equivalent semi closed deck tips the scales at 24.6Kg, illustrating the additional amount of material used in closed deck blocks.



STi Closed Deck Block

Now that you have decided to modify the internals of your WRX engine, they can be grouped in the following areas:

16.3.1 Cylinder Block

At the risk of sounding corny, the cylinder block is the heart of your engine, treat it accordingly. Do as much as your budget permits and don't fall into the trap of leaving the cylinder block alone. Engine rebuilds that consist of removing the cylinder heads, swapping the OE pistons for new items, and then slapping the whole thing back together without disassembling the cylinder block is a cheap imitation of a real engine build.


Semi Closed Deck Block


Std WRX open block

Some engine builders do not do all machining work in-house, and is not necessarily a bad thing as they normally will have a preferred specialist supplier for this kind of work. Where trouble can develop is using two different suppliers working in isolation, leading to the "it's the other guy's fault, not mine" type scenario.

The original equipment oil and coolant pumps have proved to be excellent units, but do need to be checked carefully for signs of wear or damage. If in doubt, fit a new oil pump, oil cooler and coolant pump if your engine is not a spring chicken anymore.

16.3.2 Crankshafts

The OE Subaru crank has proved to be a reliable item even at extremely high power outputs, but still requires careful checking for signs of out of round, cracks, wear and mechanical damage.

Crankshaft counter weights can be sharpened to help "cut" through oil mist in the crankcase. Casting marks and other irregularities should be carefully removed. In certain situations the counter weights can be machined back to reduce the rotating mass of the crankshaft to improve throttle response. This is an extremely specialised job, and if done incorrectly can lead to a situation where the crankshaft can accelerate faster than the valve train, leading to potential cam belt failures.

Pic STD Vs Modified Crankshaft

If the intention is to produce a high revving, big power engine, nitriding the crankshaft is a worthy consideration. Nitriding is the process by where the surface hardness of the crankshaft bearing journals is improved by way of a special chemical process. It is expensive, and involves a lot of heating and soaking in a bath of chemicals which can sometimes warp the crankshaft, requiring further work to rectify this. Nitriding and de-warping of the crank costs around A$500.

16.3.3 Connecting Rods

A big reduction in the price of good quality high strength aftermarket connecting rods means even the tightest budget has room for these parts, falling into the category of being a no-brainer when it comes to performance engine rebuilds. High power outputs stress conrods in two ways: Firstly from greater inertial loads that increase exponentially as RPMs rise, and secondly higher cylinder pressures placing more pressure on the piston and rod assembly. Quality aftermarket conrods feature beefier construction, making use of better materials and manufacturing standards. Conrods from companies such as Scat, Arrow, Carrillo and Eagle start from A$635 per set.

Connecting Rods

If the standard rods are to be retained, either by choice or due to racing regulations, as a minium, they should be crack tested, checked for bend, stress relieved and shot peened to improve surface hardness and fatigue resistance. OE conrod bolts should be ditched for high strength items. A set of ARP rod bolts start from A$190

What is Piston Slap?

Modern manufacturing techniques have pretty much made piston slap a thing of the past on standard production engines. Slap is caused when sufficient clearance exists between the piston and the cylinder bore for the piston to tilt slightly, rattling at TDC and BDC of the pistons travel. Forged pistons are denser than OE pistons, meaning they expand by a much greater margin as they get hot, compared to cast ones. In order to avoid the pistons seizing in the cylinder bore, they must be installed with more clearance than stock. Actual installed clearances change according to both piston brand and intended application. Performance pistons also feature shorter piston skirts for reduced friction. These factors can lead to a small amount of piston slap, especially when warming up, and unless excessive is nothing to be concerned about.

Ultimately the amount of piston slap in an engine is an audible display of an engine builder's skill.

16.4.3 Pistons

Piston selection is important. Forged pistons are used in place of the stock OE cast items, for their superior strength and tolerance of heat and pressure. In the past forged pistons were expensive and difficult to get. Off the shelf choice was limited to STi items, available in a couple of sizes, but costing upwards of A$2,600 per set for the privilege. Otherwise it was a case of placing an order with a piston manufacturer, taking a number and joining the queue, waiting upwards of 4-6 weeks in order to have custom pistons machined to suit.

Pic Forged Pistons

Hypereutectic Pistons

Subaru use these pistons in their turbocharged 2.5ltr engines. More than just a mouthful to pronounce, what are they? Hypereutectic aluminium alloys are characterised by having a high content of both dissolved and free silicone crystals. Silicone improves the hardness of the piston increasing its resistance to wear. It also gives the piston a lower coefficient of thermal expansion. Disadvantages of high silicone content aluminium alloys include a significant loss of structural strength at high temperatures and low ductility. In plain English this means a hypereutectic piston is hard wearing and only needs small piston to bore clearances, eliminating piston slap for quiet engine operation even when cold. Less favourable is a degree of weakness at power levels higher than stock, along with a degree of sensitivity to shock damage caused by detonation, requiring special attention when being tuned.

Good news is this has all changed, with more off the shelf choices available than ever and at bargain basement prices. Not so good is all forged pistons are not created equal, with key differences including piston dish shape, size, piston pin height (the amount of material above and below the piston pin), skirt length and overall accuracy of the machined finish. Certain types of pistons don't feature a drilling in the oil ring groove to lock the oil control ring in place in the same way as the OE piston, which can lead to exhaust smoking on initial start up. High quality JE, Omega, Aries or CP forged pistons start at A$850 excluding piston rings.

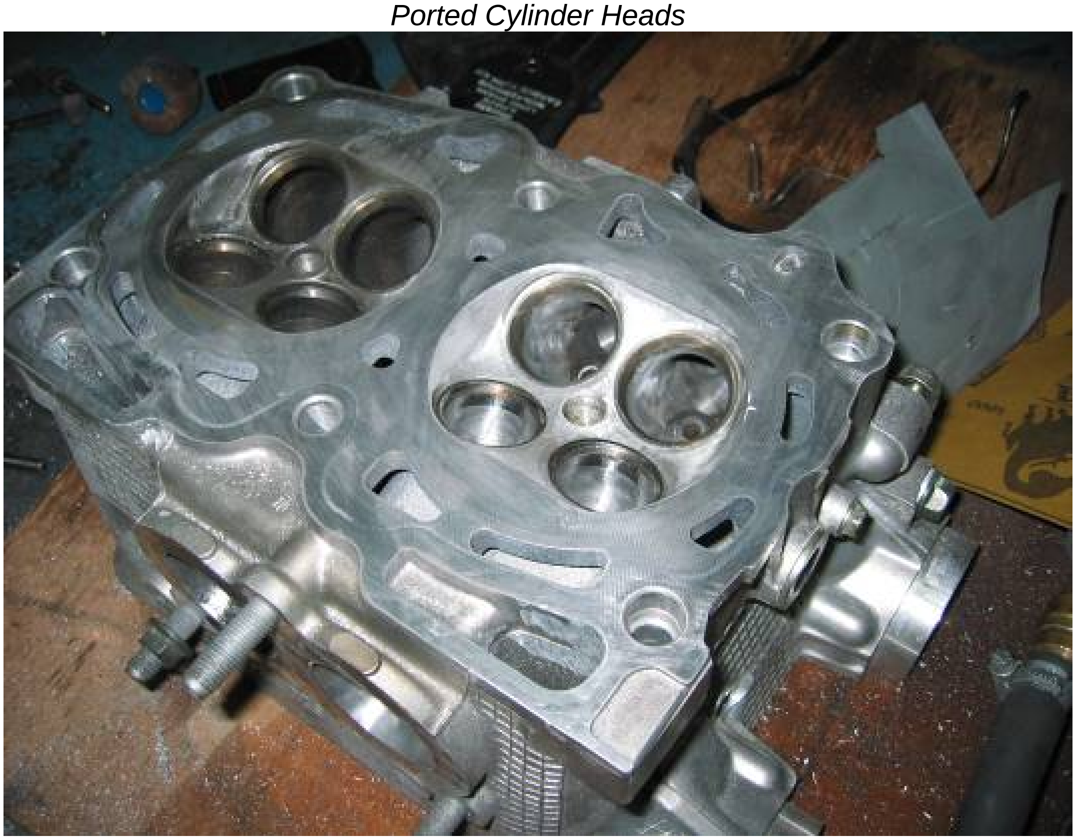
Worthwhile improvements to a set of new pistons is to have the skirts molybdenum coated to reduce friction, along with ceramic coating of the crowns. Coating of the piston crowns creates an insulating barrier between the harsh environment of combustion chamber and the piston. This reduces the amount of heat transferred into the piston, lowering thermal stresses and expansion of both the piston and piston rings. As a result, more heat is retained in the combustion chamber, requiring minor changes to ignition advance mapping. Moly and ceramic coating starts at A$ 350 per set of four pistons.

Genuine piston rings are strongly recommended even for high performance applications, as they are the piston ring that was designed to suit OE cylinder bore material. Non genuine piston rings can suffer from a material incompatibility problems leading to engine blow-by and excessive oil consumption. Check with your engine builder to ensure that replacement pistons have a small drilling in the oil ring in order to "lock" oil ring end gaps in the correct position. Oil smoke on engine start-up can result if piston rings are not installed correctly into this locating hole. Gapless rings are more for specialised racing applications and are not recommended for street use. Genuine piston rings start at A$300 per set depending on engine type.

16.4.4 Cylinder Heads

Advances in cylinder head and camshaft development have been one of the major contributing factors towards driving power outputs higher and higher. Version VII and later engines use smaller diameter intake and exhaust ports, along with redesigned combustion chambers, making cylinder head work more important in the quest for horsepower than ever before. Cylinder heads become critical when undertaking 2.2ltr or 2.5ltr conversions. So much so, if the upgrade is done without any thought given to cylinder head and camshafts, ultimate power outputs will be severely compromised.

Ported Cylinder Heads



In standard trim the OE heads are well made and reasonably efficient, and don't require too much to have them performing at their peak. But for really large gains in power, porting of the cylinder head is required. Increases in raw airflow numbers of 35-40% more over standard are achievable with well executed cylinder head mods. Expect pay around A$3,300 for a set of cylinder heads that have had the "works" done to them. This covers such work as ported intake and exhaust, oversized stainless steel valves and new valve guides done to a high standard of workmanship and capable of supporting massive amounts of power.

In addition to power adding modifications, standard cylinder head service procedures should not be neglected. Cylinder heads require the same careful attention to detail as the engine block. Servicing of the valves and valve seats should include a performance three-angle cut, and vacuum check of valve sealing. In practice OE valve springs and hardware prove to be reliable if peak RPMs and cam profiles are kept within sensible limits. Engines with projected RPM limits greater than stock, or cams with large amounts of lift will need replacement heavy duty valve springs to suit. Heavy duty valve springs start from A$285.

Ceramic coating of the insides of the combustion chambers is not recommended, unless done to suit a very specific set of engine requirements. Ceramic coating of the combustion chamber interferes with heat transfer into the engine cooling system, leading to elevated combustion chamber and exhaust temperatures. While actually improving thermal efficiency, it places more stress on parts such as valves, pistons, rings and can promote detonation in highly stressed applications.

16.4.5 Camshafts

Re-Ground Meet Billet

Performance cams come in two different flavours. They can either be re-manufactured out of the OE part, with profile changes achieved by a process of building up the cam lobe with weld, and then grinding (hence the name) to the desired profile. Billet cams take a brand new lump (billet) of heat treated steel, ground down to suit the desired profile. Reground cams sounds like a lot of stuffing around, but actually works out cheaper than the cost of brand new billets. In reality, unless the cam grinder is well and truly on the ball with accuracy and heat treating, long term durability can be suspect with regrinds compared to billet items.

Camshaft design is another area that has seen some major advances of late, especially now with AVCS becoming standard equipment on late model WRXs for most markets. In the past owners of Version III, IV, V and VI WRXs had the easy option of fitting STi spec cams. These worked well, but at a price, costing upwards of A$2,400 for a set of four. Ouch!

Thankfully prices have come down, and now there are more specialist camshaft grinders offering a wider range of camshaft choices to suit most applications, including newer WRX models with AVCS cam control. Useful gains can be achieved by fitting cams to otherwise stock heads, but for really spectacular increases, they should be combined with supporting modifications to improve cylinder head airflow rates. A set of four replacement cams can start at A$1,450 for reground items, up to A$1,990 for billet items.

Pic Billet Performance Camshaft

Fitting new cams is not an easy job, as valve clearances will require adjustment to suit. Sometimes new valve adjusting shims are required at a cost of A$40 a piece. Normally good cylinder head specialists can reset valve clearances at the same time as serving the cylinder heads, without the expense of new adjusting shims. Static cam timing is another very important operation, as performance cams are set to a very specific set of specifications governing when the cams open and close the valves. Engines with AVCS cam control are particularly sensitive to cam timing and require a skilled operator familiar with Subaru's cam control system in order to make timing adjustments. AVCS is no substitute for poor cam timing setup.

16.4.6 Stroker Kits

A stroker kit consists of a replacement crankshaft, connecting rod and piston set, designed to increase the cubic capacity of a WRX engine. This is achieved by fitting a crankshaft with a longer stroke, increasing the effective distance the pistons move up and down boosting the engines swept volume. Modified pistons and connecting rods are required to enable this longer stroke to be incorporated within the OE 2.0ltr block. Stroker kits offer a number of benefits: Increased cubic capacity means the potential for more grunt both on boost and off boost. A bigger engine creates more exhaust energy, and can be put to use either spooling up a turbo earlier, or spooling a really big turbo. Lastly torque is improved as a result of the conrods increased leverage on the crankshaft, and occurs at lower RPMs when compared to the OE 2.0ltr unit, in turn improving driveability.

Pic 2.2ltr Stroker Kit

Upside of down – a 'War Story'

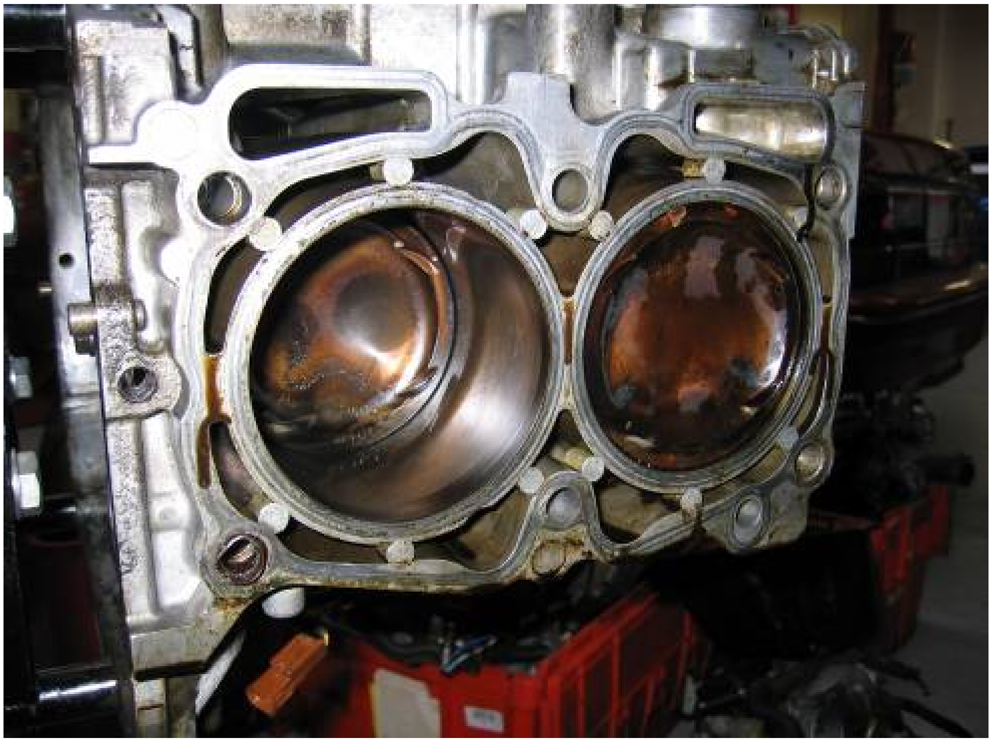
A WRX was towed into MRT performance with huge oil leaks and some nasty noises originating from under the bonnet. The owner had done a "monster tune" by another workshop. No corners had been cut, with all the OE internals replaced with forged pistons, stronger conrods, a replacement ECU, bigger turbo and a larger TMIC, among other items. All the right bits were there, and should have added up to a quick car, except for one item.

Tracking down the culprit did not need the services of a CSI unit, as it was quickly established a simple act of indiscretion saw the new manifold pressure sensor to suit the replacement ECU installed upside down. Over the space of a few months it began to fill up with oil and water vapour from the intake manifold. Gunk slowly made its way down the pressure sensor vacuum hose, damaging its delicate sensing element.

As a result of this contamination of the map sensor, the new ECU no longer had an accurate picture of fuel and ignition requirements, causing the engine to run extremely lean and with too much advance, setting a chain reaction of events. Post mortem results were not pretty, the piston rings were extensively damaged causing excessive blow-by past the piston. This in turn over pressurised the engine block, which then blew out the rear main crankshaft oil seal, creating a huge oil leak. Engine oil levels then ran low starving the main and big end bearings, resulting in terminal damage. It was a tribute to the strength of the forged pistons that they did not fail, but was of little consolation to the owner given the state of the rest of the engine.

When the first edition of Training WRX went to print, the only stroker kits were available from legendary Japanese tuning houses such as Jun and Toda, and were stratospherically priced and hard to get hold of. This changed once companies such as MRT, AVO and Possum Bourne motorsport began to supply custom made conrods and pistons to suit early model Liberty/Legacy 2.2ltr naturally aspirated crankshafts which as it turns out bolts straight into a 2.0ltr block. An effective conversion, essentially costing the same as overhauling a 2.0ltr engine, but with the small additional cost of a new OE crankshaft on top. Well built 2.2ltr engines with correctly matched turbocharger and supporting mods are capable of making in the region of 270kW ATW on pump fuel and sensible boost levels.

As good as the 2.2ltr stroker kit sounds, it has been completely overshadowed in recent times by the advent of the 2.5ltr "big block" engine fitted to North American spec STis. Somewhat of a revolution in the Subaru performance industry, it has opened up whole new avenues of tuning potential for canny operators. 2.5ltr conversions are not new in concept, having been around for some time, but in the past it was a case of taking a naturally aspirated 2.5ltr block and doing some serious machining work in order to fit stronger cylinder liners and other mods. NA 2.5 mills have smaller engine bearings, open deck block construction, and with such a large diameter bore, are prone to flexing and distortion. This can cause problems with piston ring sealing and resultant blow-by at high power levels. Turbocharged variants of the 2.5ltr block use a semi-closed deck block construction to bolster liner integrity and seem to be quite durable in this respect.



Modified 2.5 NA Engine Block

Being an OE part, complete short blocks (industry speak for an engine block supplied with crank, rods and pistons but without any other components) are readily available and at a pretty sharp price. Although manufactured to suit a turbocharged application, it uses plain old cast hypereutectic pistons dished for a lower compression ratio and relatively weak production style conrods, restricting the engine to similar maximum boost constraints as a stock OE 2.0ltr mill. Two distinct modification paths are available when using a 2.5 short block:

- Bolting up the 2.5ltr bottom end to an existing pair of 2.0ltr cylinder heads in conjunction with some basic cylinder head and camshaft work, re-using original parts such as oil and coolant pumps, intake manifold etc. Engine management and fuel system upgrades with this sort of conversion are essential, as is selecting a suitable turbocharger, while respecting the limits of the OE 2.5 pistons and rods.
- Carrying out the above modifications with the addition of replacing the OE 2.5 pistons and rods for stronger items for a much tougher base mechanical package, capable of producing a higher final power output reliably.

Pic Engine Building Room

Considerations worth talking with your engine builder when undertaking a 2.5ltr conversion must include modifications to combustion chamber size. 2.5ltr pistons are 7.5mm wider in diameter, a significant increase compared to the 2.0ltr items, leading to the situation where the inside edge of the combustion chamber overlaps the edge of the piston, by a greater amount than stock. This leads to a situation where the ratio of piston crown to cylinder head "squish" is increased, potentially changing the burn characteristics of the combustion chamber, possibly promoting detonation. Squish is something of a controversial subject among engine builders and tuners alike, but in general, high performance manufacturers such as Porsche and Ferrari use chamber designs with very little squish at all. At the very least, respect must be made to the original relationship between cylinder bore diameter and combustion chamber diameter that exists with the OE 2.0ltr engine. Brand new 2.5ltr short blocks start at around A$4,000, with replacement forged pistons and rods to suit adding around A$1,700+ depending on specifications and brand.

Oil Surge

The environment that is exists inside your engine sump is pretty harsh. Consider the plight of a hapless goldfish in a bowl on the back seat of a car taken for a spirited drive, and you will get some idea of what is taking place within the oil system of your WRX engine. High RPMs, heavy cornering, acceleration and braking place extreme G forces on the oil sloshing around in the bottom of the sump and contribute towards a situation known as oil surge. Under the right (or wrong) set of conditions, the engine can actually starve of oil as there is not enough oil available around the oil pump pickup, causing the engine to get a big gulp of air. Normally there are no second chances when this happens, culminating with a trip to the engine doctor for a consultation.

16.4.7 Competition Oil Sumps

Replacement oil sumps are now available, and should be a serious consideration for those chasing maximum power and/or any form of track racing. Competition sumps benefit in several ways: They have an increased oil capacity, leaving more available for extended high rpm running, where oil tends to pool around the extremities of the engine and is slow to return back into the sump. A larger volume of oil also takes longer to heat up. Additionally, competition sumps feature very complex baffling to more accurately hold engine oil around the pickup, even during sustained high G manoeuvres. Japanese tuners ARC, along with Hyperflow here in Australia manufacture high capacity replacement sumps, featuring fins on the bottom of the sump for improved oil cooling, and start at around A$900 for the Hyperflow unit.

MRT High Capacity Sump

16.4.8 Oil Catch Cans

Heavy Breathing
All engines will by-pass a certain amount of oil back into the intake system, but how much is too much for a modified engine? While there is no such thing as an absolute, when new and in good condition it may pass around a teaspoon of oil every 5000km, slowly increasing in quantity as it begins to wear. Sudden jumps in the quantity of oil found in the bottom of a catch-can or the intake system of an engine normally points to serious mechanical problems. See the car doctor – stat!

Crank-case ventilation is an important issue to deal with on a turbocharged engine like the WRX, but what is it? Every time a cylinder fires, a very small percentage of combustion gas by-passes the piston rings (imaginatively called *blow-by*) ending up in the crankcase of the engine. Added to this is the amount of air that is displaced within the crankcase by the action of the pistons moving up and down in the cylinder bores, with the crankshaft spinning away in the middle. This makes the interior of a WRX engine is a decidedly drafty place, and all this pressurised gas needs somewhere to go. It cannot be vented to the atmosphere as crank-case gas contains vaporised engine oil, weak acids, hydrocarbons and other nasties.

Pic Oil Catch Can

Normally crankcase gas is drawn off and recirculated back into the engine air intake to be burned, instead of ending up in the atmosphere. This is not so much of a problem on a stock engine, but becomes an issue on engines that are modified and are making more power. It is inescapable, as power outputs climb, so does cylinder pressures causing ever increasing quantities of blow-by. So much so, at high RPMs, in addition to gas, small amounts of liquid oil can be discharged from the crankcase breather pipes and back into the engine. This is dangerous to the health of your engine for the following reasons:

- Oil can make its way into boost control solenoids disrupting boost control
- Intercoolers loose efficiency when coated heavily with oil on the inside
- Oil mist or liquid oil drawn into the air-fuel charge entering the engine has serious consequences, as its low-flashpoint temperature (compared to petrol) will cause it to self-ignite resulting in severe detonation

Too Much Of a Good Thing – a War Story

Recently a Version VII STi came through the doors at MRT, lacking power and rough running. The car was modified with a slightly bigger turbo, TMIC, complete exhaust and a piggyback computer. It had done the rounds of several "specialists" without any success. A quick roadtest with EcuTeK's delta dash connected a review of the data immediately made it clear "Houston we have a problem". Both the boost control and AVCS were not working properly, and the engine was detonating quite badly. The cause was pretty easy to track down, the engine had been overfilled with engine oil on the last service, causing oil to be discharged out of the breathers and into the engine. Draining the litre of extra oil from the sump, a clean of the intercooler and boost control system restored the STi back to health. Luckily the problem was caught early, before permanent damage was done. Once realising how close it had been to suffering an engine haemorrhage, the owner gladly did one final modification. A bright shiny new catch-can!

Hyperflow Catchcan

Fitting an oil breather catch-can is an easy solution in response to these potential problems. It connects into the OE breather system, re-directing all crankcase gas through a series of internal baffling to separate out oil and other residues. This “cleaned” gas is then returned back into the engine intake as before. Not all catch-cans are created equal, and things to look for in a good one are large diameter breather hoses, some sort of sight glass to for inspecting oil level, and an easy way of draining any collected oil. Catch cans also need to have at least a minium capacity of at least 1.0litre in order to be effective. A worthwhile modification for a WRX at even mild power levels, it does become mandatory at anything more than 180kW ATW. A monster tune without one is madness! Catch cans start at A$220

16.4.9 Cylinder Head Studs

As power outputs climb, more and more stress is placed on humble items such as nuts and bolts. No better example of this is the job cylinder head bolts have to play. Often misunderstood, or just plain ignored, is the reality that just as much force is acting on the cylinder head and gaskets, is at the same time acting in the reverse direction on the piston. Such are the cylinder pressures and forces generated by elevated power levels, the OE head bolts can begin to yield resulting in poor headgasket sealing. No serious engine build should be completed without the addition of high tensile head studs. ARP head studs cost around A$300.

High Strength Head Studs

16.4.10 Underdrive Pulleys

Lightweight Underdrive Pulleys

Underdrive pulleys are sold in sets of three for Version VI and older models, replacing the crankshaft, alternator and power steering pulleys. The Version VII and later WRX have the power steering pulley press fitted on the pump shaft, so kits for new cars only have two pulleys. Either way, underdrive pulleys fulfil three separate functions:

- They have different diameters compared to the OE parts, meaning they take less power per engine revolution, as in effect the alternator and power steering pumps rotate at a slower speed compared to before. This means alternator and power steering outputs run less efficiently, but in practice its a small difference that does not cause problems.
- Made from light alloy, weight is reduced, especially when comparing the OE crank pulley damper to the new billet alloy item. Throttle response improves as there is less rotating mass to accelerate.
- Underdrive pulleys are available in a number of anodised colours, and add a bit of flair to an otherwise drab engine bay, for that all important car park cred.

16.4.11 Gaskets and Miscellaneous Items

For 99% of all applications genuine Subaru gaskets and oil seals are more than adequate. Even the OE stye multi-layer metal headgaskets have proven to be completely reliable, especially when used in conjunction with heavy duty cylinder head studs. Extremely high power applications may require "o" ringing, a process where a small groove is machined into the top of the cylinder bore, in which a ring of piano wire is fitted for improved "bite" into the headgasket. In extremely specialised applications, a system of "W" or gas rings can be used and are similar in concept to o-rings. Headgaskets of different thicknesses are useful for making adjustments of compression ratios without machining or replacement of pistons etc. One word of warning, be mindful changing to thicker or thinner than stock headgaskets as it can lead to valve timing adjustment problems.

Pic "W" Ringed Cylinder Block

Dynamic balancing is another very important inclusion. Minute differences in individual piston, conrod and crankshaft weights can manifest into big out of balance problems at high RPMs. Don't just stop at balancing only engine internals, as for the best results you should also include the crankshaft pulley, flywheel and even the clutch pressure plate to be used. Badly balanced engines wear out faster, and suffer funny bearing problems and other vibration related issues.

Suck Oil, Not Air – a 'War Story'

MRT was recently faced with a challenging situation, a monster tune WRX built by another workshop with oil system blues. As often is the case, there was no chance of any sort of preventative medicine as the long suffering engine was already exhibiting the deep knocking sound associated with failed conrod bearings, and an expensive repair bill.

While MRT's pathologists were busy performing a post of the dead engine, a time line of events leading up to this point were investigated. It seems that almost immediately on completion of the original monster tune, intermittently the oil pressure warning light would flicker, indicating all was not well with the lubricating system. The owner dutifully went back to the engine builder reporting this occurrence, only to walk out having been sold a new cast alloy competition sump as the fix. Still beset with a flickering oil pressure light, the owner went back once again to the engine builder. This time a new oil pump was fitted and charged for as the solution. Entirely unchanged in behaviour, the oil light continued to intermittently flicker at odd occasions.

In a fit of frustration, the owner decided that it had to be some sort of other problem with either the light or oil sensor, and chose to do a spot of racing down at the track. A half a dozen laps later the oil light illuminated and stayed on permanently, coinciding with the emergence of a horrible clanking racket from the engine.

After digesting this information, along with a careful examination of the engine, the cause was obvious. Not exactly a hanging offence, but more a momentary lapse of concentration on the part of the original engine builder. The wrong sized "o" ring that seals off the main oil gallery joint between the two engine block halves had been fitted, causing air to drawn into the lubricating circuit of the engine, leading to failed conrod and main bearings along with a knackered crank. I'll leave you to draw your own conclusions on this one!

16.4.12 Performance Engine Building

In general, the art of engine building is a poorly understood procedure and is shrouded by a lot of unnecessary secrecy and lore. Most engine builders tend not to do themselves any favours either, preferring to stay out of the public eye, stashed away in dimly lit workshops full of interesting but scary projects. As a consequence, the art of performance engine building remains a mystery to most and is often subject to an excess of drama. In reality most aspects of engine building are more to do with diligence rather than any great excess of intelligence, especially when assembling an engine using tried and tested parts, to a known set of specifications. Where real genius comes into play are for those jobs such as developing new engine packages from scratch, or accurately diagnosing why the last one went bang. In this section we will look at some of the techniques and procedures used when assembling a "monster tune" WRX engine.

Like most things, the devil is in the detail. Hugely powerful engines are not created out of thin air, but the product of supreme attention to detail and careful preparation. This extends to a lot more than simply making sure everything is clean before bolting the thing together. A competent engine builder will ask plenty of questions of the customer, finding out such things as a realistic power goal, intended usage for example; street or the track, type and size of turbocharger, transmission type and the grade of fuel to be used. This is the sign of a real engine building professional as after all it is their reputation at stake.

Inspection

Is always the first step of any performance engine project, with the engine builder subjecting all parts to a process of careful examination, irrespective if they are original engine components to be reused or brand new replacement items.

Teardown of the Original Engine

In the case where major components such as the engine block and crankshaft are to be reused, wear patterns and other witness marks can provide an invaluable guide to solving any pre-existing problems with the engine, or by highlighting areas that require further improvement.

Cylinder Head

The cylinder heads are another very important set of components that require very careful attention. Basic checks include inspection for any mechanical damage, signs of overheating, bending of the head gasket face, corrosion and camshaft bearing journal condition. In addition, specialised tests looking for any cracks or pressure leaks within the cooling galleries and combustion chambers are carried out. This is an important consideration for cylinder heads that are going to be machined to accept bigger valves or will undergo the removal of large amounts of material from the intake and exhaust ports.

Measurements

Some believe this is where all of the fun starts; others will tell you that it is the height of tedium. Whatever the opinion, correctly measuring just about every single part of an engine is of the utmost importance. Any serious engine builder will have an impressive array of specialised precision measuring equipment, such as inside and outside micrometers, bore and depth gauges. Even lab equipment such as pipettes, burettes and finely graduated measuring cylinders are regularly used. A big horsepower engine will literally live or die by installed clearance between a part and its neighbours. Production engines by their nature use a broad tolerance of measurements (although Subaru engines are much better in this respect than most) that are unacceptable for a high performance engine.

Blueprinting

A term often misused to describe even the most basic of engine builds. Slamming a set of forged pistons and rods into a WRX does NOT constitute a blue-printed engine. As the name suggests, it actually involves a painstaking process of making sure that installed dimensions of all engine parts conform to a rigid set of specifications. Areas of critical importance include; individual cylinder bore and piston diameters, piston ring land dimensions, piston ring end gap, conrod alignment and big end bearing bore, crankshaft big end and main bearing journal diameter and engine block main bearing bore alignment, bearing oil clearance and crush to name but a few.

Blueprinting also involves making sure that not only do parts measure correctly, but are consistent across all four cylinders of the engine, especially in the case of combustion chamber and port volumes. This is done for two reasons, the first is to check and equalise the compression ratios of the individual cylinders so that they are all the same, and secondly, so that each cylinder receives the same physical amount of intake charge.

Compression Ratio Checking

The compression ratio of an engine is the physical amount by which the fuel air charge is compressed by the piston, ending up crammed into the combustion chamber in the cylinder. This is known as an engines static compression ratio, and is determined by taking the total swept volume of the combustion chamber and cylinder divided by the swept volume of just the cylinder. Measurements and calculations done in order to achieve this include; combustion chamber volume, cylinder head gasket volume, piston crown dish volume (or dome in the case of hi-compression pistons), deck height of the piston crown (either above or below the gasket face of the cylinder block), top piston ring land volume (the area above the top piston ring and below the piston crown) and a mathematical calculation of cylinder volume from its bore and stroke to determine actual cubic capacity. Nothing is too small to be left out. Builders of race engines for highly restrictive categories will go to the length of measuring spark plug electrode volumes in the quest to ensure 100% compliance with racing regulations.

Measuring Combustion Chamber Volume

Measuring Piston Crown Dish Volume

Chamber, piston crown and top ring land volumes are determined by placing a flat piece of Perspex over the part to be checked, and then by carefully measuring the amount of liquid used to fill the resultant void. Large compression ratio adjustments are normally made by specifying a piston dish volume when ordering pistons. Headgasket thickness can also be used to perform an overall compression ratio change, while smaller adjustments are made by either removing or adding small amounts of material to the combustion chamber or piston crown.

Naturally aspirated engines use atmospheric pressure is the driving force behind cylinder filling, making it easy to select a compression ratio, but can become complicated with a forced induction engine. This is because boost pressure increases cylinder filling causing a big jump in the actual dynamic compression ratio. Coming to grips with this is of vital importance in the quest for good reliable horsepower. An engine with an 8.0 to 1 static compression ratio can quite easily end up with a dynamic ratio of 11.0 to 1 or more at full boost. Of equal importance with a performance engine is making sure that all cylinders have exactly the same compression ratio, as a variation between cylinders as small as two or three percent can cause big problems with consistency when tuning ultimately compromising power output.

Cylinder Heads

Bigger valves, porting and polishing and match porting are all terms used to describe performance improvements to the cylinder head. As with other aspects of engine tuning, the desired aim when modifying a cylinder head is to increase the amount of air it can efficiently flow, so as to burn more fuel to hopefully make more power. Cylinder head airflow is increased by the following methods;

Match Porting - A simple operation that involves the squaring up of where the intake and exhaust manifolds bolt onto the cylinder head. Normally in production engines tolerances for this can be rather sloppy resulting in minor misalignments which hinder efficient gas flow through the cylinder head.


Marking Out Port Dimensions

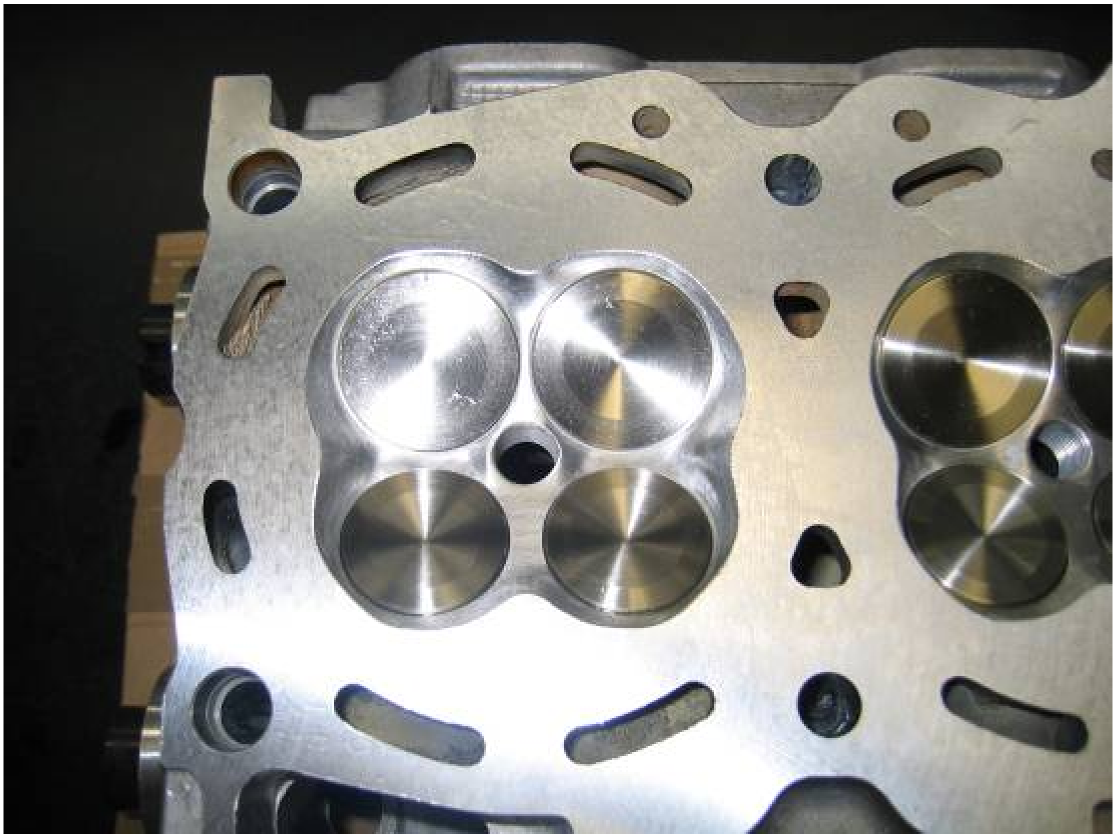

Die Grinding an Exhaust Port

Big Valves - As the name suggests, the OE inlet and exhaust valves are replaced with larger diameter items. In practice, space limitations restrict what ultimately can be fitted into the head to around 0.50mm. While not sounding very much, it does result in a significant increase in airflow potential. Dispensing with the OE hollow / sodium filled valves from late model cars with solid-stem stainless steel items is prudent from a strength and reliability point of view. Engines destined for really stratospheric power outputs will have the OE valve seats replaced with hi-tech (and extremely expensive) exotic beryllium alloys on the exhaust side for greater temperature resistance. Valve guides are substituted for high performance phosphor bronze items, again with the aim of improving reliability at high temperatures and engine speeds.


Valve Spring Tester

Other operations associated with valve train work include matching valve spring installed heights for consistent valve seat pressures and adjustment of the valve clearances. Earlier model engines use graded sized replacement valve adjusting shims, while Version VII and onwards engines use complete replacement camshaft buckets of graded size increments.

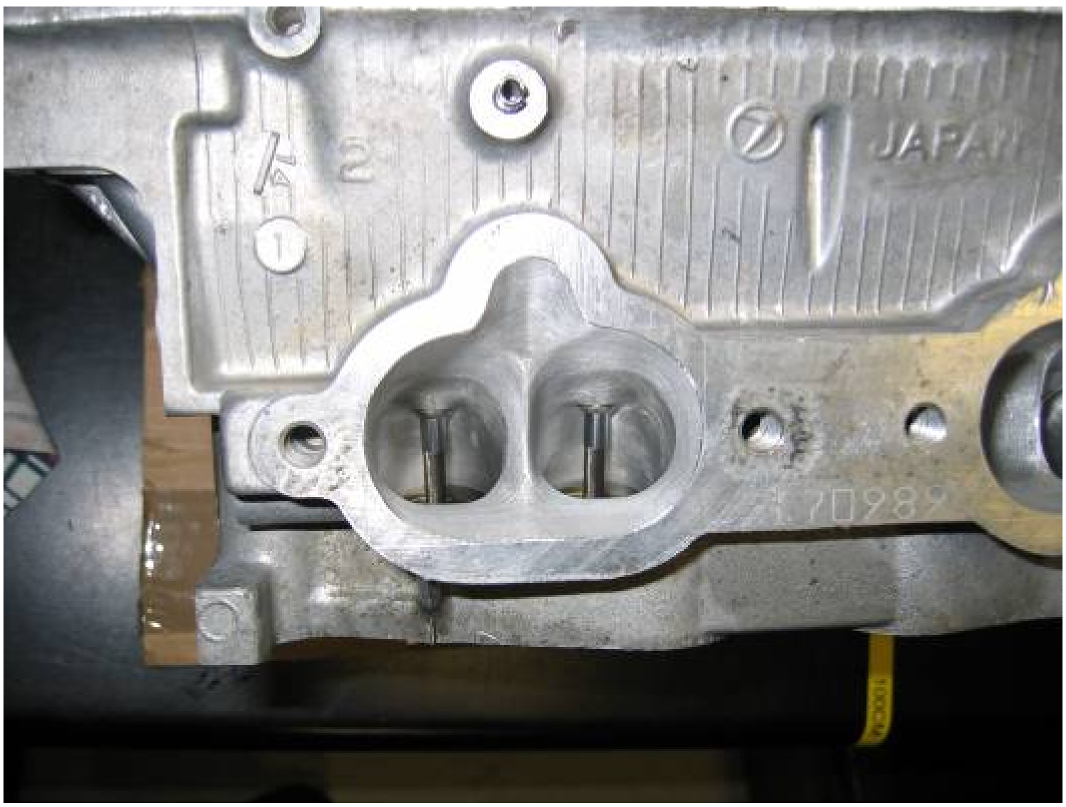
If you had not already guessed, this sort of work is an extremely specialised operation, with any number of potential risks if not done properly, such as valve seats falling out, valves that seize in their guides or premature cracking of the combustion chamber between the valves and around the spark plugs.



Big Valve Head

Porting and Polishing - Is a generic term to describe the subtle re-shaping of the air entry into the combustion chamber and the exhaust outlet from the head. It is not a case of grinding out as much material from the intake and exhaust ports of the head as you possibly can. Bigger is not always better in this situation. Complexities such as maintaining airspeed and intake air turbulence over a wide range of engine RPMs and valve lift requires more than just a DIY dremel kit or die grinder.

Cylinder head porting is done in conjunction with a flowbench, a machine that can accurately measure the airflow of parts such as intake and exhaust ports, in order to make before and after airflow comparisons. Consider it as being able to road test changes that have been made to the intake and exhaust ports. Experience is essential when it comes to cylinder head porting as the majority of technical information available on the subject is to suit large capacity naturally aspirated V8 engines. It does not take an expert to realise that techniques that work on a pushrod 2 valve per cylinder V8 will not necessarily work on a high revving quad cam turbocharged Subaru engine.



Ported and Polished Intake Port

The polishing part of the name comes from the final surface treatment that is given to the throat area of the intake and exhaust ports. The idea being that it will reduce the amount of friction generated as high velocity gas flows in and out of the cylinder head. Generally intake ports are finished with a slightly rougher surface than the exhaust side, the theory being that this roughness prevents a boundary layer forming that can precipitate the formation of large droplets of fuel against the walls of the inlet port.

Polished Combustion Chamber

As a final finishing touch while respecting individual combustion chamber volumes, all sharp edges, casting and tool marks are removed so as not to provide imperfections that either hinder airflow or could cause the propagation of detonation.

Pre-Assembly Preparation of the Cylinder Block

Measurements taken in the first part of the build process are now put into use as components are matched to suit individual cylinders of the engine. They include;

Pistons – each piston will vary by a miniscule amount in its finished diameter. As tiny as this variation is, the same sort of difference can occur with the cylinder block, allowing a process where individual pistons are matched to suit a specific cylinder bore in order to achieve the best possible fit.

Measuring Piston Diameter

If required, bore diameters are sometimes adjusted by a light finish hone in order to achieve the best possible fit. Piston to bore clearance is absolutely critical to an engines performance and longevity, especially when using forged pistons. Too much clearance and the engine will rattle excessively and will suffer problems with oil consumption and large amounts of blow-by. Pistons that have insufficient clearance run the risk of seizing within the cylinder bore at high temperatures from expansion. All machining work and measurements are taken with a torque plate bolted up to the cylinder block. A torque plate simulates the effect on the cylinder block when the heads are installed and fully torqued up. A cylinder block that is machined in its un-stressed state can develop problems with the cylinder bores either going out of round or becoming tapered when the cylinder heads are bolted on due to minute distortions of the cylinder block. However small, these differences can rapidly become a real headache at very high power outputs, as it reduces the accuracy of piston ring to bore contact promoting ring leakage and ultimately piston failures. Does your engine builder understand and appreciate this? You did choose your engine builder wisely?


Torque Plate


Measuring Cylinder Bore

Once the pistons have been matched to a specific cylinder, one final check is made of piston weight. Differences in piston weights cause balancing issues and funny harmonics between cylinders. Good quality aftermarket pistons normally have very tight weight ranges, but in the case of any difference, material is removed from the heaviest piston in order to match the lightest of the set.

Pic Checking Piston Weight

Final checks of the piston include careful examination of the circlips or spiral locks that will secure the gudgeon pin into the piston, along with a check of actual piston pin fit into the piston to ensure there are not any clearance problems.

Piston Rings – as with the pistons themselves, there are a number of very critical checks to be made prior to fitting the piston rings. Best practice dictates that piston rings should be matched to individual cylinder bores and are graded on the basis of installed ring end-gap.

Pic Checking Piston Ring End Gap

Just as pistons expand when hot, so to the pistons rings, especially the top and second ring as they are exposed to large amounts of heat. In extreme situations a piston ring with insufficient end gap can close up to the point where they will butt together causing the ring to partially seize within the bore. This results in catastrophic damage to the piston ring and often the piston itself, in the form of broken ring lands. Ring gaps are adjusted (made bigger) by way of a small grinding tool, and once finished are hung on a marked rack in matched cylinder groups. Installed piston ring side clearance is a final important check. A ring that has insufficient clearance to the piston ring land can seize up due to expansion, which is an important consideration given that forged pistons have very high rates of thermal expansion. Rings that seize even partially in a piston will cause oil consumption and blow-by issues, and ultimately piston failure.


Piston Ring Side Clearance Check


Piston Rings Ready for Fitting

Conrods – Again consistency is the name of the game with conrods, especially when it comes to their individual weights. As with pistons, conrods that have even small differences in weight can cause harmonic and balance problems. Big end journal measurements are checked and referenced against journal diameters of the crankshaft in order to match conrods so that installed bearing clearances are as close to optimum as possible.


Measuring Big End Bore Diameter


Measuring Crank Big End Journal Diameter

Once the conrods have been assigned to a cylinder they are stamped (carefully) or engraved with a corresponding cylinder number. This done, further checks are made to ensure that the installed clearance of the gudgeon pin to little ending bushing of the conrod is within specifications.

Marking Conrod to Cylinder Numbers

Crankshaft – Earlier measurements made of crank bearing journal diameters are cross-referenced against the inside diameter of both the conrod big ends and the actual cylinder block crankshaft bore. A lot of number crunching later, it is possible to establish the precise bearing thickness required to achieve the desired installed bearing clearance. Good engine builders will have a box full of assorted bearings so that they can be mixed and matched to suit each crank and big end bearing individually. This extends to checking and adjusting (if required) crankshaft end float, which is the amount of axial the crank has once installed in the cylinder block.

Assorted Engine Bearings

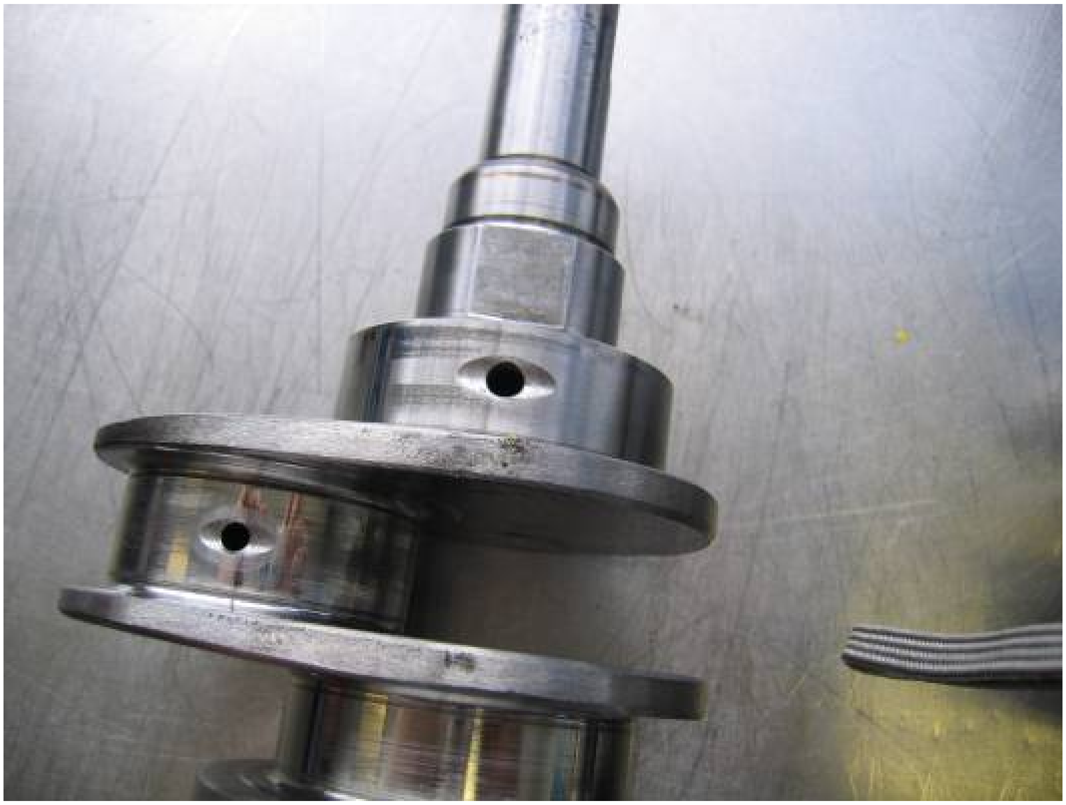
Measuring Crankshaft End Float

This procedure is called setting the bearing oil clearance. Metal to metal contact between the crankshaft journal and the soft metal bearing surface is to be avoided at all costs, and this is achieved when the engine is running by squirting high pressure oil in between the crank and the bearing surface. As a consequence bearing to crank clearance has to be exactly right in order to achieve the strongest possible film of oil, in order to make use of the dual properties of surface tension and fluids in compression so as to resist the terrific pounding crankshaft bearings receive. Too little clearance and seizure of the crank bearings can occur through expansion. Too much on the other hand reduces film strength, while wasting power as excessive amounts of oil squirts out the sides of the bearings adding to frictional losses through windage.

E16.24 Insert Pic

Measuring Bearing Crush

As well as bearing oil clearance, simple checks are made of the amount of bearing crush. When installed, the bearing must bear down on its opposing number by a carefully regulated amount. This not only ensures that the bearing is pre-stressed so as to conform to a particular shape, but also so that it is locking into place. Bearings with insufficient crush are susceptible to “spinning” in its bore which leads to almost instantaneous bearing failure. Too much crush and the bearings will distort by an excessive amount causing oil clearing problems and an early demise of the engine.



Crank Bearing Oil Gallery

Oil galleries and their finish are particularly important for ensuring a good supply of oil to the bearings, and are thoroughly examined for any surface imperfections, nicks or burrs. Each oil gallery has a lead ground into the bearing journal either side of the oil outlet from stock, which is then enlarged even further in order to increase the depth of the lead improving lubrication of the bearings.

Oil and Coolant Pumps - are carefully checked and modified where required. Certain tricks such as porting the inlet and outlet of the oil pump and modifications to the oil pressure regulating valve are done to improve oil system operation at high power outputs. Coolant pumps destined for big RPM engines have the edges clipped from the pump impellor to reduce maximum pump RPM. This reduces the risk of cavitation of the coolant as it flows through the pump, while at the same time it slows peak coolant flow rates at high RPMs so as to allow more time for heat transfer out of the engine and into the coolant.

Assembly

The WRX engine, with its flat four cylinder arrangement and split crankshaft dictates that engine assembly takes place in a specific order, and is done in the following steps;

Crankshaft – A dry run is done first, whereby the conrods are fitted to the crank with a small piece of plastigauge laid across the bearing surface. The rod bolts are then torqued to specifications and then un-done and the bearing cap carefully removed. This in effect "squashes" the plastigauge according to the amount of bearing oil clearance and is done as a final check to make sure that measurements and calculations made when selecting bearing sizes were done properly. The same process is repeated with the main bearings requiring the partial assembly, and then disassembly of the cylinder block halves.

Torquing Rod Bolts for Clearance Check

Reading Plastigauge Squash

Once this lot of verifications are done, final assembly of the crankshaft and cylinder block takes place. Due to the layout of the engine, the conrods are assembled onto the crank without pistons. The combined crankshaft/conrod assembly is then fitted into the cylinder block halves.

Bearing Assembly Lubricant

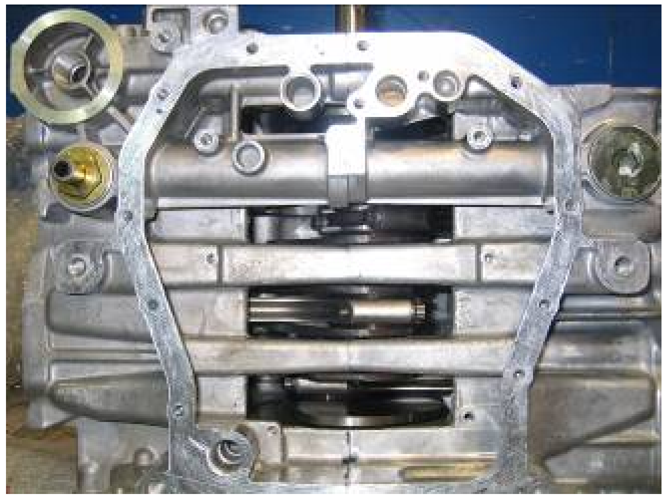
Fastener Assembly Lubricant

All bearing surfaces are generously coated with special assembly lubricant so as to protect the bearings during the final phases of assembly and initial engine start up. Special molybdenum grease is applied to the threaded sections of all conrod and cylinder block fasteners. This is to reduce the effect that friction has on fastener torques. A dry un-lubricated fastener will apply approximately 40% less clamping force compared to a lubricated fastener torqued to the same value. Poor clamping loads caused by either substandard or incorrectly torqued fasteners can cause a whole host of problems, especially in the areas of head gasket sealing and crankshaft main bearing alignment.

Measuring Bolt Stretch

High quality fasteners for critical areas such as conrod bolts are done up not by torque, but by measuring the amount of stretch they are set to. This places the fastener into what is called the elastic zone, meaning that it can yield minutely to accommodate changes in clearances brought on by temperature changes without any reduction in tensile strength. Stretch is measured across the length of the fastener, by means of a ball bearing in each end and a micrometer.

Fitting Together Cylinder Block Halves



Cylinder Block Assembled

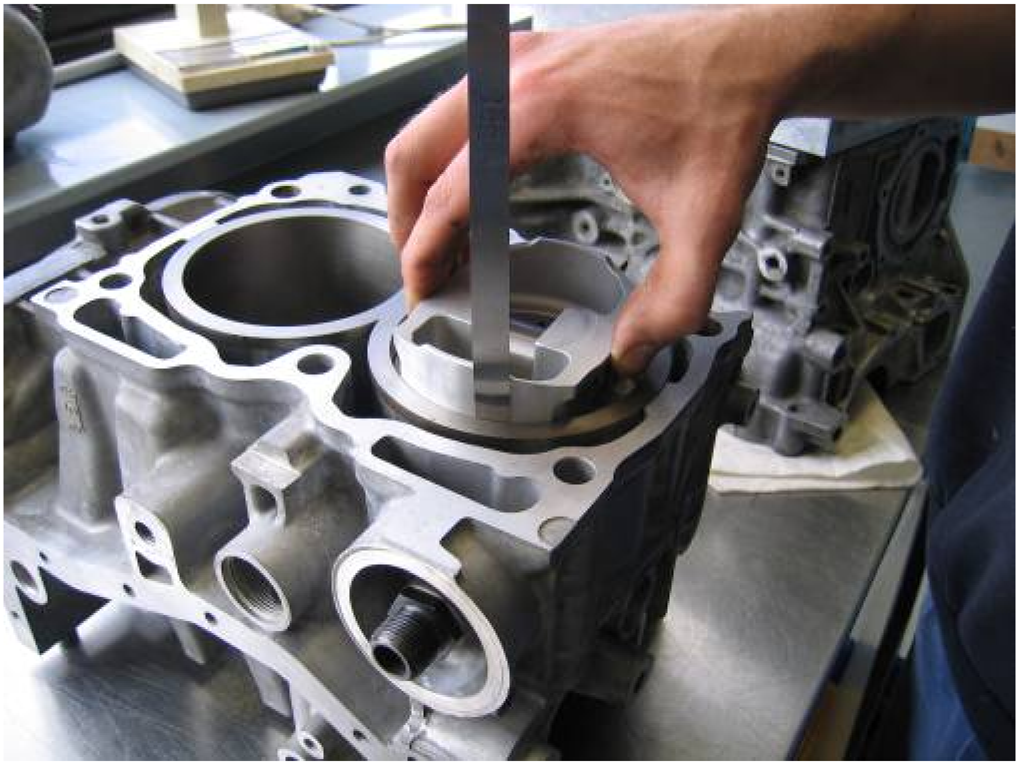
Cylinder block - Prior to assembly all jointing surfaces between the cylinder block halves are checked and double checked for nicks, burrs or other imperfections and then coated with a thin layer of Three-Bond brand flange sealant. The wrong sealant, or application in over enthusiastic quantities can lead to oil system failures due to blockages caused by displaced beads of excess sealant. There are also several "O" rings that are critical to oil system performance fit in between the cylinder block halves and require careful attention when assembly the block. Slowly and squarely the two block halves are fitted up together with some encouragement by way of a plastic mallet.

Staking Rear Main Oil Seal

Once the cylinder block halves are assembled and torqued up, the oil pickup can be fitted along with the rear main oil seal. Very carefully the metal surrounding the seal is staked using a sharp punch, locking it in place to eliminate the possibility of it “popping” out due to elevated crankcase pressure.

Piston Ring Pliers

Pistons – Before fitting the pistons as a final check of the piston to bore clearances computed earlier, a dry run is made by hand using a set of long engine assembly feeler gauges. A good operator will know instinctively how much “drag” it will take to pull the feeler gauge out past the piston when installed in its corresponding cylinder bore.



Checking Piston to Bore Clearance

The piston rings are fitted to their respective matching pistons by means of a pair of piston ring pliers. This is absolutely critical so as not to over stress or distort the rings, which is something that can happen using the traditional method of "winding" the rings on by hand. The entire piston is then soaked in a container of good quality mineral oil to ensure adequate lubrication on start up. Then it is fitted to its respective cylinder carefully using a piston ring compressor. In somewhat of a key-hole surgical procedure, the gudgeon pin is inserted through a threaded access plug in the cylinder block joining the piston to the conrod, followed by a circlip to lock the gudgeon pin in place.

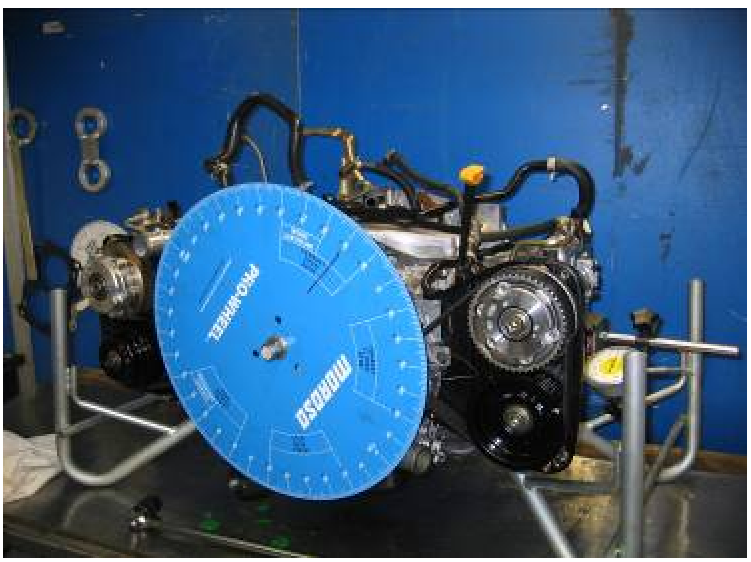
Pic Gudgeon Pin Access Plug

Fitting the Cylinder Heads

Of utmost importance before permanently bolting up the cylinder heads to the cylinder block to ensure that there is adequate clearance between the piston crown and both the edges of the combustion chamber and the valves. At certain stages throughout the engine cycle piston to valve clearances can be extremely fine. Even the smallest miscalculation of the piston crown profile, valve lift or cam timing can have disastrous consequences, especially at high RPM when conrods “stretch” minutely closing up clearances even further. Piston to valve clearance is checked by placing a piece of modelling clay over the piston crown and then bolting on the cylinder heads to do a dummy installation, using an old headgasket (of exactly the same thickness as those to be used). Once bolted down and the cam belt is fitted, the engine is then rotated over by hand several times to open and close the valves.

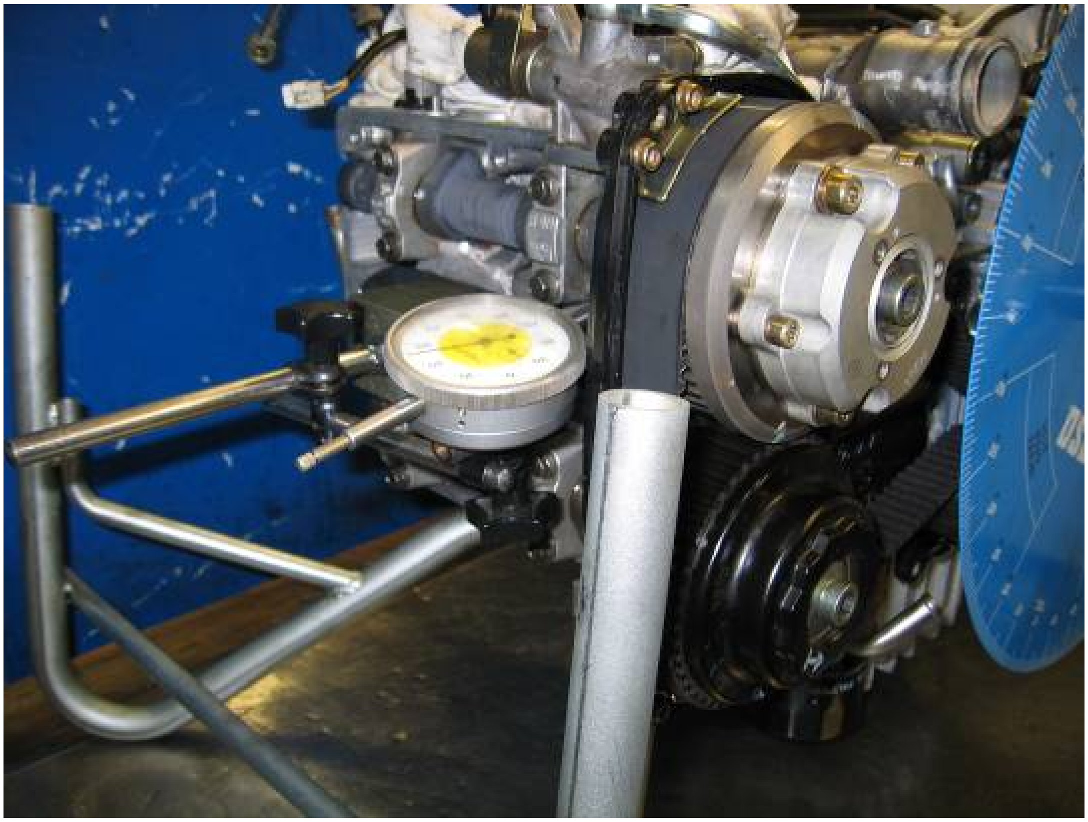
Then the heads are then taken back off the cylinder block, and the resultant imprint made by the valve in the modelling clay is measured to establish actual clearance. (The exact same process is used to measure piston skirt to conrod / crankshaft webbing clearance at bottom dead centre of piston travel). A time consuming and extremely laborious a process it is, but conscientious engine builders maintain this is the price of a good nights sleep!

Once this is done, the cylinder heads are installed permanently following Subaru’s quirky head tensioning sequence. Failure to tension the cylinder heads in the right order and to the right tension can result in cylinder block and head distortion, and the possibility of combustion leaks at high load.



Valve Timing - Correctly setting the point at which the inlet and exhaust valves open and close is of the utmost importance, especially when using custom made camshaft profiles and engines with AVCS. Small variations can have a major impact on engine power and torque. Achieving the correct settings can be a difficult task, one that is not made any easier by the widely spaced boxer layout of the Subaru engine. Machining of the cylinder head or cylinder block face, or different thickness headgaskets can all have an effect of valve timing and must be allowed for.

Pic Cam Degree Wheel Installed



Measuring Camshaft Lift

A dial indicator gauge and a crankshaft degree wheel are used to establish exactly at which point in the crankshafts rotational cycle that the intake and exhaust valves open. Performance camshafts are always supplied with cam timing recommendations on what the valve timing should be set to as a base starting point.

Pic Vernier Camshaft Pulley

Valve timing adjustment is made by either custom made vernier style adjustable pulleys or by carefully slotting the camshaft sprocket to allow offset installation of the camshaft.

Start-up Procedure

Once the engine is installed back into the car, ensuring that the engine has sufficient oil pressure prior to starting the engine for the first time is of vital importance. This is done by fitting an external oil pressure gauge so that the engine's vital signs can be monitored during the critical phase both before and after engine first start-up.

Engine Oil Pressure Gauge Fitting

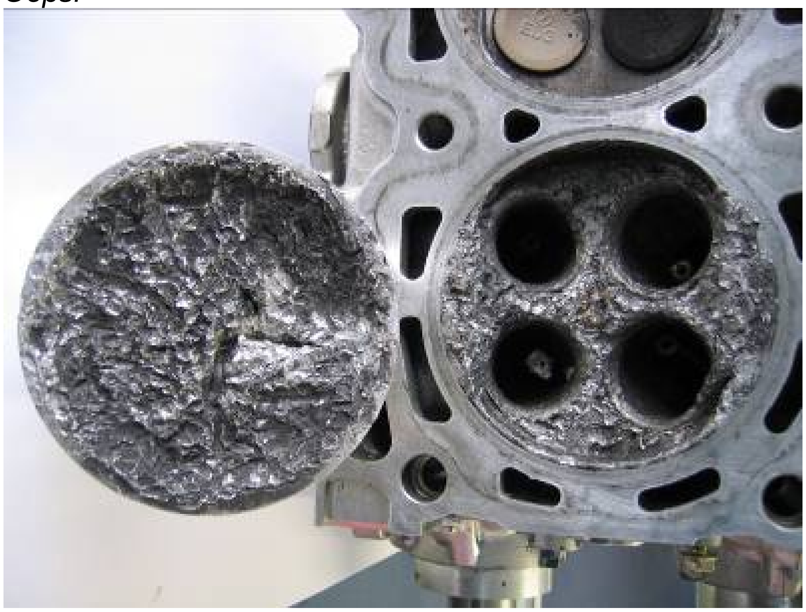
Even with a fully primed oil pump, quite often on first start up it can take a significant time for pressurised oil to make its way to all parts of the engine oil system. The best way to minimise the effects of this is to wind the engine over on the starter motor with the spark plugs removed. Taking the plugs out removes any compression loads on the big end bearings reducing the possibility of damage while oil pressure is low, while also increasing the speed at which the engine turns over, improving oil pump performance reducing oil system fill time.

Once the external gauge registers oil pressure the starter motor is shut off for a complete external inspection of the engine for any oil leaks or other problems. Only then are the spark plug refitted and the engine started and allowed to run under its own steam. Once started, oil pressure is once again carefully checked to make sure that oil pressure is within the expected range. At the same time as this a close watch is kept on the engine for any signs of leakage or excessive oil smoke. It is also closely monitored for any unexpected noises. Somewhat of an anxious time for some, very much like watching a toddler taking its first steps. This is not the time to go off and make a cup of coffee!

16.4.13 Running In

Once your monster tune engine is all assembled and ready for startup, choose your first sump full of oil carefully. Previously it was considered important to use a specialised running-in oil, but in practice most brands of running in oil are the wrong grade for use in modern turbocharged engines. What is more important is to select a good quality non-synthetic engine oil. Synthetic oils contain additives that can interfere with the important process of bedding in the piston rings. Consequences of poor bedding in of the rings include excessive oil consumption and blow-by. Change the engine oil and filter after 1,000Km of running, but do not change to a synthetic engine oil immediately, waiting instead until your baby has at least 5,000Km under its belt.

Oops!



Talk to twenty people about how to run-in a new engine, and you are sure to get twenty different answers, and tends to be a controversial issue. Basically there are two schools of thought, with the first being the “Treat ‘em mean and keep ‘em keen” camp. Devotees of this technique advocate that the driver of a new engine should immediately sink the boot, keeping it buried in the floorboards, driving it like you stole it. Diametrically opposed are those that believe a new engine is something to be babied, and educated in the finer details of life by staying conservative with RPMs and generally driving like you have an egg between your right foot and the throttle pedal, for at least 1,000-1,500Km. Which method is best?

Ouch!

The correct answer is that there are elements of truth in both methods, and it basically boils down to how good a job your engine builder did in the first place. Professional racing teams don't spend thousands of kilometres running in engines, as this is ridiculous when you have an engine that is meticulously assembled and set to incredibly precise tolerances. All that is needed are a dozen or so runs with increasing load to bed in the piston rings. Equally ridiculous is the concept of thrashing a brand new "green" engine that is still very much tight within an inch of its life immediately. Play it safe and strike a balance between the two methods. Keep boost pressures under 0.8bar and engine speed below 5,000 RPM for the first 500-1000Km, but don't be afraid to stretch its legs and exercise a bit of full throttle, while respecting RPM and boost limits discussed.

Once the initial running-in period is over, at this point have your engine inspected top to bottom for oil and coolant leaks, along with a compression test. This will be a good indicator how well your engine has bedded in, and can indicate any potential problems before it is too late. Better still is a cylinder leak down test, a specialised diagnostic test, measuring actual percentage of air leakage past the piston rings and valves. Less than 10-14% leakage denotes a well run-in and healthy engine. Leak down takes more time than compression testing, and costs more, but ultimately worth it considering the amount of cash invested in the entire project to this stage.

16.5 Conclusion

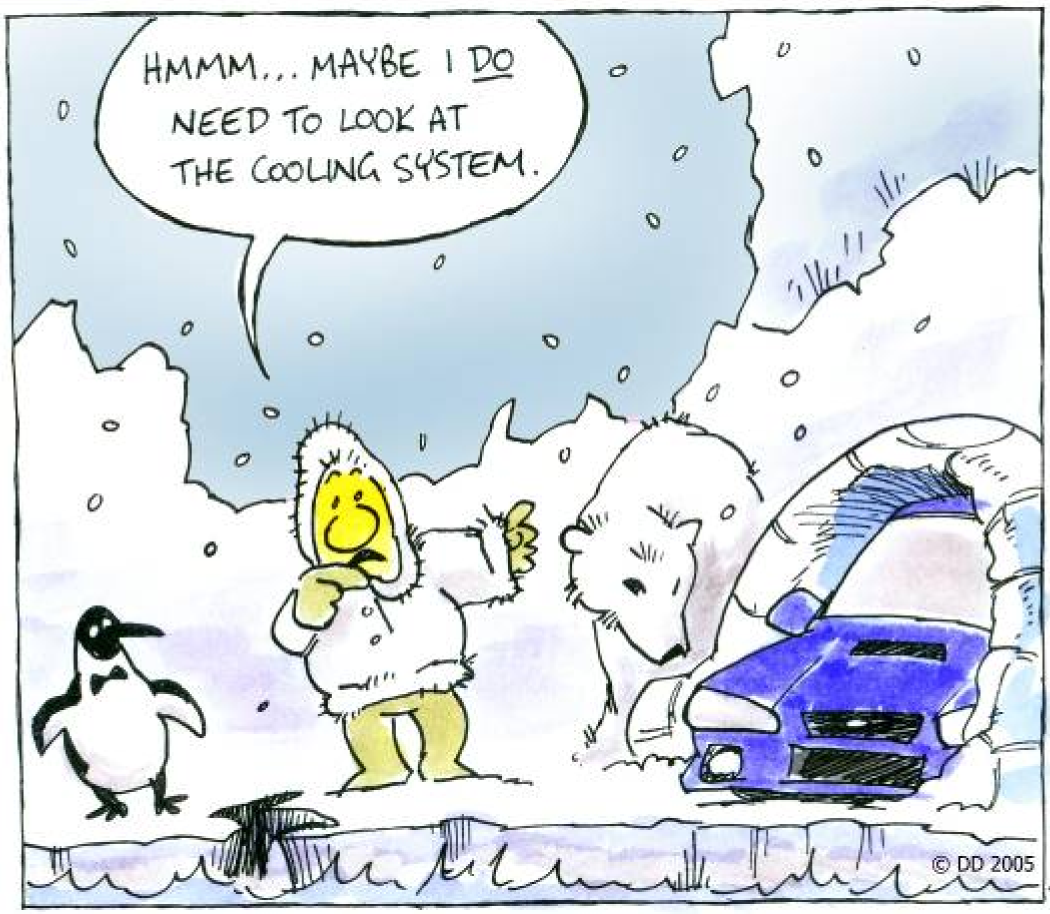
Subaru, like all OE manufacturers utilising mass production techniques, spend a great deal of time and effort designing and manufacturing any new model car, ensuring both technical and assembly related issues are debugged early on in the build cycle. You toss this design integrity and hard work away when you re-build your engine, or other parts of the car for that matter.

Embarking on a monster tune, even to a relatively mild standard is one of the biggest single expenditures you can make, with a professionally built monster often leaving no change from A$14,000, *without* taking into account the cost of supporting mods. Engine upgrades are also one of the most common areas for owners and workshops alike to get into conflicts over costs, given the complexity and time consuming nature of the beast. Building a performance engine is not a plug and play operation, and is renowned for running way over budget and over time. Additionally, once completed, living with a monster tune does not stop there; consider it being more of a wild child, needing lots of supervision and encouragement along the way, translating into frequent trips to the engine doctor for tinkering and tweaking.

Doing a monster tune right is a hugely complex, costly and time consuming process and things don't always go to budget or to time. What does this mean for a prospective owner? Your engine builder must be painstaking in their work, thorough and up to date with all the latest developments in parts and techniques. You must also have clear lines of communication with your builder of choice, for those inevitable snags or overruns that pop up unexpectedly. Lastly, and most importantly, you as the owner must have a clearly defined set of goals and expectations in mind that are understood and appreciated by your engine builder, before letting loose a spotty faced mechanic on your car with a set of spanners. Choose wisely.

Engine Building Clean Room

Chapter 17



Cooling System

Cooling System

In the quest to make more power, more fuel has to be burned efficiently. This much we already know. This creates more heat and pressure, the driving force on the pistons, which is in turn converted into mechanical energy. But there is a catch, as more heat is made everywhere, particularly into the cooling system. Increased torque loadings result in more heat generated inside within the transmission from friction. In this chapter we will look at what can be done to improve the cooling system of the WRX.

Wetter Water – What?

Ok, it sounds silly, how can you get water wetter than well, er water! It's actually easy and it all has to do with surface tension. Water actually has a comparatively tough skin; as witnessed by certain bugs that are able to walk across water. That's surface tension in action. (David Attenborough eat your heart out) What does this have to do with a WRX, and its cooling system in particular? Plenty, if anecdotal evidence is to be believed. Reducing the surface tension of water improves heat transfer rates out of the cylinder head as the cooling liquid "interfaces" better with metallic surfaces. It also resists the formation of microscopic bubbles of gas sticking to metal surfaces causing localised hotspots in the engine. Sound like hocus pocus? Maybe, but plenty of professional race teams and enthusiasts alike swear by water wetters. Give it a try, but remember water wetter won't raise the boiling point or the freezing point of water. So if you live in subzero temperatures the addition of anti-freeze is required.

17.1 Engine Cooling

The OE engine cooling system fitted to the WRX is very good, engineered with a reasonable margin of excess capacity. But in hot climates (40DegC +) and around 180kW ATW, the OE cooling system hits an upper limit, especially if driven at high speeds and loads. Obviously at lower ambient temperatures, much higher engine power numbers can be run without overheating, especially if the car is not operated at sustained levels of high load for long periods.

Another contributor to overheating can be a FMIC. When Subaru originally designed the OE cooling system, no allowance was made for the disruption to airflow that an FMIC will cause. Again, for most this is not an issue for street use, but circuit racers will often have problems with overheating when ambient temperatures climb above 35DegC. Additional heat exchangers such as engine and transmission oil coolers suspended in front of the radiator will also reduce airflow to the engine cooling system.

17.1.1 Thermostat and Radiator Cap

Useful improvements can be made here for not a lot of coin. For those living in hot climates with engines in excess of 180kW ATW, replacing the OE thermostat with a cooler one with an opening temperature of 85DegC will lower peak engine operating temperatures. Not recommended for cold climates, as colder thermostats will result in extended warm-up times, increased fuel consumption and engine wear. Colder thermostats cost around A$25.

Pic Thermostat

Replacing the OE radiator cap with a higher operating pressure is a good modification for any car, regardless of ambient temperatures or the state of engine tune. Increasing cooling system pressure raises the temperature at which the coolant in the system will begin to boil. While this may not seem important in engines that are not exhibiting the classic signs of overheating, at high engine power outputs, localised areas around the combustion chambers in the cylinder head can flash into steam. These "hotspots" are a major contributing factor towards one cylinder running hotter than others, and can also hasten the onset of detonation on that particular cylinder. Increased cooling system pressure resists the formation of steam pockets. STi high pressure radiator caps start at A$92.

STi High Pressure Radiator Cap

17.1.2 Radiator

At very high power outputs, the OE radiator will struggle to cool the engine efficiently, even at low ambient temperatures. There simply is not enough surface area to exchange the heat being produced by the engine. This can also be the case with cars that have reduced frontal airflow, due to a FMIC or other heat exchangers. In the past, the only solution was to have a larger capacity radiator hand made, but this was a costly and time consuming process. Supply is no longer a problem, as nowadays a good range of off-the-shelf heavy duty radiators are available at reasonable prices. Fitting a heavy duty radiator is relatively easy, with a minium of fettling required to get everything to slot in. Heavy duty radiators start at A$835.

Ethylene Glycol, Cheap Wine and the WRX

Odd sounding mix? You bet. Ethylene glycol is the active ingredient in engine coolant, and is the chemical directly responsible for lowering the freezing point of water and its boiling point. Trouble is, high concentrations of glycol actually decreases the heat transfer properties of water, meaning cooling system performance drops. But before draining the coolant out of your engine and replacing it with plain H_2O, consider this; Subaru's all-alloy engine block is very sensitive to coolants, requiring high quality coolants with good corrosion inhibitors to keep it in tip-top condition. Where possible use the genuine coolant as recommended by Subaru or an equivalent. But don't go overboard with concentrations, especially if not exposed to below zero temperatures. The other use for glycol at one time was as an additive to cheap wine. Highly illegal, it was done to sweeten awful wine into something slightly more palatable. I don't recommend trying this at home, even under adult supervision, as side effects of glycol consumption can include blindness.

Heavy Duty Radiator

17.1.3 Header Tank

OE Version I-II Header Tank

Alloy Header Tank

Applicable to early model '89-'92 model RS Liberty/Legacy and Version I-II WRX. These cars came equipped with a composite plastic coolant header tank. With age, this part is prone to springing a leak at the most ill-opportune time, often leading to a seriously overheated engine. An easy fix is to replace the troublesome OE unit with a hand fabricated welded alloy tank. Extremely strong, it also looks a million bucks for that true WRC underbonnet cred. Replacement header tanks bolt straight on and fits up to all hose connections without modifications and costs A$314.

17.2 Engine Oil Cooling

Engine lubricating oil contributes to a significant amount of total cooling effort in the WRX engine. Even in standard trim Subaru fits a small oil to water heat exchanger in light of this, but it is easily overloaded, especially in the case of highly modified engines.

Oil Cooler core

Oil Filter Adaptor and Line

Engines with power outputs 220kW ATW and higher should have an engine oil cooler fitted as part of any serious performance package. Siting the actual cooler core can be tricky depending on configuration, especially if a FMIC is fitted. In this case, fitting the oil cooler in the space previously occupied by the OE TMIC, is a neat solution, but requires much longer oil lines from the engine to the cooler. High quality oil cooler cores are available from Earls or other specialty suppliers in a variety of sizes and thicknesses. Kits containing fittings, high pressure oil lines and oil filter adaptor cost around A$350 depending on the size and where it ends up on the car.

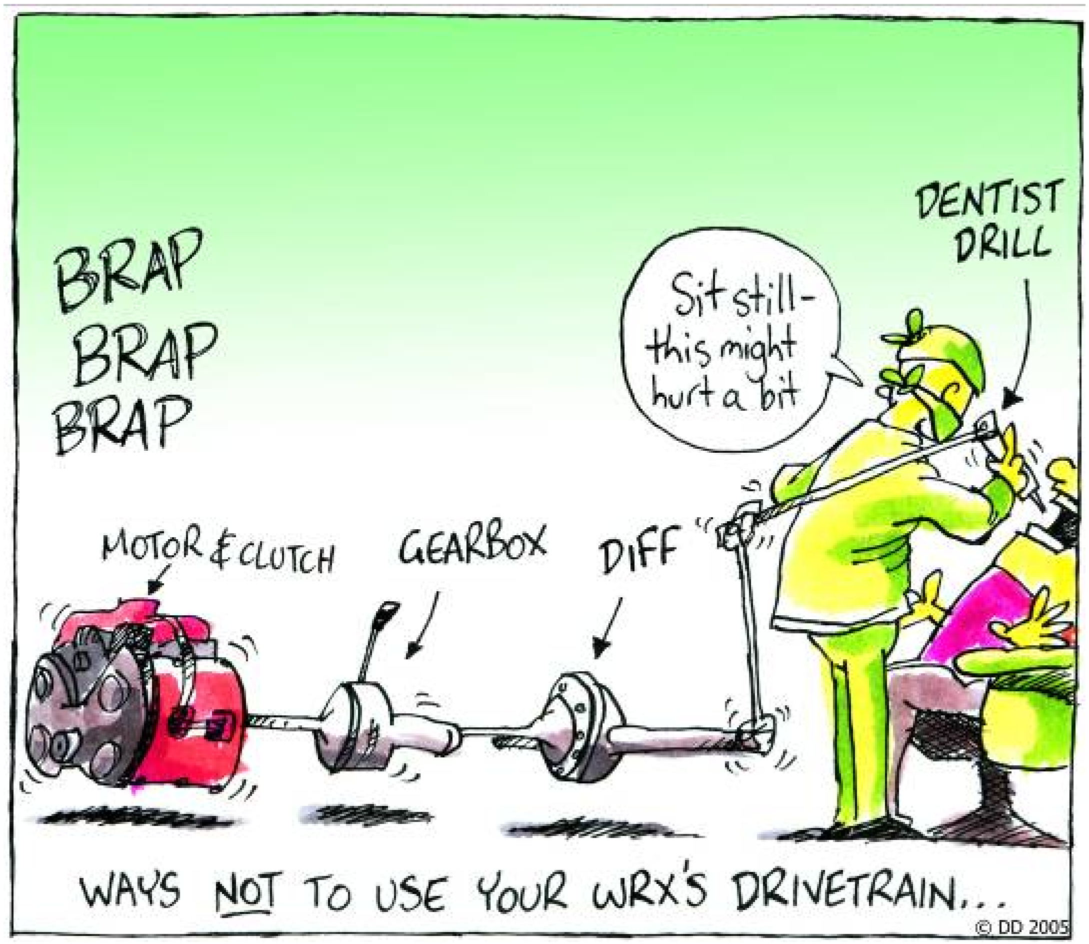
17.2 Manual Transmission Cooling

Manual Transmission Oil Cooler

Not so much of an issue for road-going WRXs, keeping transmission oil cool is an important issue for owners of high powered cars that engage in heavy track or off-road work. Especially if you have shelled out a large lump of cash for a dog gear set. As oil temperature rises, the lubricating properties of oil decrease, promoting wear. Very high oil temperatures in excess of 140DegC begins to affect the hardness of all the gears and associated parts promoting accelerated wear of shift dogs. Subaru have recognised this problem and all late production spec C (tarmac and gravel spec) STi use an automatic transmission coolant radiator, and transmission oil is run through the oil cooling circuit built into the radiator. Not an easy job to retrofit an oil cooler to a 5MT, this is a task best done early on and at the same time as the transmission is apart for modifications etc. Hardware includes an electric oil pump, connecting hoses and small oil cooler core and can costs around A$850 excluding labour.

For information on automatic transmission oil cooling, see the *Drivetrain* chapter for more information.

Chapter 18



Drivetrain

18 Drivetrain

Subaru's All Wheel Drive system is a catchy marketing gimmick, but when allied with a powerful turbocharged engine, is the major contributing factor towards the universal appeal and huge popularity of the WRX. As mentioned in the Suspension chapter, AWD increases the median performance envelope available to the driver, allowing the driver to use more of available grip and with a higher degree of confidence. Within the WRX line-up, there are three different transmission combinations available; five speed manual, four speed automatic and for late model STi models, six speed manual.

The packaging of Subaru's engine/transmission assembly is unusual in its arrangement. Most compact 2wd or 4wd cars mount the engine and transmission assembly transversely across the engine bay, a good example of this being Mitsubishi's Lancer Evolution series. Subaru, with its comparatively wide boxer engine configuration, mounts the engine/transmission assembly north-south in the chassis. This arrangement complements the boxer engines inherent low centre of gravity. Locating the transmission aft of the engine also benefits weight distribution, but requires a large transmission tunnel similar to a rear wheel drive car.

Pic Manual Transmission Overhaul

In this chapter we will look into Subaru's AWD system, and what can be done to further improve its performance.

18.1 AWD Overview

Simple in concept, AWD distributes engine output between all four road wheels, reducing the amount of load placed on each individual wheel during hard acceleration and spirited driving. In marked contrast to most other types of 4wd, Subaru's AWD system is in operation at all times without the need for any driver intervention in order to switch it on or off. Differentials are the key to this system and as the name suggests, they compensate for differences in rotational speed between not just individual wheels on a given axle, but also for speed differences between front and rear axles. AWD without differentials would be impossible, and is one area Subaru has continuously developed and fine tuned since the introduction of the WRX in the early nineties.

18.2 Automatic Transmission

An automatic option has been around since the introduction of the Version V back in '99 and Subaru refers to it as the E4AT. Available only on the less hairy-chested WRX, is utterly conventional in design and operation. How it interfaces with the rest of the AWD system sets it apart from manual transmission variants though. Subaru describe the centre differential as using an electronic torque distribution system, or just a fancy name for an electronically controlled clutch on the back of the auto trans that sends drive to the rear wheels when needed. Torque distribution is computer controlled, and changes in reaction to front wheel slip compared to the rear wheel slip, progressively apportioning more torque to the rear axle if front wheel slip continues to increase. Cruise or light load conditions see torque split at around 95/5% front to rear. Although a near perfect torque split of 51/49% front to rear is theoretically possible under extremely slippery conditions, such as driving on an ice rink, in real world conditions the electronic clutch cannot achieve less than a 60/40% torque bias front to rear at best.

On the road this does not greatly affect an unmodified WRX, but as owners of even mildly modified cars will attest, the electronic clutch is easily overpowered, and simply is not strong enough to deal with more torque over stock. This manifests itself into loads of mid corner power-on front wheel spin, torque steer and understeer through low to medium speed corners. Full throttle gear changes are also a problem, especially the 1st to 2nd shift, often resulting in a cloud of tyre smoke from the front wheels as they momentarily loose traction. Ultimately a big obstacle for those wishing to use big power engines and automatic transmission, extensive modifications are required in order to beef-up the quirky centre differential and electronic torque distribution system in order to put the power to the ground.

Automatic Transmission Selector

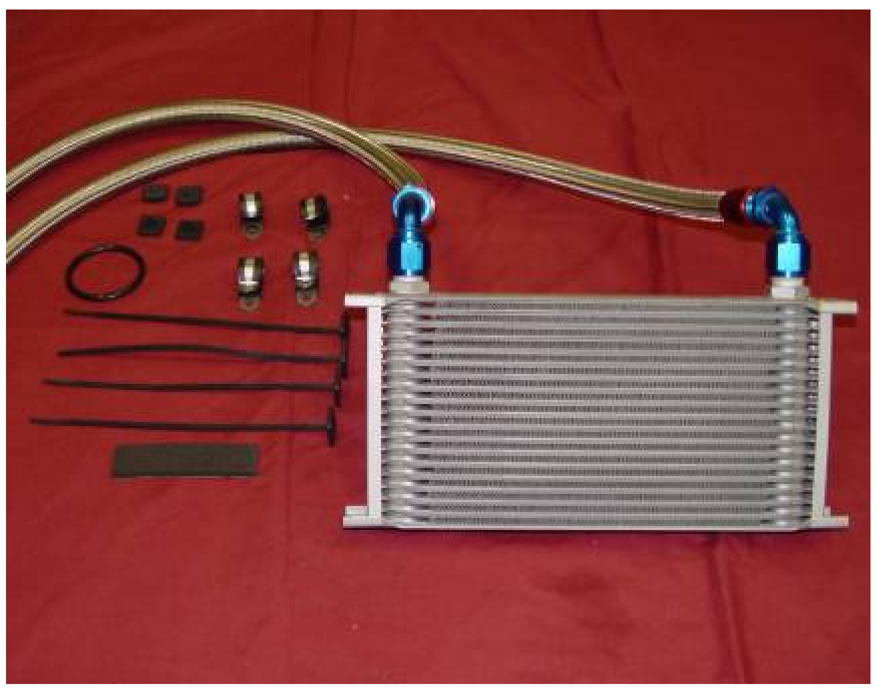
With the release of the Version VII, Subaru updated both transmission control hardware and software to fine tune shift performance and quality, introducing a degree of self-learning and adaptation in response to transmission wear and environmental conditions. Other software additions include modes to hold a lower gear while climbing and descending steep hills.

18.2.1 Automatic Transmission Oil Coolers

Automatic transmissions generate lots of heat, and the WRX transmission is no exception. As engine torque increases, so does the amount of heat generated within the transmission. Irrespective of the brand, heat remains the No.1 enemy of all automatic transmissions. Overheating results in burnt clutch and brake band materials, warped and heat spotted metallic clutch plates, along with accelerated bearing wear, seal and gasket failure. Fitting a complete stand alone transmission oil cooler is the best way to safeguard against heat damage. Companies such as Earl's and Serck offer a wide range of high quality oil cooler cores in a variety of shapes and sizes. Quality does not come cheap, costing around A$650 for a decent sized core (220 x 300mm) complete with fittings and high pressure oil hoses. There are many other oil cooler cores available on the market for a lot less cash, but are next to useless in dealing with large amounts of heat and don't belong in a high performance car. They are instantly recognisable by their comparatively thin BBQ grill shaped core. Further improvements can be made in the form of high temp synthetic transmission oil for superior lubricating properties at higher temperatures, while respecting manufacturers recommend transmission oil grades.

Under Pressure – a War Story

Recently an auto trans WRX came through MRT's workshop. It had just spent a week down at the local auto trans shop having a mad scientist type experimental valve body shift kit fitted. You could hear the car a block away, exhibiting the characteristic squeal of a badly overstressed transmission oil pump. It seems that the transmission "specialist" got a bit overenthusiastic in increasing the amount of oil pressure in the control system of the trans in an effort to firm up gearshifts, even to the point of defeating OE pressure relief valves fitted to prevent such a thing from happening. The owner was immediately informed of this problem and was sent away to have it checked out by the shop that had done the mods. A week later the very same car arrived back at MRT's workshop, this time riding on a tilt-tray tow truck. The prognosis was not good, the car had no drive in gear, terminal noises from the torque converter area along with a massive oil leak from the front of the trans. It turns out the owner decided to do an over-the-phone check with the transmission supplier over MRT's advice and was told "are they transmission experts sir?" End result, the overstressed oil pump chewed its way through the torque converter nose bearing damaging both the torque converter and oil pump, spreading lots of nasty swarf throughout the entire transmission hydraulic system. Transmissions are not something to be experimented on, especially if it belongs to you!



Automatic Transmission Cooler

18.2.2 Automatic Transmission Mechanicals

In the interest of long term durability and operation, substantial increases in power, such as new turbochargers etc, should be done in conjunction with upgrades to the hydraulic control system of the transmission. Transmission gear shifts are achieved by means of a very complicated set of electro-hydraulic solenoids and spring loaded shuttle valves, combining together to activate carefully timed sequence of clutch and band applications within the transmission. Increasing an engine's torque output must be combined with a proportional increase in actual transmission shift speed. Otherwise a condition occurs whereby engine torque is sufficient to "blow through" the OE shift thresholds, sometimes resulting in the engine bouncing off the RPM limiter, especially in the lower gears when wheelspin is present. Slow to engage clutches (including lock-up converter clutches) that slip excessively during "lazy" shifts heat up enormously and are another major contributing factor towards transmission failure.

Automatic transmission improvements fall into four general categories;

Autotransmission Valve Body

- **Valve Body Modifications** – A transmission valve body is the control centre of a transmission, and is where the majority of hydraulic control solenoids and valves are located. Its job is to meter and direct pressurised oil to the various actuators in the transmission. Upgrades to this assembly are commonly referred to as shift kits or hydrosystems, consisting of a set of parts including up-rated springs, different sized shuttle valves and pistons along with a set of precisely calibrated changes to the size of select oil metering holes. These parts combine together with the desired aim of increasing shift speed in line with increases in engine torque, which is important to note, as a shift kit designed for a 20% increase in torque will not work properly with an engine that has 50% more torque. Fitting a shift kit requires specialist skills and is best left to transmission professionals.
- **Modified OE Torque Converters** – An auto trans torque converter is in essence a fluid clutch, transferring engine torque via a set of impellers and guide vanes into the transmission without a direct mechanical coupling. All torque converters have a "stall" speed, or the RPM at which the converter begins to efficiently transfer torque from the engine into the transmission instead of slipping. A stock WRX converter has a relatively low stall speed, somewhere around 2000 RPM, meaning when you launch at full throttle from a standstill, the engine is operating well below the point at which the turbo begins to operate, contributing to un-inspiring off the line performance. Fitting larger turbos merely magnifies this situation. Raising the stall speed of the OE converter will significantly improve off the line performance, as the engine RPMs are better matched to the operating band of the turbo. Another benefit is the driver is better able to "stall" the engine at the line, a process of simultaneously holding the car on the brakes and throttle carefully, spooling the turbo so that positive boost pressure is available for those quick get-aways. Increased stall speeds is not all good news. Engine RPMs at low speed cruise tend to be higher, as under even light loads the converter will want to stay close to its new higher stall speed, increasing engine noise and fuel consumption.
- **Complete Replacement Torque Converters** – For serious high performance applications, further gains in torque converter performance can be made. Custom made units allow more flexibility in fine tuning converter performance around a pre-defined stall point, along with upgraded converter-lock up clutches. Complete replacement torque converters also feature a smaller diameter, greatly reducing converter inertia, improving throttle response.
- **Custom Performance OE Transmissions** – Very high performance applications such as drag racing requires further modifications that simply cannot be achieved through torque converter and valve body modifications alone. OE components within the transmission have a finite torque capacity and typically performance transmissions will include upgraded bearings, oil pump mods, higher capacity clutch friction plates and brake bands. Other techniques such as increasing the number of clutch plates per clutch pack, along with larger capacity actuators to boost clutch pack clamp loadings. Very difficult to achieve as a plug 'n play type modification, fine tuning and tweaking of the transmission normally has to be done on site by the transmission builder to suit the actual application at hand for peak performance.

-
- **Transmission Software Reprogramming** – Still very much in its infancy for Subaru applications when compared to makes such as Ford or GM, work is being done to enable the remapping of electronic transmission control parameters contained within the WRXs electronic control unit. Benefits of this will include changes to RPM/load shift thresholds, faster and firmer shifts along with more positive downshifting. While this sort of software change cannot be depended on to perform miracles on its own, due to OE mechanical strength limitations, where it will really come into its own is in combination with intelligently designed shift kits and other mechanical mods.

Performance upgrades of anything more than mild increase over stock will require some sort of auto trans upgrade. This does not mean that owning a WRX equipped with auto trans precludes the possibility of increasing engine power, its more that some careful research and planning is required for a good end result. After all, a properly modified and setup automatic transmission, coupled with a powerful engine can be devastatingly quick from both a standing start and point to point. Level 10 products in North America have been working extensively on both mild and wild performance applications for the WRX auto trans. Level 10 Hydrosystem's start from A$935 and upgraded OE converters from A$665. Serious stuff such as custom performance torque converters and complete exchange transmissions start from A$1730 and A$5320 respectively.

18.3 Five Speed Manual Transmission

Referred to as 5MT by its abbreviated form, this transmission is another long serving piece of equipment that predates even the introduction of the WRX in 1994. So much so, its origins date back as far as the early 1600cc and 1800cc L series Subaru's, and as such basically a conversion of an existing Fwd transmission into AWD. These very early model WRX transmissions are pretty ordinary, with long and clunky gear shift throws between gears and weak synchromesh easily defeated if pushed.

5MT out on the Bench

Major upgrades of the 5MT have included an improved dual cone synchroniser assembly for 2nd gear in Version II and later cars, while Version V and later models feature a new and improved transmission casing, stronger and better braced in an effort to reduce case flex, along with eight instead of four transmission to engine block bellhousing bolts for improved strength and reduced NVH. Shift rails and shift detents were refined for better gearshift feel. 3rd gear copped an upgrade to a dual cone synchroniser, while a completely new transfer case with modified centre differential gears and viscous coupling. Version VII and later transmissions use cold forged gears, along with the addition of shot peening, or a process of surface hardness improvement to boost gear strength and durability. Version IX see dual cone synchromesh on 1st gear adopted.

18.3.1 Why Your 5MT Died

As mentioned elsewhere, the AWD system of the WRX provides substantially more grip than conventional 2WD cars. While largely a good thing, it should be remembered that wheelspin (a.k.a "The Chirpy") acts as a shock absorber in most 2WD cars. Sidestepping the clutch from a standstill with a lot of throttle in a 2WD you will chirp the tyres and may impress the hard-of-thinking without severe consequences. Doing the same thing enough times in the WRX and you will damage the drivetrain, including the transmission big time!

Transmission Trauma

What is the cause of this situation? There are many contributing factors towards this, but they all stem from one root cause, excessively high shock loadings. Big RPM launches and flat changes set in train a cascading series of effects throughout the transmission. Torque follows a long and complex path through the transmission, and in particular the input shaft that feeds torque into the transmission twists and flexes, while pre Version V transmission casings are particularly prone to distortion.

Under heavy load the transmission casing swells minutely due to opposing loads generated created by the meshing of helical type gears attempting to "corkscrew" them selves apart in opposing directions. Even miniscule amounts of distortion can cause the gears to move away from each other under engine torque, reducing their contact area and therefore strength. Torque loadings are transferred outwards to the gear teeth tips, instead of the base where they are the strongest. It simply boils down to the transmission design getting a bit long in the tooth (pardon the pun) and is just not being strong enough for the task at hand.

18.3.2 Improving the 5MT

Mechanical sympathy is the first order of the day and is by and far the cheapest and most cost effective way of improving the reliability of the 5MT. As mentioned, big RPM launches, full throttle gear changes sans clutch can all contribute to gear failure, a wallet averse event. Do not get the impression that the 5MT transmission is a cheap and nasty unit made from recycled pots and pans, and will break the first time you get stuck into it. Quite the opposite, prior to the homologation of dog gear sets for use in Group N, these rally cars used the stock casing and OE style gear sets without too many problems, proving that it is a reasonable unit. You don't even need to drive like Granny to look after your 5MT. Just avoid the cruel approach. This advice comes free of charge with this book.

Transmission Transplants

As more second hand Japanese import parts begin to trickle through, swapping out the 5MT trans for the more manly 6MT is starting to become a cost effective alternative to a brand new gear set. Apart from a complete STi 6MT in good condition, what else is needed?

1) 6MT cross-member and mount
2) 6MT gear lever, linkage and shift boot and reverse gear interlock cable
3) 6MT tailshaft or a shortened OE 5MT unit
4) A change to 3.9 rear diff gears if your unit is different
5) Not essential, a change to a larger diameter 6MT flywheel and clutch is recommended
6) Early model GC cars can use 6MT driveshafts, but are 10mm longer and must be carefully checked to ensure they do not bottom out on full suspension compression.

Budget Upgrades

Next in order of cost is a change of gear oil. Subaru fill the transmission as standard with mineral based gear oil and is another cost/performance compromise. Replacing this with synthetic oil protects the gears and bearings more effectively, as synthetic oil better resists oil film breakdown under the huge pressures exerted as the gear teeth rotate in mesh. Quality gear oils include offerings from Neo and Redline. Refilling the 5MT transmission with synthetic oil will cost around A$120. A good candidate for a DIY job, refer to your owners manual for information regarding oil viscosity and fill capacity.

A word of warning in gear oils and viscosity ratings. The temptation exists to use the heaviest possible grade of engine oil in worn out or damaged transmissions, as this tends to improve shift operation, while at the same time quietening noisy components. This works to a degree, but can backfire as correct lubrication depends mainly on oil splashing around inside the transmission casing. If the transmission oil is too thick, it can often fail to reach all parts of the transmission, actually accelerating wear related failures.

Competition Gear Sets

This is an area in the WRX performance industry that has improved in leaps and bounds since the first edition of Training WRX way back in 1999. At that time the only real transmission options were either STi synchromesh gear sets, or WRC spec dog boxes, the latter available from Prodrive, who are better known for their superb quality, rather than their bargain basement prices. This has all changed now, with a sometimes bewildering array of gear sets and ratio combinations available on the market.

STi gear sets, while being similar to OE parts, are made from stronger materials and are manufactured to higher tolerances featuring shot peened gears. These are made specifically for motorsport applications, for use with competition engines and peaky power bands. As a consequence ratios are closer together and lower in ratio, with the exception of a taller ratio 1st gear. Top speeds are reduced to around 210km/h @ redline, which is not a problem for rally cars, but not much fun in either the Northern Territory here in Australia, or on the German Autobahn! Fuel consumption will also be higher, and more clutch slip is required to move away from rest.

Gear Set Options

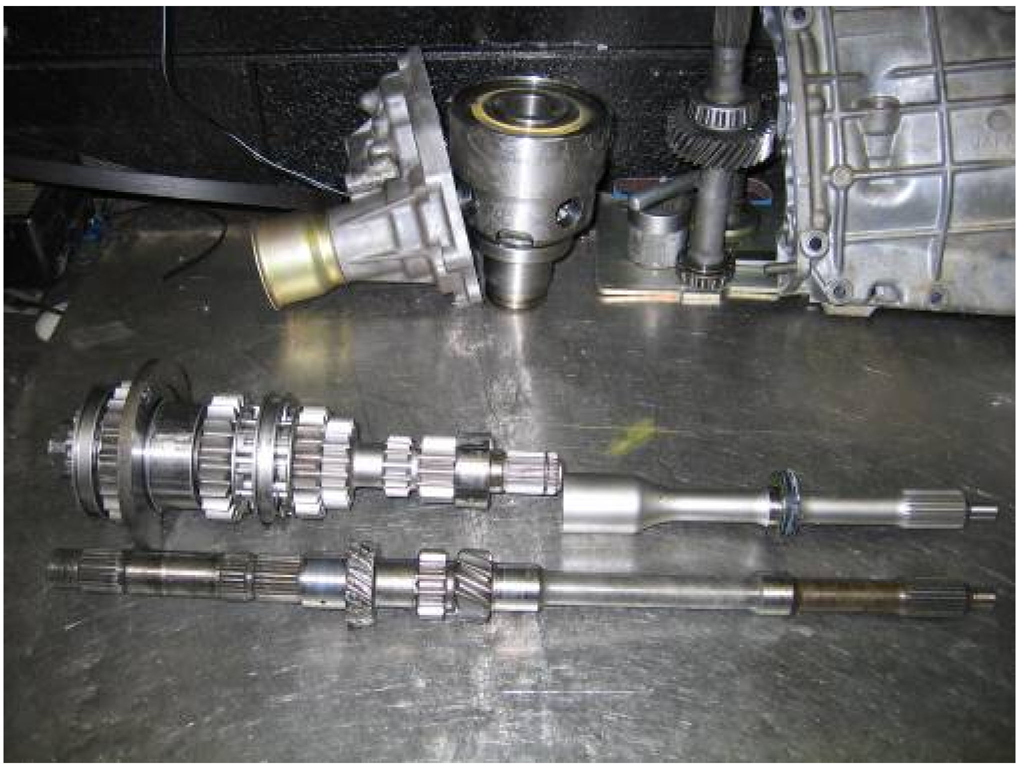
Helical Gear

Straight Cut Gear

When choosing a replacement gear kit, a few different decisions have to be made regarding both the type of gears used and the method of gear engagement. They are;

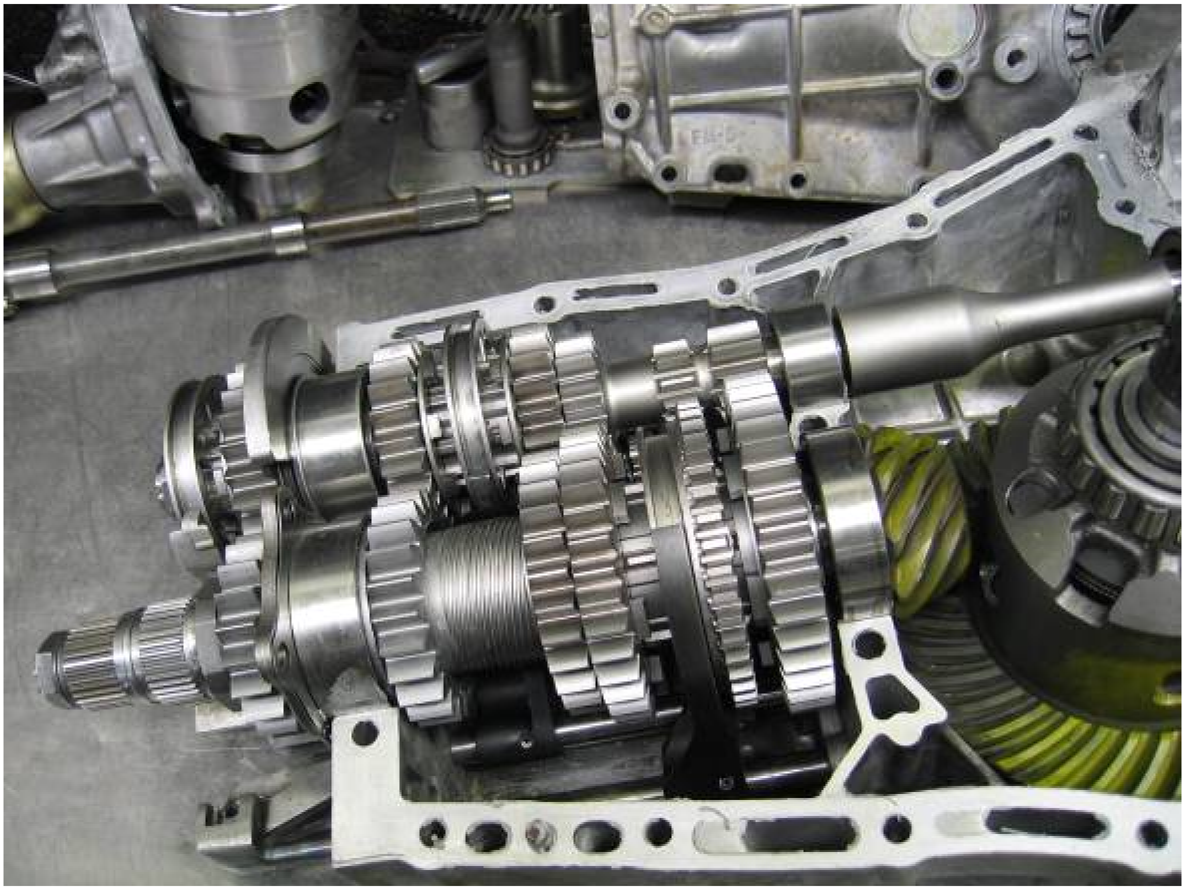
- **Helical vs spur or straight cut gears** – arguments rage over the merits of these two different types of gears. In applications with limited space, straight cut gears seem to have a strength advantage, and are the gear of choice for professional motorsport. This comes at the cost of horrendous amounts of gear whine both on and off the throttle, mostly absent from helical gears. Listening to WRC in-car shots on the telly will give you an idea of how much racket they make. Some gear kits use a combination of both types, with straight cut 1st, 2nd and 3rd gears, retaining conventional helical gears for 4th and 5th in order to reduce transmission noise on cruise.

- **Synchromesh vs dog engagement** – Easier to answer as results are readily quantifiable. Dog type engagement is the preferred method for competition use. Positives include lightning fast gear changes, ability to flat shift and upshift / downshift at any RPM. Not so positive is the special driving technique required to shift gears without prematurely wearing out the shift dogs. Synchromesh on the other hand is easy to use and smooth. Disadvantages include a relatively slow shift action, while over enthusiastic use can cause synchroniser and shift fork breakage. Some gear kits use a combination of both methods, but this can lead to compromises in gear selector design integrity to cater for the two distinctly separate methods of engagement.



Two-Piece Input Shaft vs OE Input Shaft

MRT have a wide range of replacement gear sets to suit the 5MT transmission, and both ratio and type can be custom ordered to suit a particular gear/engagement combination. Ratio choice is dependant on your intended use, and is broadly grouped into ratio sets for rally, track, road and a special drag ratio set, to suit either 3.9 or 4.4 differential gears. See the gear ratio comparison chart appendix located in the back of the book for more information. Notable features of the full five speed MRT gear kit include a two-piece input shaft for reduced flex along with a fully splined main shaft gear cluster.



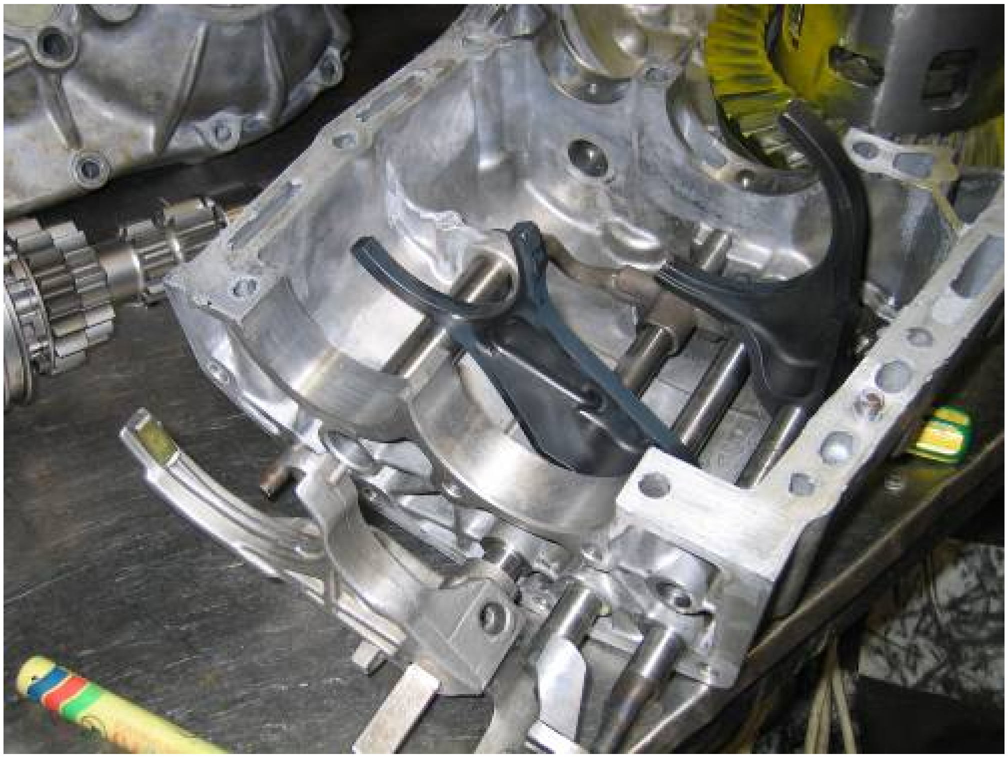
Dog Type Gear Kit Installed

Basic 1st-2nd upgrade sets start at around A$2,700, while an all singing and dancing straight cut 5 speed dog box costs around A$8,700. Replacement gear kits sometimes do require some case modifications in order to fit certain components. Other important considerations when purchasing gear kits include clearly establishing the suppliers warranty policy, if additional hardware like shift forks etc are required, along with fitting costs and an estimated allowance for any un-expected costs such as bearings, seals and gaskets.

18.4 Building A 5MT the Right Way

Over-enthusiastic usage, or just plain driver abuse will have your 5MT turning its toes up in short order. This is a well understood point. What is less well appreciated is once a transmission is overhauled it may not be the end of all the trouble, as many will go onto suffering repeated failures, even after fitting heavy duty components. Why is this the case? Rebuilding a 5MT properly is not exactly rocket science, but it is amazing how many so called "professionals" stuff it up, getting it very badly wrong. Here are a few points to run past your transmission builder, and if you get nothing but a dopey expression in return, we suggest a quick exit stage left!

Transmission Selector Mechanisms



Heavy Duty Selector Forks

Irrespective if it is a simple overhaul using OE parts or a full-house competition conversion kit, all selector hardware should be scrutinised closely. This includes gear stick link rods, pivots, bearings and bushings. Any wear, play or damage is a serious health risk, as any excess play can lead to the gear "bouncing" on engagement as it is not being positively driven home. In particular, the nylon wear pads on the OE shift forks must be carefully checked for wear. If fitting a dog engagement set of gears, saving a few dollars and re-using the OE shift forks is just plain silly.

Synchro Dog Teeth

Synchro Hub Slider

On synchromesh boxes, selector sleeves and hubs should be checked for wear. The small teeth on both the hub and sleeve must have sharp point in order for gears to engage positively. These teeth must also be free of burrs and damage, or jamming in gear can result. 3rd gear has an over select stop in the form of a washer between the synchro dogs and gear. This must be checked for fatigue wear and damage. Over enthusiastic drivers that shift too hard can shear this washer off, which is then free to move around inside the transmission, normally getting chewed up between the gears causing further damage.

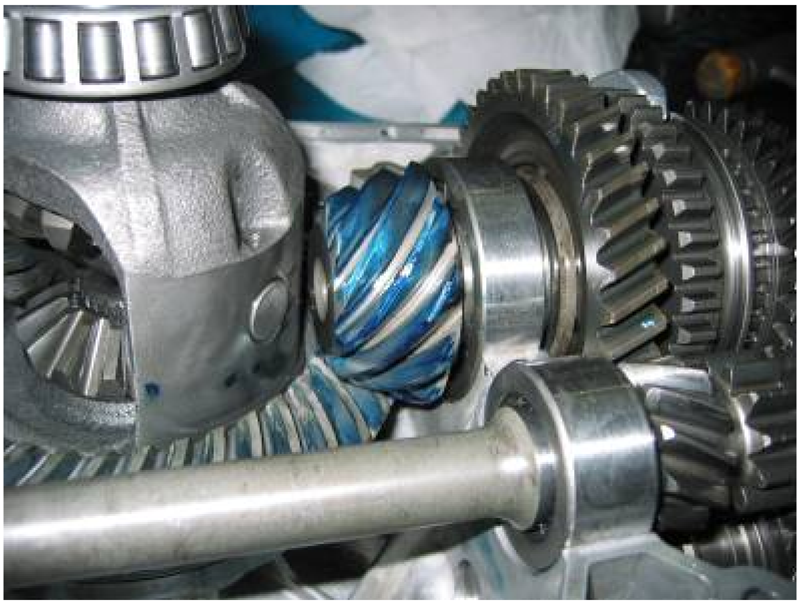
Differential Pinion Height

Setting the front differential pinion height set correctly is absolutely critical, stuff it up and the diff pinion will fail to mesh properly with the crown wheel, leading to premature failure and/or excessive noise and slack in the drivetrain. If this is not bad enough, pinion height determines the alignment of mainshaft and counter shaft gears. Even small misalignment of the pinion height, if not corrected will lead to reduced gear to gear mesh contact area, weakening gear strength, promoting accelerated gear failure. A genuine Subaru pinion height tool is the only way to set pinion heights. It very quickly and accurately calculates the correct thickness of shims required to set the pinion to its correct height. End of story!

Pinion Height Tool

Differential Crown Wheel Position

Must be set in relation to pinion shaft height, meaning if this measurement has been ignored, guessed or left to chance and is wrong, attempting to get crown wheel alignment is a lesson in futility. This is one area where an experienced operator is imperative, as there is no miracle tool to automatically establish crown wheel position. Instead, both crown wheel and pinion are painted with bearing blue, (a.k.a Prussian blue or machinists dye) the two case halves assembled and the differential rotated. Case halves are separated and the witness marks are inspected, with adjustments made according to mesh patterns. Adjustment is made by threaded front differential bearing caps in either transmission case halve.



Pic Crown Wheel + Pinion Tooth Contact

Transmissions built for competition use, or big power, should have the crown wheel bolts either locked with aircraft tie wire, or fixed with high temperature Loctite thread locking compound.

Pinion Backlash

Once a satisfactory crown-wheel and pinion mesh has been set, as a final quality assurance, a dial indicator gauge is used to check differential “backlash”. This odd term describes the amount of clearance between two rotating gears. Not enough and when everything gets hot, clearances can close up enough for the gears to bind and learn other nasty habits. Too much and you will be forever under your car trying to discover the source of that irritating clunking noise on and off the throttle. Too much backlash reduces tooth mesh weakening overall strength.

Checking Backlash

Centre Differential and Transfer Case

Early model (Version IV and earlier) transfer cases are very reliable. They do need careful checking after a transmission failure, as they can be hiding places for pieces of gear debris. The centre viscous coupling in these early units should be checked for "humping". Later model Version V and later centre viscous couplings generally turn into an open unit when damaged. Viscous couplings are rated in 10, 12 and 20 kg/metre. This is the torque reading exerted by holding one side of the viscous coupling stationary with a torque wrench, while rotating the other at 100 RPM. Does your transmission builder know how to do this?

Pic Transfer Case

Late model Version VII and later WRX transfer case changed from ball type bearings to tapered roller bearings, and can start to become noisy very easily. All shafts inside of the transfer case are preloaded by means of graded shims and washers. This includes the gasket on the rear housing of the transfer case which is part of the preload calculation. Deleting this gasket and replacing with just silicone will significantly change the loadings in the transfer case.

Miscellaneous Preparation

Just about every single circlip, washer and shim used inside the transmission is critical for setting preload and alignments, requiring a good supply of these parts in stock when rebuilding transmissions. Attempting to rebuild a transmission without a selection of these parts is a pointless exercise.

Transmission case bolts must be clean and in good condition, with grease or anti-seize applied to the threads. A small detail but very important, as up to 50% actual bolt clamping load can be gobbled up by friction between inner and outer threads of the case bolts. A tension wrench must be used to torque all case bolts to the recommended setting. No room for guessing here. Of equal importance is the special sequence case bolts are tightened in, avoiding possible distortion or stressing of the case.

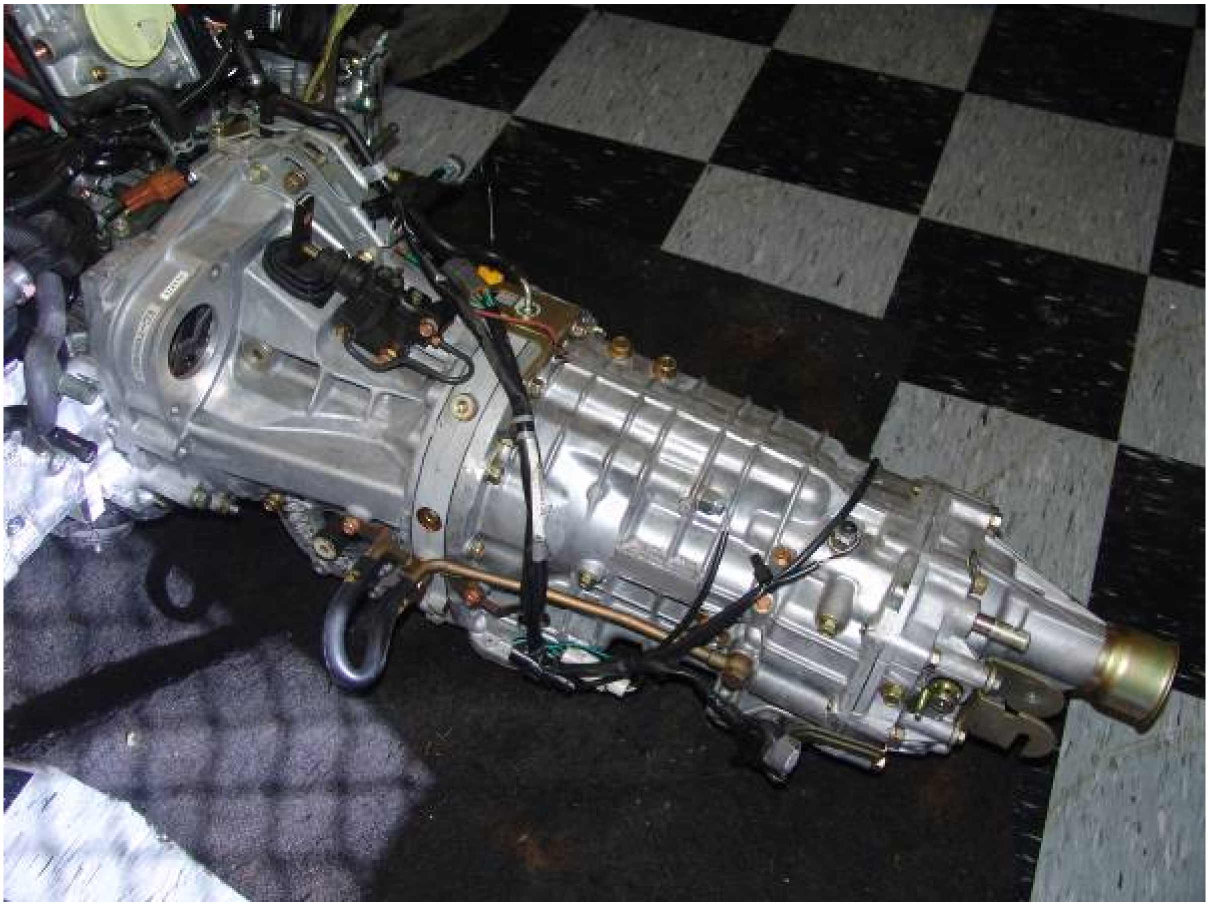
Good quality high temp sealant must be used on case flanges. For this you cannot go past Three-Bond brand flange sealant. Plain 'ole silicone just doesn't cut it. Transmission case integrity depends on a strong bond between the two halves. Good operators go easy on the amount of sealant used too, as the excess has a nasty habit of flaking off on the inside, clogging oil holes causing a whole host of undesirable outcomes.

Jigsaws for Grown-Ups

18.5.3 Six Speed Manual Transmission

Hot news for the Version VII STi was the introduction of the 6MT, a long anticipated improvement, especially given the Aussie spec STi's somewhat narrow power band which really does need a close spread of ratios to keep it on the boil. Best of all, Subaru finally decided to build from scratch a completely new transmission design that promises to fix much of the strength and shift quality issues that have plagued the 5MT.

Version VII 6MT Out of Car



The 6MT is both longer and has a much greater girth and weighs almost 28kg more compared to its little brother. The transmission case is no longer split in two parallel halves, instead using a one piece transmission main casing. A cast steel sandwich plate mounts the gear set, and is bolted to the front differential/bellhousing casing, supported at the rear by the main transmission gear casing. In addition to an extra forward ratio, gear sizes are dramatically bigger in size and strength, as are all the bearings for improved durability and gear mesh accuracy even under high thrust loading conditions. The shift mechanism is completely different, shortening the gear shift, while the addition of selector shaft bearings on the shift forks reduce friction and shift effort. 1st, 3rd and Reverse gears all feature dual cone synchronisers, while 2nd gear has a heavy duty triple cone synchroniser.

Bigger gears and bearings, heavy duty multiple element synchronisers and a stronger and stiffer transmission casing has greatly improved durability. In addition to this, the transmission lubrication system has finally joined the 21st century, featuring a gear driven oil pump providing pressurised oil feed to the mainshaft, pinion shaft and transfer gears, along with spray lubrication of mainshaft gears. Quite complex in design, the lubrication system features a pressure regulating valve and pressure relief valve in the event of a system blockage. Another clever feature is a second oil chamber that fills with oil while the car is in motion, lowering the oil level in the main oil sump of the transmission to prevent aeration of the oil by contact with rotating gear elements.

18.5.4 Improving the 6MT

The 6MT is significantly stronger and more durable than the 5MT, but those with a PhD in mechanical abuse will still find it possible to break gears and damage synchromesh. A degree of care is still required when shifting gears and launching and besides, strengthening of the transmission merely highlights the next weakest link in the drivetrain, typically the front axles and driveshafts. As with the 5MT, a refill with synthetic oil is highly recommended.

Competition Gear sets

The majority of gear kits available for the 6MT are dedicated motorsport items, featuring straight cut gears and dog type engagement, putting it out of the scope of the majority of road users. PPG here in Australia manufacture gear kits to suit drag racing and group N rally applications. Prices range from A$9,000 for a basic 5 speed drag race kit right up to A$12,000+ for a full-house 6 speed group N rally kit. Yikes!

6MT Straight Cut Gearset

Transmission Summary

Upgrading your WRX transmission is a major cost sink hole, and is worth spending as much time as you can researching the topic. Don't consider purchasing on price alone, as there is no such thing as a high quality cheap gear set, as you most certainly get what you pay for. "Cheap" gear sets can rapidly become expensive once all the additional hardware is purchased in order to fit the new parts. Long term durability is also a concern, as is technical assistance and backup. Dealing with a reputable supplier with a proven track record is probably the best advice we can give.

Reality Check

Finally, ask the question "do I really need a new gear set?" Many WRX owners jump prematurely into the wrong transmission upgrade without making an informed decision on what they really need. Use resources such as the Internet and WRX car club to get a better understanding of the issues at hand. Banging up and down the ratios like a WRC machine, with the gears whining like a pommy at bath time may be a thrill in the beginning, but can rapidly become tiresome as time goes on.

18.6 Quickshift Kits

The quick-shift is a gear lever mechanism that has been modified or constructed with the aim of changing the pivot point of the gear lever, in order to change its movement ratio. In other words, the driver moves the gear lever less, but with a greater resultant movement at the transmission. This may not sound impressive, but most owners report a huge improvement in feel. It does involve a compromise, as the physical effort required to change gears increases. But this is very small indeed, especially when compared to the big increase in shift feel and quality.

Pic GFB Quickshift Kit

A quick shift can be as simple as a modified OE unit, or as complicated as a completely new replacement part featuring an adjustable pivot point. Other useful features of really good quality quick shifts include a small decrease in the overall hight of the stick, along with a more pronounced backwards bend in the stick. Without this bend, a stick with an increased pivot point will move the gear lever too close to the centre console and will be odd to look at and use.

This upgrade is almost mandatory for owners of Version I-II cars as they have a gear shift with all the precision of a wooden spoon in porridge. Subaru has subsequently steadily improved the quality of the gearshift in later cars. This aside, late model cars will still benefit from a quick shift, but to a lesser degree. GFB quickshifts made to suit both the 5MT and 6Mt start at A$130 for a simple replacement gear lever up to A$255 for an adjustable pivot point item.

18.7 Clutch

Everyone who drives a manual transmission car is familiar with the clutch and its prime function of providing a means of connecting and disconnecting the engine and drivetrain. As we have discussed elsewhere, the WRX's AWD system provides tremendous grip. This means that any shock loads from the engine into the drivetrain is less likely to be cushioned by a bit of wheelspin, instead, in the WRX this job falls on the clutch. The OE clutch is not indestructible, far from it. Hot launches, flat shifting and other extreme conditions will cause the clutch to slip, reducing peak shock loadings on the drivetrain. Clutch slip is not without its own set of perils, as slippage generates large amounts of heat. As heat builds up the friction coefficient of the clutch facings decreases, promoting further slippage and generating yet more heat. Too much will overcook the friction material, drastically reducing its lifespan, along with severely damaging the flywheel friction surface. Really talented abuse of the clutch can see it wearing out in well under 10,000Km or less.

Pic OE WRX Clutch

The clutch in the WRX is a single plate pull-style diaphragm pressure/cover plate. Translating this into plain English, imagine the clutch assembly as a sandwich. The bottom layer of the sandwich is the flywheel and is connected to the engine. The filling is the clutch plate and has friction material riveted to its circumference. The input shaft of the transmission is splined to the clutch plate. Completing the sandwich is the pressure plate which bolts the whole lot to the flywheel. The pressure plate acts like a large clamp. When you release the clutch pedal, the spring in the circular diaphragm of the pressure plate clamps the clutch plate to the flywheel, making a connection between the engine and the transmission. Version IX WRX's have gone back to a more conventional push type clutch pressure plate.

18.7.1 Clutch Upgrades

Improving the clutch follows a similar path to the brake system, that is to say increasing the performance of the friction material along with improved thermal management. OE clutch plates and pressure plates are another product of the never ending cost vs performance compromise. High performance clutches fall into three different types:

Heavy Duty Conventional

This clutch is closest to the operating characteristics of the standard item, and the driver does not need leg muscles like Arnold Schwarzenegger to operate it. Gains in clutch performance are achieved through careful modifications to the internals of the pressure plate to boost clamp loading, in conjunction with a higher quality conventional organic style clutch plate. Clutch "bite" is increased by approximately 25-30% over stock, and is less sensitive to high temperatures. This type of clutch can be ordered as either an exchange item, reducing the cost as certain "core" components can be rebuilt and recycled. Quality heavy duty clutch kits start at A$595 for an exchange item to A$795 for a brand new item. Includes a replacement release bearing and spigot bearing.

Heavy Duty Ceramic or Brass Button

This type of clutch is a combination of an upgraded high-clamp pressure plate in conjunction with a very special type of clutch plate. Whereas a conventional type clutch uses a continuous band of friction material arranged around the circumference of the clutch plate, match-boxed sized "buttons" of special high friction mixture of brass and ceramic materials are used instead. Normally between four or five of these buttons will be arranged around the centre of the clutch plate in a radial fashion, much in the same way as spokes of a wheel.

Ceramic Button Clutch

This is a serious clutch and achieves an approximate 50% increase in performance over a stock OE unit. The inevitable downside is that a button clutch is difficult to use, as it does not tolerate any slip on take-off, making it somewhat of a tiresome chore on the daily commute. These high friction coefficient buttons will also wear out the flywheel and pressure plate. It is not unusual for up to 1.5mm of metal to be removed from a flywheel during the life of a button clutch, and if that's not enough, it is noisy too. One last consideration, this additional clutch grip means more shock loadings will be transferred from the engine into the drivetrain, especially if a non-sprung clutch centre is used. Tearing of the clutch centre from the plate can result. Ceramic button clutches start at around A$590 Exchange and A$850 for a brand new unit.

Twin-Plate Clutch

It may not come as a surprise to learn that these clutches use twin friction plates. That much is obvious, but how do they work? Even heavy duty ceramic button clutches have finite limits to the amount of torque they can handle, due to a limited surface area imposed by the diameter of the OE flywheel. Twin plate clutches become mandatory for big grunt monster tune engines or heavy hitting drag cars.

Pic Twin Plate Clutch Kit

In the quest for more clutch operating surface area, the size of the flywheel cannot be made any bigger, or it will not fit inside of the OE clutch housing. A twin plate clutch neatly sidesteps this problem by using a conventional pressure plate in conjunction with two friction plates. A second driven plate neatly slots in between the two friction plates, interlocking with a special flywheel completing the sandwich. This big increase in surface area greatly improves torque capacity. Friction materials differ according to the brand of clutch, with some using conventional organic facings, while others use brass/ceramic mixtures.

A further advantage to a twin plate clutch is a reduction in outer diameter and mass, reducing rotating inertia and improving throttle response. A twin plate clutch that use brass/ceramic friction materials will exhibit the same driveability traits as the single plate button, and again, more shock loadings will be transferred from the engine into the drivetrain. Exedy twin plate clutch kits consisting of a pressure plate, dual friction plates, driven plate, flywheel and release bearing start at around A$2,800 for a complete kit including release and spigot bearings.

Clutch Hydraulic System

Pic OE Clutch Restrictor

STi models use a restrictor fitted to the clutch hydraulic system that slows down the speed at which the clutch engages, even if the driver side-steps the clutch pedal. While kinder to the transmission, it can promote clutch slip because of the delay in achieving complete clutch engagement under heavy load conditions. This can be easily fixed by fitting a one piece braided clutch hose starting from around A$200 for an STi part.

Pic STi Braided Clutch Hose

18.8 Flywheel

OE Dual Mass WRX Flywheel

The word “flywheel” is not a very descriptive term to describe this component in the drivetrain in your car, and have been around almost as long as the wheel, and can be found in such dawn of the industrial age technology as steam powered traction engines.

The flywheel in the WRX is a cast iron disc approximately 30cm in diameter and serves a dual purpose. It is part of the clutch assembly, providing the medium on which the clutch grips. Kinetic energy from the engine is stored, exerting a smoothing effect on what would otherwise be two power pushes for every revolution of the crankshaft. A further benefit of this stored energy is it can be used for reducing the amount of effort required to move the vehicle from a standstill. As you release the clutch, the momentum of the flywheel helps overcome the inertia of the car, without needing huge revs and lots of clutch slip so as not to stall the engine.

STi Stepped Flywheel and Clutch

Flywheel spec changed with the Version VII, with a dual mass flywheel adopted for the WRX in the quest to improve NVH, while STi models use a quite different stepped design.

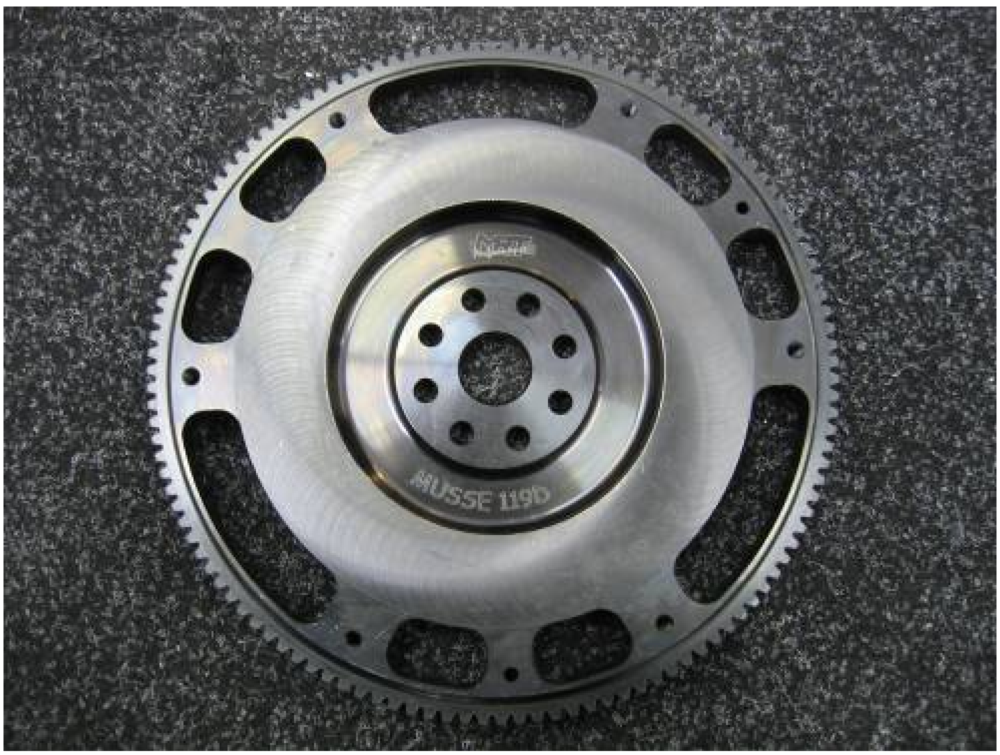
18.8.1 Flywheel Improvements

Like most aspects of OE design and engineering, flywheel mass is a compromise. The OE flywheel is a real porker, tipping the scales at around 10.4Kg and is great for easy starts, but dramatically affects the rate at which the engine accelerates and decelerates. This takes some of the sparkle out of the car, and leaves substantial scope for improvement in the flywheel. The choices are to either lighten the OE unit, or replace it with a purpose made steel unit.

Lightened Flywheels

The OE unit can be lightened through a process of careful machining to remove material from the reverse side. Up to one kilo of cast iron can be removed in this fashion, but take much more and you risk a catastrophic failure from the centrifugal forces generated by engine rotation. This would be similar to letting off a grenade in the engine bay. After machining, it is also important that it is dynamically balanced to avoid bad vibes damaging the engine or transmission. Lightening the OE unit will give a noticeable improvement to the response of the engine, but without really affecting the ease with which the car can be moved away from rest. Costs vary considerably, but expect to pay around A$320 Late model dual mass flywheels cannot be lightened due to their radically different internal construction.

Billet Flywheels



Billet Flywheel

As mentioned before, the OE flywheel is made from cast iron. This is a hard but brittle material, and has to be fashioned quite thick, in order to resist centrifugal forces generated at high engine RPMs. This ultimately restricts how light a cast iron flywheel can be made from new. The alternative to this is one of the many new brands of machined steel flywheels now on the market known as billet flywheels. A true monument to the imagination of engineers is the naming of a lump of metal as a billet. This aside, such is the strength of quality steel, a very light flywheel can be made without the constant worry of fragging your leg if you rev it too hard.

Billet flywheels are significantly lighter at around 4.9Kg in weight. These parts result in a dramatic improvement in the responsiveness of the engine both on and off the throttle. Braking actually benefits, as the kinetic energy stored in the flywheel must be dissipated when you brake in addition to the mass of the car. The engine will be easier to stall, but nothing too difficult to manage unless your significant other is a touch uncoordinated. Engines with aggressive camshafts and other mods can become a touch unstable at idle, and may require a slight increase in base idle speed. For the enthusiast the negatives are far outweighed by the benefits. Owners commonly report that it is one of the best value for money modifications you can do, with quotes such as "makes other performance cars feel like they have manhole covers for flywheels". Expect to pay around A$650 for a billet flywheel.

18.9 Wheel Hubs

Wheel bearing strength and durability has not traditionally been a strong point of the WRX and STi, with the front particularly prone to damage. Normally not so much of a problem in road cars, unless you have a preference for clobbering curbs and the like, weaknesses really show up when exposed to the rigours of competition. High cornering loadings generated during track work, or rough off-road use generating massive heat which contributes towards premature wheel bearing failure and pad knock-off. (For further information on pad knock-off see *Track Days*) Why is the reason? The OE wheel bearings and hubs are simply not strong enough in these situations.

Rear Wheel Hub

Wheel Bearing Hub Flange

Late production Version VIII STi (05 year model and on) have improved considerably in this respect, featuring bigger wheel hubs that house much stronger wheel bearings. This has necessitated a change to a bigger wheel PCD of 114.3mm, up from the previous size of 100mm, a dimension that has existed since even before the introduction of the WRX. This means that it is no longer possible to interchange wheels between models. The WRX sticks with existing wheel hubs and PCD dimension. As second hand Japanese parts begin to filter through, it will become a cost effective upgrade for those seeking to go racing with improved reliability on older model cars. Otherwise, apart from a trip to your local Subaru parts agent, NRG Automotive here in Australia sell brand new CNC machined billet wheel hubs and 30% bigger front wheel bearings to suit 100mm PCD WRX's starting at around A$2,400 a pair.

18.10 Differentials

As previously touched on, differentials are what makes AWD tick. The WRX has three of them, with one on each of the drive axles, front and rear, and one in the centre.

There are two broad categories of differentials, either open or limited slip differential (LSD). Open differentials do the job of allowing speed differences between two wheels admirably, but fail miserably when it comes to controlling torque delivery, as torque will go to the wheel with the least amount of grip – hence the nick name "single-spinner" for OE open diffs. The LSD is a much better unit as in addition to providing differential action in turns, it will also control torque distribution, transferring torque to the wheel with the most grip, making best use of the available traction.

18.10.1 Centre Differential

By and far the most important differential in the AWD system, without it differences in front and rear wheel speeds, created by turning, wheel spin or skidding would cause transmission "wind-up", putting the whole drivetrain under considerable stress.

Version I-VIII WRX Centre Differential

The centre diff fitted to manual transmission WRX's use a viscous coupling (VC) LSD, making use of a special silicone fluid as the medium for torque transfer between the front and rear axles. In much the same way as an automatic transmission torque converter, a VC relies on the properties of fluids in shear in order to transfer torque. VC diffs are also referred to as speed sensing diffs, as the greater the speed difference between sides, the greater the amount of torque transferred to the slowest side. Large speed differences also cause heat build up within the VC diff, causing the special silicone fluid inside to thicken, further improving torque transfer.

VC diffs are ideal for road use, as they are civilised in their operation, with none of the noise or jerky operation that characterises some types of LSD differentials. However, as torque transfer occurs through a fluid medium, it can never achieve 100% lock up unlike other forms of LSDs. In extreme circumstances enough heat can build inside to cause the internal parts to expand and close up the very fine tolerances that exist inside, effectively locking the VC diff into a solid unit and is known as "humping". This normally only occurs in a very limited range of situations, such as a vehicle driven with grossly miss-matched wheels or tyres, or where the car is driven for extended periods with a broken driveshaft or something similar. Normally a VC will be permanently damaged after such an occurrence.

Version I-IV Viscous Centre Differential

Although capable of a near perfect 51/49% torque split when driving in a straight line and light engine loads, actual dynamic torque split at the wheels is dependant on road conditions and load distribution, and as a result a more realistic figure is 60/40% front to rear static torque distribution. Japanese spec STis since the Version IV have had basic forms of driver adjustable torque split as an option, while competition models stuck to a heavy duty VC, until the recent advent of the Version VIII and its sophisticated DCCD system.

DCCD System

Acronym Engineering
A favourite of Japanese manufacturers used to describe proprietary technology. A few of my personal favourites:
HICAS – High Capacity Actively Controlled Steering.
ATTESSA – Advanced Total Traction Engineering System For All.
MIVEC – Mitsubishi Innovative Valve Timing Electronic Control System.

Short for Driver Control Centre Differential – in itself a triumph in Japanese acronym engineering. Seriously though, DCCD is a relatively new addition as standard equipment on the Version VIII STi, and is a sophisticated mix of electronic and mechanical elements combining together with the aim of maximising the amount of engine power transferred into the road surface, in addition to the basic task of providing differential action between the front and rear axles. DCCD is controlled by a stand-alone ECU that takes inputs from a wide range of parameters, including lateral "G", brake light switch, handbrake switch, ABS activation status, throttle pedal position, rear differential oil temp, individual wheel speeds and finally DCCD auto/manual switch status. Version IX STis use a steering wheel angle and yaw sensors in addition to further fine tune system operation.

Mechanically three major components make up the centre diff; a light duty electromagnetically controlled "pilot" clutch which controls a reaction ramp that directly clamps on a set of heavy duty LSD clutches. This in turn directly drives the operation of a planetary transfer gear set, which is the final determining factor in dynamic torque split. A Static torque split of 35/65% front to rear is a pure function of mechanical advantage set by the ratios contained in the planetary gear set. Perhaps in reaction to safety concerns, the Version IX STi has gone back to a more neutral 45/55% front to rear torque split.

DCCD In Car Controls

Control decisions are made by the DCCD ECU, continuously adjusting dynamic torque distribution in reaction to a combination of pre-determined operational conditions, as laid out by the following table:

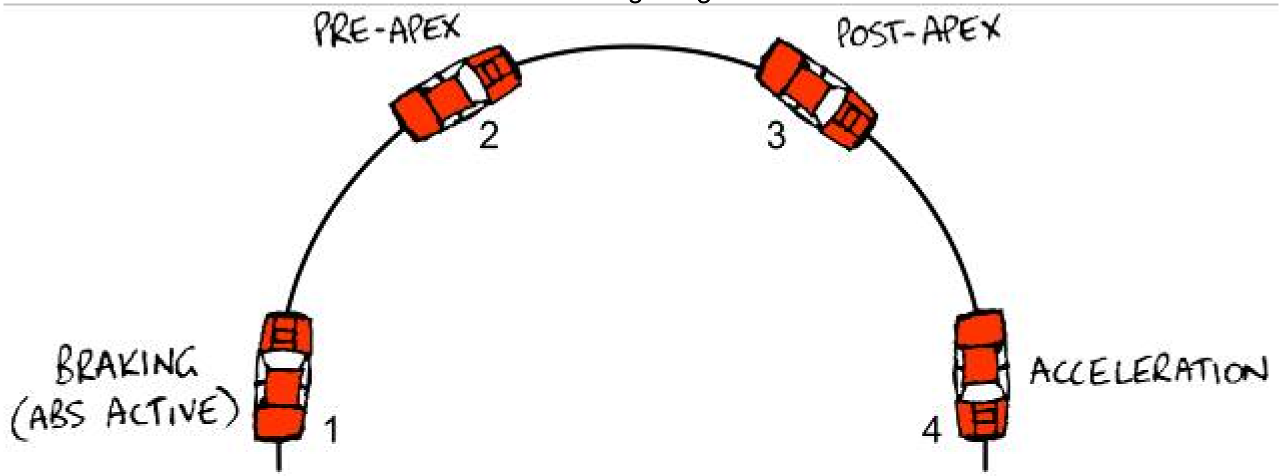
DCCD Operational Condition	***Manual Mode***	***Auto Mode***
System failsafe mode	Yes	Yes
Rear diff oil over-temp control	Yes	Yes
Throttle based torque control	Yes	Yes
Brake switch signal based torque control	Yes	Yes
Handbrake switch signal based torque control	Yes	Yes
ABS activation torque reduction control	Yes	Yes
Low speed cornering torque control	Yes	Yes
High speed cornering torque control	No	Yes
Wheel slip based torque control	No	Yes
DCCD torque split thumbwheel switch input	Yes	No

Definitions of each condition are:

System failsafe mode – On detection of an input sensor or system fault the DCCD ECU will attempt to work around the problem preserving as much of system operation as is possible. In the event of a major sensor or pilot clutch failure DCCD operation is shut down reverting back to a static torque split condition.
Rear diff oil over-temp control – Once rear diff oil temp raises above approx 140DegC, a warning light illuminates on the instrument panel, and DCCD dynamic torque control decreases. Normal operation resumes once rear diff oil temp decreases sufficiently.
Throttle based torque control – The DCCD ECU will increase operational force on the LSD clutch unit in response to increases in throttle position, keeping pace with input torque into the centre differential as progressively more throttle is used, in order to achieve optimum dynamic torque distribution according to actual road conditions.
Brake switch signal based torque control – Even light application of the brakes, will cause the DCCD ECU to command a reduction in dynamic torque control so as not to delay or interfere with any impending ABS activation.
ABS activation torque control – DCCD dynamic torque control reduces immediately on activation of the ABS system, so as to reduce the possibility of interference with ABS system control.
Low speed corner torque control – Left vs right wheel speeds are monitored to determine situations such as tight "U" turns or car parking. Dynamic torque control is reduced to provide more differential action easing driveline stress during these manoeuvres.
High speed corner torque control – All four wheel speeds are monitored in conjunction with lateral G, steering wheel position and yaw (Version IX) and other inputs for optimum dynamic torque control.

Dynamic torque distribution is best described using a slow in and fast out cornering situation:

Cornering Diagram



1) The vehicle is braking hard for the corner and the ABS system is active. Inputs from both the brake pedal and ABS unit dictate that very little dynamic torque control exists so as not to interfere with their operation.

2) Cornering has begun, and lateral G forces are rising. The throttle is still released at this point, so torque distribution is maintained around its static ratio with very little DCCD activity, giving priority to a neutral cornering attitude and good turn-in.

3) Once passing the top of the curve, the vehicle begins to accelerate generating large lateral G forces. LSD clutch application continues to increase in force as throttle openings progressively increase, with dynamic torque control increasing proportionally shifting priority to maximum grip under acceleration.

4) Cornering has finished and the vehicle is now travelling in a straight line accelerating hard. Lateral G has tapered off significantly and now dynamic torque control increases to maximum, with full priority towards maximising grip on acceleration, with the AWD system approaching, but never reaching completely an even static torque split.

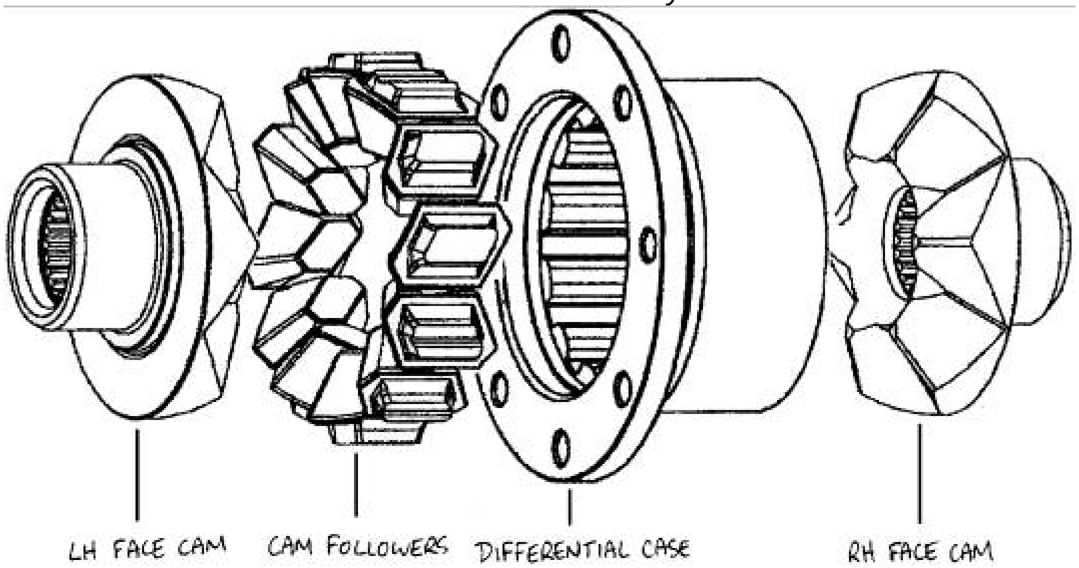
Wheel speed based slip control – Individual wheel speeds are monitored, and the DCCD system will adjust dynamic torque control in an effort to reduce individual wheel slip where possible.
DCCD torque split thumbwheel switch input – When manual mode is selected, torque distribution commanded by the driver is given priority, setting the level to which the DCCD unit seeks to intervene in controlling actual wheel slip, except in those situations as outlined by DCCD operational conditions.

18.10.2 Front Differential

The WRX front differential is an open differential and is a fine example of the cost vs performance compromise. For the majority of drivers and situations this does not cause any appreciable problems. Where it does become noticeable is under hard acceleration during spirited cornering, the inside wheel starts to spin with a resultant loss of traction, especially noticeable on loose and uneven surfaces.

With the arrival of the Version VII STi, a front LSD finally become standard equipment here in Australia and was a welcomed addition towards improved mid corner grip and ultimate corner exit speed without unduly contributing to an increase in understeer. Called a Suretrac, it makes use of a cleverly designed set of LH and RH face cams, cam followers (or interlocks) interfacing with a specially profiled differential casing. It has the advantage of having no static preload or LSD action, an important attribute on a front axle so as not to affect initial turn-in.

Suretrac Diff Cutaway



When moving in a straight line, there is no relative speed difference to the LH and RH face cams as they are splined to the front axles, and when cornering without any torque loading each of the face cams are free to rotate independently of each other, with the cam followers moving from side to side. This changes as engine torque is inputted through the differential case, as this forces the cam followers against the face cams transferring drive equally. If one wheel begins to slip relative to the other, the difference in relative movement between the face cams, combined with the angular force exerted by the cam followers causes torque to be transferred to the wheel with the most grip.

Late production Version VIII and the new model Version IX have changed to a helical front differential. A helical diff is also known as a Quaife style torque sensing diff and gets its name by the helical side gears fitted inside the differential casing. In reaction to torque differences between individual wheels, these helical gears apply axial and radial forces generated by its tooth profile. A very clever design, it distributes torque according to a "bias" ratio. For example, a diff with a 4:1 ratio will transfer four times the amount of torque able to be applied to the wheel with the least grip. For example, if the side with the least traction can support 20Nm of applied torque, approx 80Nm will be applied to the other wheel. This bias ratio is adjusted by changing the ratio of the helical gears.

Torsen style Helical Diff

Advantages include instantaneous response in a smooth and predictable manner, and when not under load it freewheels without any LSD action for good turn-in as well as interfacing well with ABS brake systems. Helical diffs are also long lasting needing no periodic replacement of wearing parts. Probably the most glaring disadvantage is that it needs a degree of preload (or at least some traction on both wheels) to operate. A wheel that is in the air before the throttle is applied, will start to spin and continue to spin – after all if there is zero torque at the spinning wheel, four times zero (bias ratio) still equals zero torque applied to the other wheel.

18.11 Rear Differential

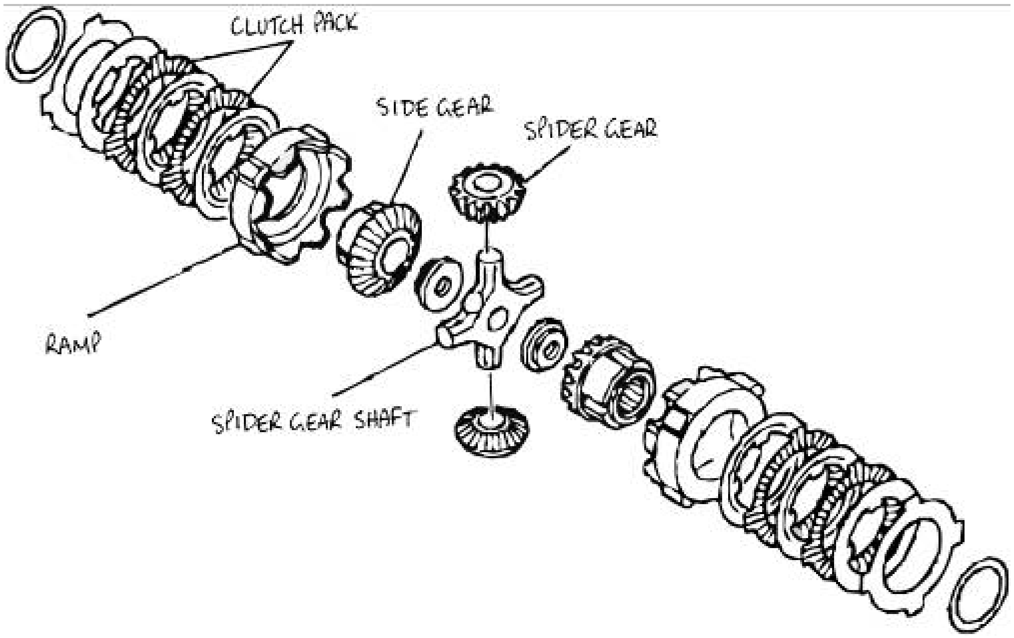
The rear differential on the WRX is also a viscous coupling LSD, and exactly the same benefits and drawbacks previously discussed apply.

Drifting and the WRX
Yes it is possible to convert your WRX into a rear wheel drive tyre smoker, but requires some specialised components to achieve this. The first thing that needs to be done is to replace the centre viscous coupling with a "spool" or a solid link in place of the differential. The fun does not stop there, as normally some sort of heavy duty centre bearing will be required to transfer torque to the rear differential. For long term durability, a R180 differential and heavy duty driveshafts are highly recommended, as is either a plated rear LSD or another spool.

Depending on the model and market, the WRX can come with two different sized rear differential units and are referred to as R160 (small) fitted to the WRX and R180 (large) for STi variants. The R180 diff is a sought after unit for big power vehicles and has a significantly stronger set of differential gears, along with a mechanical type limited slip centre. Other goodies include stronger, larger diameter driveshafts and two piston fixed callipers and ventilated rear discs.

For some markets, these larger rear brakes became available on Version VII WRX's, but with the smaller R160 diff. STi models use the R180 diff with a Suretrac LSD. Late production VIII and the new Version IX have changed back to a mechanical plate type rear LSD.

STi Plate Type Rear Differential



Salisbury Plate Differential Exploded View

The STi mechanical diff uses a Salisbury style progressive locking diff. Two sets of clutch packs, splined to the individual axles separated by a set of spider gears running inside a set of two profiled ramps. When one wheel loses traction, the difference in loading causes the spider gears to rotate "ratcheting" the two ramps apart, further squeezing the clutch packs forcing an equalisation of torque between the two wheels. The profile of these ramps is important as they determine how the diff progressively locks under both acceleration and deceleration.

Probably its greatest strength is its potential for adjustment, as different profiled ramps and preloads are a useful tool for adjusting vehicle dynamics. Additionally a degree of pre-load or pre-existing LSD action is built in, and an advantage in very slippery conditions, or where one wheel is off the ground, but is also a disadvantage as it can interfere with ABS and sometimes results in noisy operation in very tight turns. Finally, a mechanical diff that is worked hard requires regular servicing and replacement of clutch packs as they wear.

18.12 Improvements to the Differential System

For the vast majority of WRX owners, the OE differential system is more than adequate for the job at hand. But if taking your car to the absolute limit of its traction potential with a big power engine on the racetrack or drag strip is your aim, some sort of differential upgrade package will reap worthwhile benefits.

STi Plate Type Front Differential

Front Differential

Changing the different on late model STis fitted with either a Suretrac or helical LSD unit is a waste of time or money, unless intending some form of seriouss motorsport where a diff change to a mechanical LSD is made specifically to alter grip/handling characteristics.

For WRX owners, the OE open diff should be filed under R for rubbish in the garbage bin and replaced with a LSD item, boiling down to a choice between a torque sensing (helical/Torsen) or a mechanical plate LSD depending on application. For the bulk of road users a helical diff is sufficient. Helical diffs start at A$1800 and A$2600 for an STi mechanical diff.

Centre Differential

Owners with DCCD equipped vehicles the choice is easy – leave it alone! For tarmac use the OE system is pretty much at the zenith of its performance, and is difficult to see a situation where any realistic performance gains can be made by messing with it. Off-road rally use is a different situation, and a bit out of the scope of this book, but for those with a wedge of cash burning a hole in their pocket, MoTeC comes to the rescue with a complete replacement programmable DCCD control unit. Perfect for Norman no mates and cashed-up pointy heads with plenty of time on their hands to spend hunched over a laptop remapping dynamic torque control maps.

Cars equipped with a VC (viscous coupling) LSD, the option of choice comes straight out of the STi parts catalogue. Available in 10, 12 and 20kg ratings, these heavy duty VC diffs dramatically improves mid-corner stability when accelerating out of the apex, as they better resist large differences in front and rear wheel speeds. Traction in all situations is improved, as the diff can better control engine torque, distributing it to the wheels with the most grip. Such a heavy centre diff is not without its downside, at parking speeds during tight turns the car will tend to shudder as the new heavy duty VC tries to fight against the front axle from turning at a different speed to the rear. An STi centre VC costs around A$1,200 depending on the model year and the stiffness rating required.

Heavy Duty Centre Differential Centres

Rear Differential

Again, cars already fitted with either a Suretrac or mechanical diff as standard equipment need not waste money changing diffs unless chasing specific goals, such as becoming poor for religious reasons.

For the WRX with a VC rear diff, a swap to a mechanical item is a worthwhile choice, increasing grip promoting a more neutral cornering attitude as the rear end drives more aggressively out of a corner. Tinkering around with ramp profiles and clutch pack preloads can further fine tune vehicle attitude. A downside are mechanical diffs can be quite noisy during tight low speed turns, sometimes emitting loud clunking noises. STi mechanical diffs to suit the small R160 housing start at A1,520.

R180 Differential Conversions

Pic R180 Conversion

The availability of low cost secondhand Japanese import parts has made the swap to a R180 rear diff a popular mod, for owners with high power engines and those with earlier cars without the bigger two piston rear callipers. Exact specifications of the individual parts varies between markets and models, so keep the following in mind when undertaking this conversion:

- R180 rear ends from an RA competition model will come without provisions in the rear brake backing plates for ABS wheel speed sensors.
- Early model R180 brake discs have a unique larger inner diameter handbrake drum, along with heavier duty handbrake shoes and mechanisms and will not fit on Version V and later WRX's with R160 wheel hubs.
- Version VII rear brake discs are the same diameter as R180 discs, but use the smaller inner diameter handbrake drum.
- Early model R180 differential drive flange has a larger diameter and different bolt pattern to the R160 tailshaft, requiring drilling in order to fit.
- R180 driveshafts will not fit R160 wheel hubs and R160 driveshafts will not fit a R180 diff.

Differences in drive shaft sizes are as follows:

- R180 Outer shaft has 27 splines and an OD of approx 27.7mm with larger rear wheel bearings and hub flange.
- R180 Inner shaft has 27 splines and an OD of approx 27mm
- R160 Outer shaft has 25 splines and an OD of approx 25.8mm
- R160 Inner shaft has 24 splines and an OD of approx 24.8mm

OE R160 Driveshaft vs R180

18.13 Suspension Tuning With Upgraded Differentials

Upgraded differentials will dramatically change the handling characteristics of your car, especially improvements to the centre and rear differential. As a consequence aftermarket performance suspension parts and settings to suit an OE drivetrain will not be suitable, resulting in a car that is difficult to drive. In certain situations it may exhibit handling characteristics that are dangerous.

As more torque is distributed rearwards, suspension setup must follow more along the lines of a powerful rear wheel drive car, rather than AWD. Sway bar rates, particularly in the rear can be reduced, with a corresponding increase in front bar diameter. This is to transfer more weight back onto the rear axle as understeer is less of a problem courtesy of improvements in differentials. Importantly, rear toe adjustments can be backed off substantially, which should not be more than 0.5mm of toe out per side (1.0mm total). Talk to your suspension supplier for further advice on setup to suit upgraded drivetrain parts.

Conclusion

Improving Subaru's AWD system is another area full of blind alleys and other pitfalls. Not to mention another one of the major cost centres for those serious in the quest for maximum performance. Plenty of patience, research and planning are required to make sure you make an informed decision, and purchase the right parts for your application the first time and in the right order.

Cost effective upgrades such as better quality gear oil and a quickshift are a no-brainer and can be done immediately. Other more expensive items such as the clutch and flywheel normally can wait until you have got the maximum wear from the OE unit before giving it the flick. If you have the engine out for any particular reason have your mechanic check the clutch at the same time.

Gear kits require a real leap in the amount of cash invested, treat this purchase accordingly. If your transmission is going to be apart for a new gear kit, consider saving some money on labour and fit a differential and a new clutch at the same time if this is your intention.

Reality Check

If you have massive amounts of power 300kW or more ATW, drivetrain options become very focused towards the strongest and most aggressive differential setups, in order to transfer all this grunt to the ground. An inevitable downside is the negative effect on driveability around town and during parking manoeuvres. Remember the following points:

- Torsen style LSDs require grip to work and are next to useless on dirt or very slippery surfaces without special driving techniques such as left foot braking while accelerating to preload the differentials.
- 2wd spool conversions are exceptionally hard on the rear drivetrain as 50% more torque now has to be transferred compared to before.
- Plate type LSDs are prone to wear requiring regular adjustment and can be a real handful to drive if not setup properly.
- A 20kg centre viscous coupling will not allow handbrake turns.

Chapter 19

Wheels and Tyres

19 Wheels and Tyres

Bigger seems to be better, if OE wheel sizes are anything to go on. Since its introduction back in 1994 WRX sizes and diameters have inexorably increased, starting out with 14x6" wheels as standard equipment on Version I-III WRXs. Part of the way through the model run of the Version III, 16x6.5" wheels previously seen on STi models were made standard equipment. Version IV-V continued with this wheel size. The Version VI stuck with 16" sizing, but the wheels copped a minor restyle. Wheel size jumped again with the advent of the Version VII, 17x7" for WRX and 17x7.5 for STi. North American WRXs continue to use 16x6.5". Australian and JDM spec Version VIII WRXs continue with 17x7" wheels, while STi variants use 17x7.5" BBS 10 spoke gold coloured wheels.

Despite Subaru slowly getting more adventurous with OE wheel specification, it is still hard to think of an easier way to spend money on your WRX than on a brand spanking new set of flashier wheels and tyres. And unless you really pinched pennies and purchased tyres suitable only for taxis, an improvement in grip should be immediately apparent. Not only that, your investment will be in plain view for you and your mates to marvel at. This improves the visual appeal of your car, while separating it from the rest of the herd, as long as you consider "there's no accounting for good taste". No truer words have ever been said, especially when faced with the mind-boggling array of replacement wheels available on the market. In this chapter we are not going to try and define what constitutes good taste in a wheel, but we will take a look at a few important points.

Pic Low Profile Tyres

19.1 Wheel Rims

Offset

Wheel diameter and width is appreciated by most, but a further dimension, known as offset is less well understood, and of importance for the WRX when selecting replacement wheels. Offset is the distance between the mounting face of the wheel rim (fits up against the wheel hub flange) and actual true centre of the wheel rim – as seen from the end of the wheel rim. Standard offset for a WRX wheel is 55mm, while current model STis with 17x7.5" rims have a slightly smaller offset of 53mm. Offset should not stray too far from the standard amount, as this can place additional strain on wheel bearings (traditionally not a WRX strong point, particularly at the front) and can adversely affect suspension and steering performance.

Hub Spigot

How the wheel fits onto the wheel hub spigot is important – many aftermarket wheels are made to fit a wide range of brands and models, and don't often match up with the OE wheel hub 100%. Vehicle manufacturers design this spigot as the major load bearing connection between the wheel and the hub. Wheel nuts are designed to hold the wheel onto the hub spigot, and not to support the entire weight of the vehicle. Incorrectly matched wheel centres can lead to weird out of balance problems, wheel stud fatigue and in extreme circumstances actual failure. Spacers or adaptor rings are available to ensure a proper wheel hub fit, check with your wheel supplier if unsure.

Large Diameter Wheel Rims

When changing to new wheels and tyres, it is always the intention to try and maintain the same rolling diameter of the OE wheel/tyre combo. Changes in rolling diameter effects speedometer accuracy and can change overall gearing. Larger diameter rims are accommodated by using tyres with a progressively smaller and smaller aspect ratio or profile. Moving to a lower profile tyre on larger diameter wheel rims brings a corresponding changed to handling characteristics. Tyres with a higher aspect ratio tend to have sidewalls that deform and move around under cornering loads. This deformation very quickly starts to interfere with the tyres contact with the road, reducing grip and tyre life as tortured rubber scrubs across the road squealing for mercy.

Unfortunately, low profile tyres are not all beer 'n skittles. The tyres sidewall is an important part of a cars suspension. Subaru have settled on shock and spring rates that were devised with OE tyres in mind. No great leap of imagination is required to realise that a reduction in sidewall height reduces ride comfort. Additionally, a shorter sidewall still has to deal with the same dynamic weight loadings as a taller one, necessitating that it must also be far stiffer, further impacting on ride comfort. This is not to say that low profile tyres are going to turn your WRX into a boneshaker, but sharp operators will spot the difference immediately. With larger wheel rim diameters, weight increases, with a 17" wheel typically weighing 5kg more than a 16" unit. As this is unsprung weight, it has the effect of reducing suspension responsiveness (see *Suspension* Chapter), and potentially be an extra 20-25kg for the car to lug around. Finally, the use of 18" or 19" wheels will render the rims more vulnerable to damage from potholes and road debris.

As with most aspects of WRX enhancement, rim diameter comes down to the owners intended usage and preferences. As a general guideline:

- 14” rims are best for dirt roads and rally use.
- 17” rims are a good all round choice for most road uses.
- 18” rims are for high performance applications / track work.
- 19” rims and larger fit into the realm of automotive fashion.

17” Wheels remain a good all round compromise between performance and durability. 18x7” wheels are about the largest wheel rim that can be fitted on a WRX without some sort of bodywork modifications. Fitting larger rims than this size can involve rolling the “lip” on the inner edge of the wheel arch or other procedures to increase clearance.

Rolling Rear Guards

19.1.1 Rim Design and Cleaning

OE WRX brake pads will “dust” the wheels very quickly. Most performance pads will do the same thing. It always surprises us how many people fit wheels to their cars that while beautiful to look at, are an absolute bugger to keep clean. For us, we’d rather drive our WRXs than spend hours cleaning wheels. For our money, ease of cleaning is worth sacrificing a small amount of style. Taken in this light, the somewhat un-adventurous OE wheels are admirable, un-offensive looking and easy to clean.

19.2 Tyres

The WRX is a relatively noisy car, transferring a reasonable amount of road noise etc into the cabin. Certain brands of performance tyres are better or worse in this respect, and often needs a bit of research to discover tyres that perform well, without driving you mad.

19.2.1 Speed Rating

Subaru fit V rated tyres as standard equipment on the WRX. These are industry rated to be capable of speeds up to 240km/h, at the same time as handling dynamic loads and stresses placed on the tyre at these speeds. This rating is quite adequate for a standard WRX in normal use. If you have a heavily modified car, or have a hankering for breaking the land speed record, a move to Zeds are a good move. Z rated tyres are more expensive than Vs, but have a much wider range of high quality performance tyres to suit 16,17 and 18" wheel rims.

19.2.2 Tyre Pressures

On any performance car, tyre pressures should be checked at least weekly. Surprisingly enough, factory recommendations haven't changed since the switch from 14" to 16" and even recently to 17" wheels. The standard pressures on a cold tyre for all models through to current is 33psi front and 32psi rear. There is a good deal of debate as to tyre pressures in performance applications, with numbers as high as 45psi suggested for use on the racetrack! Here is our two cents worth:

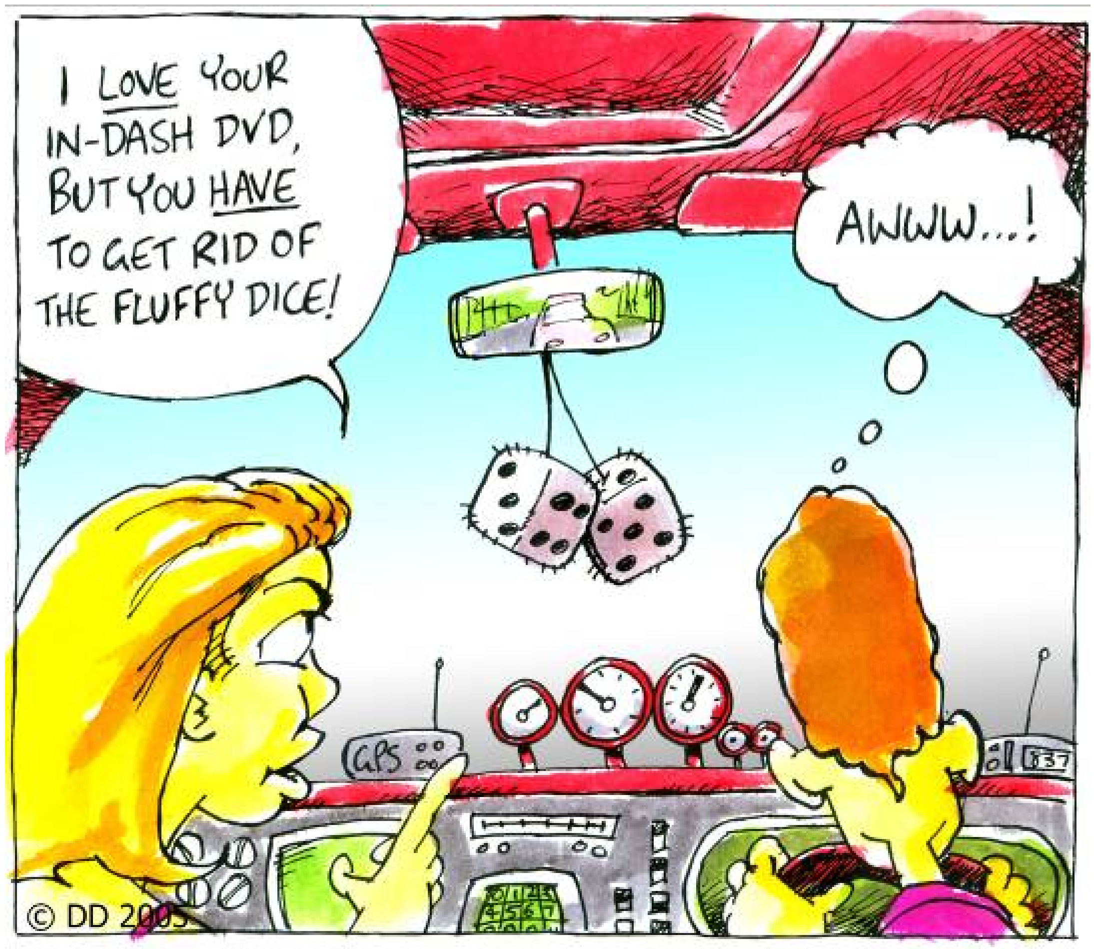
- Factory pressure recommendations are minimums. Never allow tyre pressures to fall below these levels. Low profile tyres are very sensitive to pressure changes and are very easy to damage when low on air.
- Small increases in pressure over recommended slightly decreases ride comfort, but grip improves. You need to play around with this and make up your own mind on this.
- Pressures approaching 38-40psi can start to cause uneven wear of the tyre, as some distortion of the tyres face will occur.

19.2.3 Tyre Replacement

The WRX, despite having AWD will still see the front tyres wearing before the rears due to the competing stresses of braking, accelerating and steering. It is worthwhile to periodically rotate the tyres, and is most conveniently done at the same time as an alignment check and wheel balance by your service workshop. Regular tyre rotations will mean that all four wheels will require replacement at the same time, but wallet pain aside, this is a good thing. Mixed and matched tyres have no place on a high performance car such as the WRX.

As a last word, it is very difficult to try and write anything definitive about particular tyre products, as technology is moving rapidly in this market, and today's hot news are tomorrows old news. As with most products, you get what you pay for. If you buy a premium tyre from a respected manufacturer, you will pay a premium price, but are assured of excellent results. As new manufacturers join the performance market, some real performance bargains may pop up from time to time. These need careful scrutiny. Don't be tempted to buy simply on the recommendation of one person. Shop around and get second and third opinions, once you are sure, use it to your advantage and you could enjoy top performance at a fraction of premium brand prices.

Chapter 20



The Interior and Miscellaneous Improvements

20 The Interior and Miscellaneous Improvements

Prior to the advent of the Version VII the WRX interior could never be characterised as having delusions of grandeur, being inextricably related to the more pedestrian non-turbo model Impreza. Early model Version I-II in particular were very basic, with loads of shiny grey and black plastic, cloth seats and threadbare carpets. Things improved in the shape of vastly improved front seats and re-trimmed rears for the Version III, while for the Version IV to VI a completely new dashboard and instrument cluster featuring white faced dials was lifted from the Forester. It was not until the arrival of the Version VII that the WRX got a long-awaited fresh interior. Further tweaks have been made in the form of new HVAC controls for late build Version VIII cars.

Ignorance Is Bliss – a War Story
Some people consider the addition of extra gauges unnecessary, a bit "Squadron Leader Biggles, ready for take off!" But their importance as a health indicator of the car, particularly a highly-stressed engine like the turbo WRX, should not be underestimated. Some time ago, a WRX limped its way into MRT's workshop sounding very much like a chaff cutter. Further investigation revealed the engine was only running on three cylinders. A compression test was performed and the results were tragic. No compression on cylinder No2 – a busted piston, yikes! It was time for a bit of detective work, as pistons don't fail without a good reason. The fuel and ignition system checked out, as did engine management electronics, which left the boost control system as the most probable culprit. The cause of the failure was immediately obvious, a small plastic "T" piece had failed in the wastegate pressure control circuit, leaving the turbo free to make upwards of 1.5bar of boost on a stock bottom end. The owner did mention that he thought the car was performing exceptionally well, but thought nothing of it. The moral of the story is that supplementary gauges, in this case a boost gauge, are an excellent way of keeping an eye on what is going on under the bonnet. Particularly on highly modified engines.

Version VIII Interior

20.1 Additional Instruments

Basic instrumentation fitted to the WRX is exactly as the name suggests, basic. Late model GDA/B cars have a large centrally mounted tacho, while speedometer, engine temp and fuel level gauges are laid out either side of the tach.

Version VIII Instrument Panel

20.1.1 Boost Gauges

One of the most popular interior modifications, first on the list for most owners is a boost pressure gauge. Boost gauges are available in a multitude of shapes, sizes and flavours, featuring white facings, carbon like textures and a variety of back light configurations. What does matter, is spending a few extra lira purchasing a good quality gauge. Dubious accuracy aside, cheapy boost gauges tend to suffer from fluttery needles and a reluctance to go back to reading zero when the engine is switched off. Gauge resolution is important too, many owners choose to fit small diameter boost gauges that read all the way from vacuum to 2.0bar and more. While snazzy and something to marvel at, in practice can be a little difficult to read on the fly as at OE boost levels only 25% of the gauge scale is in use.

Pic Turbo Boost Gauge

Once you've chosen your boost gauge, the next problem is where to mount it. Popular options include on the drivers side of the dashboard, in the small space between the "A" pillar and the instrument cluster surround. Colour coded pods that match dashboard finish have been available for some time now to suit either LH or RH drive, and accept a standard 52mm gauge. This type of installation is neat, low key and costs around A$88 for just the older. Alternatively, gauge mounting "cups" can be used to attach a boost gauge to the steering column or "A" pillar trim. Autometer gauge cups are available finished in either black or polished alloy starting from A$55. Boost gauges themselves can vary wildly from A$85 for a cheap one, up to A$400 for a super duper all singing, all dancing electronic unit featuring stepper motor drive.

A boost gauge is a useful device for a number of reasons. They are a bit like a "power" gauge, and its fun to watch the needle track across over into the right hand part of the scale. Secondly, they provide notice of any change in boost pressure, and are a good health indicator of your engine. Too much boost can easily occur if certain boost control hoses come adrift, and can quickly result in engine damage. Underboosting, on the other hand can be indicative of leaky pipes and connections, wastegate control system issues or simply a sickly turbo. This can be difficult to determine using the old "seat of the pants" method while driving through urban areas, without becoming a complete hooligan. In comparison, a good quality boost gauge is a model of clarity and at a glance will quickly confirm if all is well.

20.1.2 Temperature and Pressure Gauges

Pic Multiple Gauge Pod

Further information about current engine operating parameters can be displayed by additional gauges monitoring fuel and engine oil pressure, engine oil and coolant temperature, exhaust and engine air temperature. Conveniently, gauge pods are available that fit neatly into the OE dashboard with a standard appearance are capable of mounting three 45mm gauges. Aftermarket pods are available to suit 52mm gauges. Possibly of more use to owners of highly modified cars or those that regularly hit the track, a combination of fuel pressure, oil pressure and boost pressure is a good starting package.

20.1.3 Electronic Displays

One area that has grown considerably since the first version of Training WRX is the availability of good quality digital displays. Pick of the bunch for owners with Version V and later WRX is EcuTeK's in-car Delta Dash kit. This is a stand alone digital display capable of displaying all engine operating parameters, plus a couple of separate inputs, in both real time, or as logged data. Less sophisticated systems are available such as one marketed by AVO Turboworld, consisting of a 50mm gauge sized head unit that can display boost and a couple of temperature parameters along with a waterspray control function. In some cases, information is often available from EBCs, Fuel/Air Controllers and aftermarket ECUs. (See *Engine Management* Chapter for more details) Stand alone Delta Dash costs around A$1,290.

Pic Delta Dash In-Car Display

Another item that has cropped up since the first edition of this manual are dedicated "shift light" boxes. These come as a kit and include all of the gubbins necessary to set up a dash shift light. More sophisticated units allow different user defined shift points on a gear by gear basis to allow for differences in the speed at which the engine accelerates. Version VIII STis have a driver adjustable shift light and audible chime incorporated into the tacho from standard. Aftermarket shift light kits start from A$200. More sophisticated shift light kits will have a cluster of 4 or more small LED's that light in sequence as the engine approaches its preset shift point. The idea being that it gives the driver sufficient warning in order to change gears before bouncing off the RPM limiter.

Pic Staged Shift Light

This is about as far as you can go without opting for a full race dash conversion a la Petter Solberg.

20.2 Turbo Timers

As already touched on in the *Turbocharger* chapter, the main benefit of a turbo timer is to free the driver from having to sit in the car while it idles down to cool the turbocharger after hard use. It takes an adjustment to your psyche to walk away from your car when it is still running, but other factors are of more immediate concern: The timer may interfere with an alarm you have fitted or any existing OE security systems. Some alarm systems feature an inbuilt turbo timer, with the aim of providing protection for the vehicle while the engine is still idling down. In some jurisdictions it may be in fact illegal to leave the car unattended while the engine is still running. Stand-alone turbo timers are available from A$140 up to A$260.

20.3 HVAC

This is outside the scope of this book. Some markets such as Australia, get air conditioning as standard. In other markets it is an expensive option. Automatic climate control has been a feature of STi models since the Version V.

20.4 Seats

The standard seats suck. This used to be the generally accepted view, until the advent of the Version III. Since then only half of WRX owners think the seats suck – a 50% improvement! Lack of lumbar support would have to be top of the list for complaints. If you are one of the sufferers, there is a cheap fix, an expensive fix and a very expensive fix.

Version VIII STi Seats

STi Seats for Young Enthusiasts

20.4.1 Seat Improvements

The cheap fix is finding a reputable auto trimmer in your area, and have him add lumbar support to the driver's seat. This involves removing the seat from the car (4 bolts and a wiring harness depending on model), unclipping the backrest cover and pulling it halfway up and off the seat. If you watch the auto trimmer do this you will understand why we say the seats suck: the seat is only anchored to the rails on one side; with the cushion simply a piece of moulded foam over a pressed metal frame; with the cover glued to the foam, which sticks to it in little clumps when you try and pull it off. Don't panic. At this point your trimmer will be able to build up a lumbar support "pad" on the inside of the backrest. A little trial and error with your backside should see the trimmer able to fit the insert where you want it, and at the size you want it. At this point the trimmer fixes it in place with glue and replaces the cover with yet more glue. You'd expect this to create little dimples and bulges where the chunks of foam stuck to the seat cover, or are missing or in the wrong place. Amazingly enough, this doesn't seem to happen.

Once the seat is back in the car you will need to drive with the windows open until solvents in the glue evaporates, but the lumbar problem is basically solved. This kind of solution costs A$75 and a couple of hours, which is not much outlay for the big improvement in comfort.

The expensive option is to replace the driver's seat altogether with either a quality sporting seat such as Momo or Recaro, or with a no compromise racing seat. In Australia even a basic Recaro is A$1,250 fitted, which compares most unfavourably with the re-trim option. However, you do get a quality seat that you could take a long term view on, as quite conceivably it can be taken out and fitted to your next car. The same applies to a racing seat. The problem with these specialty seats is that while they have great pose value, they are about as comfortable as sticking your butt in a vice. But they come into their own when lateral "G" approaches 1.0, even if that doesn't happen very often on the road.

Pic Recaro Seats

This brings us to the very expensive option. Two Recaro-type seats, in your fabric of choice, along with a re-trim of the rear seats and door panels, will cost a lot of money, perhaps upwards of A$3,500. Add another couple of grand if you like the smell of leather. And given that you have just re-trimmed the whole car, you can't really take them with you when you sell. But this will make your WRX look like a A$100,000 car, instead of simply just going like one. Professional custom interior specialists such as Roman Autotek here in Australia can achieve just about any conceivable interior seat and trim combination you desire. Find your local reseller of premium interior equipment and discuss your requirements.

20.4.2 Harnesses

Race harnesses are right at the limits of the scope of this manual. Some people like to pose in them, while a few use them for track days. And after all, the standard seats do contain cut-outs for them. Fitting and use of these belts require some special techniques. (See *Track Days* for more information.)

20.5 Bling

Prodrive Battery Clamp

Prodrive Oil Filler Cap

STi accessories are certainly the interior accessories of choice for those so inclined, including those Barbie pink badges! A dizzying array of genuine bits 'n pieces exist, from floor mats, gearshift knobs to ignition keys and key chains are available. Internet searches, or even thumbing through an indecipherable Japanese accessory catalogue, revealing a whole new way to spend your hard earned bucks.

Pic Accessories Galore

20.6 ICE

This is a complete book in itself. In Car Entertainment (or ICE) is very much a matter of personal taste. Some folk consider it so important as to warrant spending several grand on upgrading ICE before even considering driving a new car. After all, to be fair this is, within a small margin, several grand more than the manufacturer spent on the stock unit. At the other end of the scale there are drivers that only listen to AM radio talk-back shows while in traffic.

We must also be honest and admit that we're just not going to do justice to the ICE freak. The market changes on a minute by minute basis, with keeping pace with the rapid advance in audio technology an almost impossible task. Anything written here would be almost out of date before the ink was dry.

What we can give you is a few opinions of our own though. As we've hinted, Subaru has not spent a huge amount of money on the ICE in the WRX, especially early on in the piece. Factory sound system options for Version VI and earlier cars were very limited, although empty tweeter grilles fitted to the front door trims were thrown in at no extra charge. Some models came with an option to replace the standard AM/FM radio cassette head unit with a basic Panasonic single CD player. But on the whole, most owners with early model cars started out all with the same cheapo radio/cassette unit.

Things did improve with the introduction of the Version VII, with Subaru finally seeing fit to specify an OE sound system incorporating a CD player that could almost be considered adequate. Normally in most cars even the better quality units fitted to late model cars would be glaringly inadequate. With the WRX, things are different. It is a noisy car for starters, particularly on poorer surfaces, or at high RPMs, especially once modified with exhausts and intakes. You can make it quieter, but only by adding additional sound deadening, at the price of increased weight, which rather defeats the cars high performance purpose. Therefore our ten cents worth is that the WRX is not a particularly good car to be spending loads of money on upgraded ICE.

20.7 Alarms and Other Theft Protection

The problem with any discussion of car alarms is that products and laws differ markedly country by country, and we want this manual to be useful to any WRX owner, or would-be owner anywhere in the world. However, it is true to say that there are some common areas that can be discussed. Given too, as the WRX was what seemed like one of the most stolen cars on the planet in the early days, some readers would ask why the subject was not touched on. So here we are.

One thing that is true, early model WRXs are extremely vulnerable to theft. Just about anyone above the age of a kindergarten kid wielding a screwdriver could break into and steal one without a lot of effort. The introduction of an OE immobiliser in Version IV, V and VI merely elevated the technical expertise required to knock one off up to primary school levels. It is exactly this reason why early WRXs are the conveyance of choice for joy-riders, thieves, ram-raiders and get-away drivers alike.

Theft protection varies from some sort of immobiliser, cutting fuel or ignition, right up to the spectacular South African "Blaster", which shoots two metre-long flames to deter would-be car jackers or even a trunk monkey or two. Instead of trying to describe the whole spectrum of choices, we'll concentrate on the most likely options.

20.7.1 Passive Theft Deterrents

Steering wheel locking bars, brake pedal locks and armoured collars for the ignition lock barrel to prevent hot-wiring all work to varying degrees, but mostly fall into the category of a "nuisance" factor for professional thieves.

An identification system called Data Dot, as used by Subaru Australia for the past three years, is a procedure whereby vehicle information such as VIN numbers are encoded and applied in the form of microdots in multiple locations around the vehicle. Done to discourage re-birthing of stolen cars and major components, it does nothing to protect against car-jacking or joyriding.

Data Dot Warning Label

Electronic immobilisers usually isolate or disconnect power to the fuel system or starter motor. Most range from moderately annoying to downright child's play to bypass and defeat, depending very much on the quality of the immobiliser and the original install job.

Audible alarm systems are intended to scare off would-be thieves, but the reality is these days most people filter out completely blaring car alarms, with legislation in some countries further restricting the maximum noise they can make. Some systems feature an extremely loud siren for the vehicles interior, presumably to make the job of trying to bypass the system as uncomfortable as possible. Again, the very best professionally installed systems are moderately difficult to disable but by no means impossible.

20.7.2 Remote Tracking Alarm Systems

There are three different systems that all work on a similar theme, an alarm system connected to either a GSM digital phone, radio transmitter or satellite transmitter which activates when it senses a theft attempt, alerting either a monitoring station or the owner directly. Each of these systems has their pros and cons. Highly skilled thieves can find and deactivate transmitters in minutes, others can be defeated by commercially available cellular jammers, or simply by moving the car into a garage or underground carpark. Depending on the type of system, in the situation of a GSM system, the car will either attempt to call the owner with an automated warning, or a security monitoring station will be alerted.

The key to their success lies around the units ability to connect to the owner or base station (hard when out of range or unable to connect through poor reception). There are also only so many places that the transmitter can be concealed within a WRX and professional thieves know most of them. On more than one occasion owners have come back to find a black box sitting on the side of the road next to where their pride and joy once sat.

20.7.3 Original Equipment Security Systems

Subaru has certainly lifted its game here as depending on the market, from the Version VII onwards a uniquely encoded ignition key interfaces with the factory computer, making it far harder to hotwire or bypass. In addition, Australian delivered WRX and STi models have a key pad immobiliser system that requires a four digit code to be input in order to start the car. It also features an anti-hijacking mode, activating if the drivers door is opened while the engine is still running, at which point the system will begin counting down audibly, culminating in a shut-down of the engine. Taking the negative approach, such a system is of no help if you are ambushed at the traffic lights, and dragged bodily out of the window, or if the four digit code is extracted by menace. Still, it's a step in the right direction.

Pic Key Pad Immobiliser

One thing is for sure, by and far poorly installed alarm systems cause more problems than any other type of aftermarket accessory. Don't just buy based on price and features alone. Check out your installer's reputation and guarantees. And don't forget the old security standby of a karate club sticker on the back window, or the comforting reassurance of a nice strong metal torch carried around in the door pocket of your car.

20.8 Lighting Improvements

To put it bluntly, the standard WRX headlights suck. It is ridiculously easy to out drive the feeble OE lights, even with a completely stock car in dark and foggy conditions. Adding a whole heap more engine power and suspension grip quickly makes the OE lighting system a dangerous liability. Other important considerations when thinking about headlight upgrades are:

- Your age; a 40 year old male has the same night vision as a 20 year old wearing sunglasses.
- Night blindness of varying degrees affects more than 50% of females.

There is a very simple rule in vehicle lighting – if you can't see it you cannot miss it!

The Impreza range uses a variety of lighting combinations depending on year model and configuration; early model Version I to VI WRX and STi feature a single light assembly that uses a H4 halogen globe insert combining high and low beam into one bulb and reflector assembly. Version VII bugeye STi differed by having projector style lights with H1 halogen globes for low beam and halogen HB3 high beam globes. Version VIII and later WRX and STi use a split H1 halogen globe for low beam and HB3 halogen for high beam.

20.8.1 Headlights

Serious Headlights

A commonly held belief is that by simply upgrading globe wattages, dramatic improvements can be made to the OE headlights.

There are several basic electrical lessons to remember here. In order to generate more visible light by upgrading bulb wattage, you automatically increase the amperage or current draw on the vehicles electrical & wiring system. This is an inescapable relationship governed by Ohm's law. There is a very real risk that upping bulb wattage will significantly increase the temperature of the headlight reflector assembly, associated wiring, switches and relays. Ultimately this can also lead to overloading the alternator and OE battery. Even globe only upgrades that claim to be x% "blue", Xenon charged, or Xenon filled are a complete waste of money, and achieve an increase in lighting performance simply by increasing globe wattage over standard.

High Intensity Discharge Xenon (HID)

In order to really improve the lighting performance of the WRX, a more high-tech approach is required. The best example of this being HID lighting, as fitted to high end vehicles such as BMW, Mercedes, Lexus and exotica such as Porsche to name a few. HID lights are easy to spot by their distinctive blue and white hue, while halogen bulbs in comparison produce light that is creamy in colour.

Tungsten Filament Globe

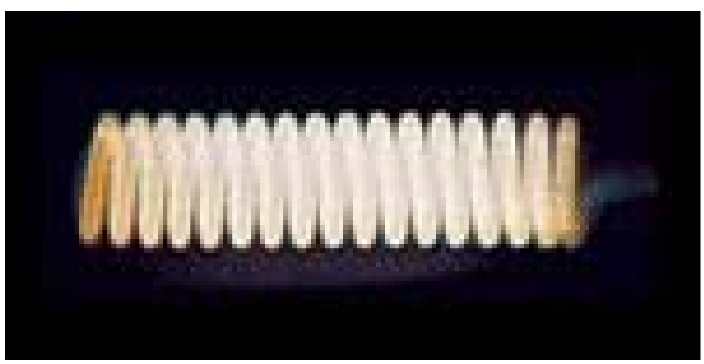
Xenon Plasma Arc

Benefits of switching to a HID headlight system include:

- Increased lighting "footprint" compared to a conventional low beam spread.
- Improved lighting penetration and "distance" compared to conventional low beam.
- Long system life – typically 8-10 years for a high quality well engineered HID system.
- Greatly reduced load on the vehicle electrical system, approximately 35watts for HID compared to 55 watts or more for a halogen bulb.

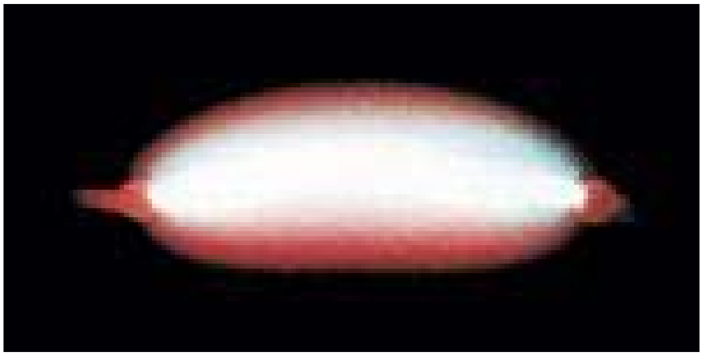
Subaru Headlight with Xenon Insert

Normal halogen light globes generate light by passing a current through a thin strand of tungsten wire strung between two poles inside a sealed glass bulb filled with an inert gas. Current flowing through this filament becomes very hot, and is the source of illumination used in most OE headlights.



Tungsten Filament Light

HID Xenon lights in comparison have no filament, using instead two electrodes inside of a glass capsule filled with Xenon gas. A special transformer (also known as a ballast) generates a voltage high enough to jump the gap between the two electrodes, creating an electrical arc that excites the Xenon gas producing a brilliant blue/white light. System current draw is at its highest when first switched on as the HID system warms up and initiates the arc. Once "lit", electronics in the transformer modulates system operation, using only the minimum amount of vehicle power in order to sustain the Xenon arc.



HID Arc Close-Up

Units of Light Measurement

Candela (cd) – is the international unit for expressing luminous intensity, and has been in use since the very early days of lighting. Back then a standard candle of a fixed size and composition was used as a benchmark for evaluating the intensity of other light sources. The higher the candela number, the brighter and more intense a light source will be. Perhaps Subaru lighting engineers used the amount of light generated by a candle burning inside a WRX headlight as the yardstick when designing their own systems?

Lumen (lm) – another international unit expressing the luminous flux (or the quality of visible light produced) of a light source. For example, a standard dinner candle produces about 12 lumens, while a household 60watt tungsten filament bulb produces around 830 lumens. As the lumen rating of a light source increases, so does its brightness and clarity.

Kelvin (K) – some may recognise this as a measure of thermodynamic temperature, but it is also used to express colour as a temperature. As heat increases, so does the colour and intensity of the light it produces, passing through shades of yellow and green progressing finally to blue and violet. As a general rule of thumb, the higher the temperature, the whiter the light produced. At well over 5000K, the light produced very closely matches that of daylight. There are practical limits for applications such as headlights. Setting fire to pedestrians or roadside flora and fauna by harnessing the power of the atom within your headlights is not desirable.

An example of the differences between conventional Halogen and HID Xenon are demonstrated by the following:

Unit	Conventional Halogen	HID Xenon
Power Consumption Wattage (W)	55	35
Lumens (Lm)	1450	3200
Colour temperature (K)	3250	7000
Irradiated light colour	creamy white	bluish white
Life expectancy	400 hours	2000 hours +

Aftermarket HID Systems

There is some controversy surrounding the validity of retrofitted HID globes into headlight reflectors originally designed for Halogen bulbs. (All factory HID setups use a projector type housing which better harnesses and directs the light output more accurately). While this is technically true to a point, the reality is that HID conversion kits comprehensively out-muscle halogen globes, more than making up for any compromises inherent with reusing the original headlight assembly. All high quality HID kits are designed to minimise this effect. Like most parts, you get what you pay for; there are high quality HID systems and then there are the cheap and nasties. Look for other factors such as a solid warranty policy, readily available technical support and supply of replacement parts. This is important if you wish to transfer the HID kit over into a new car that requires a different set of Xenon globes.

One last caveat; in most countries road regulations governing headlights can be extremely restrictive in what can and cannot be done with headlights. Most HID Xenon systems are marketed as being suitable for off-road, competition or show use. Check your local regulations and HID reseller for more information. A XenonOz headlight conversion kit for a WRX costs around A$1,495.

20.8.2 Driving Lights and Spotlight Covers

Spotlights or spotlight covers set into the front bumper are a key styling trait of Subaru's performance models. Trouble is, in the case of the WRX the bumper mounted spot lights are as useless as an ashtray on a motorbike. STi models don't have fog lights, and instead come equipped with blanking covers, paying homage to earlier homologation models that ditched the fog lights, in the quest to reduce weight.

Apart from the options already mentioned, substituting the OE fog lamps (if fitted) for a proper set of driving lights is another worthy consideration. A number of kits are available based around fitting proper reflector units by lighting companies such as Cibie or Hella.

Key issues of doing such a conversion are;

- Wattage - the OE spot lights use 55W globes, and upgrading to 100W halogen driving lights can overload and burn out the wiring. A replacement wiring loom is vital with this type of conversion.
- Ease of fitting - Subaru changed the design of the front bumper with the Version VII, and it's important to ensure you get a kit that will fit your car without drilling or major modifications.
- Wiring - If you just swapped out the OE spot lights, the newly installed driving lights will switch on and off through the OE fog light switch on the dash. This is somewhat undesirable as it is hard to hit in a hurry. A better solution is to get the driving lights wired in so that they switch on and off with "high beam". As with all modifications, the legality of lighting changes should be established in your country of residence.

Foglight Conversion Kit

20.9 Wings, Spoilers and other Attention-Getting Devices

Most WRX owners seem to thing that spoilers and air dams are a good thing. They certainly perform a few useful functions:

- The lift the appearance of what is, after all a somewhat bland looking Japanese econobox, into something that has genuine road presence.
- On the track, or at very illegal speeds they can provide useful additional stability.

On the negative side they can also:

- Attract the Police, thieves and vandals.
- Cost a lot of money.
- Look cheap and lend a somewhat pathetic, wannabe look if done badly.

In a perfect world, people would be able to (safely) dress their cars up as much as they want, without it making any difference to the law. Unfortunately we live on planet earth, and so do you. That said, we have no problem with the art of making a plain Jane Japanese commuter look like it has just been driven off the TOCA grid or a closed road stage in San Remo. We think these cars look great. It shouldn't be necessary to buy a Porsche or Ferrari to have street presence, damn it!

Chapter 21

Track Days

21 Track Days

Let's face it; these days speed is an issue that is seriously on the nose for those purporting to be politically correct. Not a day goes by without sensationalised articles featuring either in the daily scandal sheets or on some second-rate TV current affairs program, trumpeting the dangers of high powered cars. Forget world hunger or terrorism, speed is the new evil. So much so, around certain dinner party conversations suddenly admitting to dumping toxic waste, is generally received more favourably than revealing a love of driving fast! Police radar and laser, speed cameras, Volvo drivers, and card carrying members of the local bowling club four up in a Toyota Corolla; anyone driving in a hat and just plain old traffic congestion, all conspire against one's personal freedom to use a WRX like a complete and utter hooligan.

To enjoy driving one's WRX in a spirited and competitive manner while avoiding incarceration or the more severe effects of "deceleration trauma" look to the racetrack. We do not condone foolish behaviour on public roads that endangers the lives of passengers or other road users. What we do encourage is the use of a racetrack as a means of enjoying everything from a stock to a wildly modified monster tune WRX to its full potential, in a relatively safe and controlled environment. Thrashing one's pride and joy within an inch of its life may not appeal to all owners, but not much else comes close to the adrenalin rush of punting hard around a racetrack. Also, the good-natured opportunity to beat seven shades of stuffing out of your mates should not be overlooked.

Drag Racing

Devotees of drag racing may feel a bit left out as we have chosen not to cover this form of motorsport. This is done specifically because it is out of our sphere of knowledge, and best left to those better informed than ourselves. That being said, good timeslips are a product of much the same concepts that a track racer strives to attain, that is maximising of tyre grip, useable engine power and correct driver technique.

21.1 A Track Addict Speaks

To get a good feel for the addictive properties of track racing, listen to someone who's already hooked, err, enthusiastically involved. Here, in mostly his own words, is Brendan Helsham's story.

"After many years racing karts, I started my 'car' motorsport career in the Australian Grand Prix Rally in 1998. Later that year, I got stuck into the NSW CAMS Supersprint series run by a variety of clubs in the greater Sydney region. By 2000, the WRX Owners' Club in New South Wales was running its own series. Supersprinting is a step up from a drive day or track day, and involves getting the best lap time, but without the expensive risks of wheel-to-wheel racing. In 2000 the NSW WRX Club ran three classes based upon tyre choice (Road tyres; Type R tyres and Slicks), everything else was free.

Engine modifications are free in Supersprint rules, within the limits of safety and roadworthiness. Since I bought the car from new in December 1996, the engine has undergone a number of enhancements. In its present set up the engine is fully re-built in 'monster tune' spec, with a VF-22 turbo, closed-deck block, forged pistons, strengthened conrods, STi V3 camshafts, modified timing belt tensioners etc. An additional fuel pump was required, as were 500cc Nismo injectors, fuel rail modifications, surge tank, and so on.

A key component of this rebuild was the MoTeC M48 Pro ECU. This ECU has a data logging facility so I can capture all engine related information onto my laptop and email it to MRT Performance for analysis after I have been racing. In extreme cases, I can make small changes to the engine program if conditions are such that I need to adjust certain parameters at the racetrack.

Greater engine performance exposed weaknesses in other areas. One example was that the engine started to slow down due to overheating, caused by being run harder on a particularly hot day. Part of this was the initial conservative settings on the MoTeC engine management system. It had very low thresholds to high engine temps or inlet air temps and *would reduce turbo boost and ignition timing when these thresholds were reached. This was first noticed in the February 2001 test prior to the GP Rally. Over the course of the next few months, the following changes were made to allow the engine to run cooler on the racetrack:*

- *Manufactured a larger intercooler bonnet scoop*
- *Installed a splitter in the intercooler bonnet scoop*
- *Fitted an air duct chimney to the turbo from an MY94-96 model*
- *Tested different intercoolers*
- *Adjusted MoTeC thresholds*

*For Supersprints I chose to compete in the Formula "R" tyres class. Essentially, these are road legal racing tyres with big block tread patterns and soft compound rubber. Using these tyres can improve your lap times by up to three seconds per lap over road tyres, but the downside is that you are starting to expose other limitations in your WRX and will need to make additional modifications to cope with the extra grip generated by the softer tyres. So I began a project with Whiteline to rework the suspension of my old MY97 WRX.(*Becoming the first in a series of P-REX project cars. Ed.*). The main aim of this project was to provide the best compromise between road use and using the car as a "weekend warrior". Along the way we tried many different things, some worked and some didn't. We also learnt a lot about the car and the way it responds to even the smallest changes.*

At the start of the project, my car still had plated front and rear LSDs and a 20kg heavy duty centre diff. With this set-up, the car oversteered like crazy. The diffs had virtually turned the car into a rear wheel drive car. This meant that we needed a lot more roll stiffness at the front, while alignment settings on the back required significant adjustment before going back to the track.

A rear sub-frame lock kit was also developed when the boys at Whiteline noticed an empty hole in the chassis and a corresponding captive nut on the other side of the rubber bush. When this lock kit (essentially a special bolt) was installed, it actually straightened the car and made it easier to perform accurate wheel alignments. An obvious trade-off with this was the increase in NVH when driven on the road. As it is easily installed and uninstalled, this was not a problem.

We ventured back to the track for a second test once a new front adjustable 24mm swaybar was designed and manufactured. We also changed the rear springs from 220 pounds to 225 pounds (the front springs were left at 270 pounds). This test session was much more encouraging as the car behaved much closer to what we were hoping to achieve. A few more tweaks to the settings and we were ready to go racing.

The first Supersprint outing with the new package resulted in 2nd place in my class. The next two Supersprints resulted in 1st place in my class on both occasions. We were definitely on the right track and looking forward to the full season of racing in 2001, starting with the Grand Prix Rally in February.

Unfortunately, the NSW WRX Club changed the class structure for the upcoming 2001 season of racing. What this meant to us was that we would have to revert to standard diffs to run in the class that we had planned. The new class structure was much more specific on modifications and tyre choice. There were now four classes that loosely follow the description of "standard", "modified", "highly modified" and "open". Because of my existing modifications to the engine, I could not run lower than Class 3 and because of the design goals of P-REX, we could not be competitive in Class 4 unless we ran slicks and coilover suspension, so the diffs had to go and Class 3 it was.

The drivetrain was changed from the highly trick set up with STi RA ratios and plated LSDs, to a stock standard WRX set of ratios and viscous couplings. Later in 2001, the gear set was replaced with one from a version VI STi. These STi ratios work a lot better on the racetrack, and this modification was allowed within the rules for Class 3.

When the LSDs were in the car, the original front brakes were adapted and fitted to the rear. MY99 four spot front calipers were fitted to the front of the car. This provided sensational braking performance as the braking load could be shared through the drivetrain. After the return to standard diffs, there was far too much rear brake bias. We had to revert back to the original rear brakes. One consolation of this was that I regained my handbrake. Some other subtle modifications to the brakes were the fitment of "knock-off" springs to improve driver confidence when driving at the limit on the racetrack.

Removing the LSDs meant that the suspension had to be re-sorted to work with the standard diffs and we were running out of time. There was a track day early in February that we managed to get ready for and reverted to 22mm front swaybar and 24mm rear swaybar. We had returned to 220 pound rear springs and Whiteline had designed a lower front strut brace that was fitted.

Off to the 2001 Grand Prix Rally. The car balance was superb throughout the event, whether it be on tight motorkhanas or fast supersprint type events. Overall we finished 10th outright in a field of over 170 competitors and were the first of all the WRX and STi Imprezas competing.

Upon returning to Sydney, I competed in a motorkhana with the Porsche Car Club of NSW (PCCNSW) and finished 1st outright. This feat was repeated at the end of 2001, when I competed in another PCCNSW motorkhana.

During the season, I competed in Class 3 of the NSW WRX Club and finished the year in 2nd place. This included five 2nd places and one 1st place finish. We were hoping for 1st overall, but it wasn't to be. I had a season-long battle with a friend of mine, called Michael. Despite all our development work, he managed to stay a step ahead all year. I have told him that I think he has a lesser sense of self preservation than I do! The 1st place I snared at the last event of the year was when Michael graciously stayed at home, so the closest I got to him all year was 0.05 of a second at Wakefield Park in June.

This year also saw many more subtle developments in Project REX to the point that we are now lapping quicker at all circuits than we did when we had LSDs. The car is now more like a dedicated "weekend warrior" than an everyday car, but still can be returned to a comfortable car in less than 90 minutes with a few component changes if desired.

The present set up takes into account the move to 225x45x16 tyres instead of the standard 205x50x16 tyres. As it turned out, fitting this size rubber under the guards and allowing it to clear the struts was rather difficult. We needed to fit wheel spacers, 10mm at the front and 5mm at the rear. The extra offset also meant that we needed to have longer wheel studs made. The spacers press into the wheels (which were bored out a bit to allow this) and are still spigot located. The extra grip available form these bigger tyres require greater roll stiffness. The car now has a 27mm/24mm hybrid adjustable front swaybar and a 26mm adjustable rear swaybar.

If you've read this far, you should have got the idea: motorsport is fun, addictive and expensive. Go for it!"

21.2 Preparing You and Your Car for the Track

Hitting the track with your WRX need not be financially crippling. There is no need for a second mortgage on the house or to sell the children in order to pay for it, as you can go racing in an essentially standard car. Regardless of what part of the world you hail from, joining a car club with an active motorsports program is always a good start. This will put you in touch with like-minded enthusiasts and valuable sources of information. Go out and attend a few track days as a spectator. Witness the squealing tyres and roaring engines firsthand and form your own opinion. Do an advanced driving course for some hands on instruction and experience and a taste of track-time.

The Build Process

Here in Australia there are three easy steps to becoming a competitor in a grass-roots category of motorsport such as hillclimbs or supersprints;

21.2.1 Competitor's Licence

In our sunburnt country you need a basic CAMS (Confederate of Australian Motor-sport) level 2NS licence in order to go track racing. A simple application form can be downloaded from the net, filled out and posted off with the licence fee. Once processed, a valid licence will be sent out along with a competitors guide. A 2NS license entitles the competitor to compete in speed events such as motorkhanas, single and multi-car speed events and touring events that do not run over closed or timed road section.

21.2.2 Basic Safety Kit

In addition to a road registered and roadworthy car, the following requirements must be met;

- **Log Book** – This document is required if competing in official CAMS sanctioned events. Most club level or inter-club competitions do not require a log book.
- **Competitor Numbers** – CAMS sanctioned events require identifying car numbers in accordance to prescribed event regulations. Again, competitors of most club level or inter-club events can construct numbers out of adhesive tape subject to specific event regulations.
- **Battery** – A blue triangle of 140mm sides must be positioned on the exterior of the vehicle, indicating the position of the battery, or by a lightning bolt symbol within a triangle.
- **Fire Extinguisher** – An extinguisher of at least 900g capacity to Australian standards 1841 that is either new, or has been inspected within the last three years. It must be correctly installed in a part of the cabin accessible by the driver while seated and belted-up.
- **Bonnet** – A secondary restraint, such as a strap or set of bonnet pins in addition to the OE bonnet catch.
- **Glass Protection** – In the case of glass headlights, they must be covered with tape or transparent film to prevent broken glass being left on the road surface.
- **Personal Safety Kit** – Club and inter-club level events require a minimum of a helmet in good condition conforming to Australian Standard AS1698. Those helmets rated by another form of standards acceptable for use are outlined in the CAMS motorsport manual. As a minimum, neck to ankle clothing and covered shoes are required. Synthetic clothing or shoes are not acceptable. Certain championship level supersprint events require the use of an approved fire retardant driving suit.

Battery Location Symbol

21.3 Specialised Track Modifications

Once you have been out a few times on the circuit you will feel the need – the need for more speed! How much more comes down to two issues:

1) How fast you are;
2) How fast your car is.

Your own skill level is something we cannot help with, that takes good instruction and a lot of practice. Sorry, but PS2 time doesn't count here. If you cannot drive out of sight on a dark night, this manual won't help you.

21.3.1 Technique

The easiest and cheapest way to improve lap times is to work on sharpening your own skills. Take the time prior to going racing to walk the track and check out the corners at a more sedate pace. Pay particular attention to the correct lines through the corners, noting important features such as ripple strips, camber and run-off areas. Don't be scared to ask! Speak to the track operator or other more experienced drivers for suggestions. After all the aim is to have fun and maximise the amount of time spent attacking the track the "right" way, rather than having to work it out the "hard" way.

Once on the track for the first time in your car, take a bit of time to familiarise yourself with the correct lines, progressively increasing speed. Don't be a hero and try and set the fastest time on your first lap, as often this will result in a trip into the kitty litter or sand trap for a long wait. Bucket and spade time!

Pushing Hard

After getting comfortable with the track, select one corner at a time to begin exploring both your own limits, and that of your car, but choose those corners with plenty of run-off. This will go a long way to boosting confidence in testing the limit, knowing that you will not hit anything if you do run wide. Practicing in this manner is invaluable for attacking those corners that are not so forgiving of driver errors.

One last important technique is to master the art of realising when you are not going to make it through a particular corner. When this happens, don't be a hero and try to "hang-on" to the car, as it is far better to choose a point a which to exit off the track, rather than having it forced upon you. That way you remain somewhat in control. Always try and drive off the track straight, rather than sideways, as nothing is more dangerous than riding over kerbs and ripple strips sideways, as it maximises the potential for rollovers.

21.3.2 Seats

In order to control the vehicle properly under the more extreme stresses of acceleration, braking and cornering at the track, the seat must firmly locate the driver in place. The delicate balance mechanism located in our inner ears is what we use to help detect understeer and oversteer. If the driver is flopping from one side to another in the seat, it will be far harder to sense what the car is doing.

The seats fitted to early model WRXs were simply atrocious, and should be given the flick post-haste for even the most casual of racers. Later model seats are an easy upgrade, otherwise, bite the bullet and purchase a purpose built fixed back racing seat, and suffer all the associated drawbacks. Getting a good grip on your bod takes precedence over comfort. Late model seats are reasonably good, and adequate for most forms of basic motorsport.

Pic Competition Seats

Seat mounts are important, as the very best competition seat is useless if connected to the floor of the car by recycled soup cans. Most quality aftermarket seats such as Recaro or Momo will have dedicated runner kits to suit the WRX. Hand fabricated seat mounts on the other hand are not a DIY item, requiring specialist skills.

21.3.3 Competition Seat Belts

Four or five point racing harnesses are a worthy inclusion as they assist with holding the driver into the seat when cornering and braking. Occupant safety also takes a major step forward as long as the harnesses are installed correctly. Harness installation is absolutely critical, as poorly mounted belts can be more dangerous that the OE belt in the event of an accident. Drivers do not emerge unscathed from huge accidents through good luck, but from sound safety conscious engineering.

Competition Seat Belts

Never take the shoulder belts through the front seat and then down onto the floor behind the seat. In the event of a frontal accident, this will cause the belts to bear down on the shoulders of the driver, potentially causing compression injuries of the spine. Using the ISO child seat anchorage in the rear parcel shelf or floor (five door models) to attach the shoulder belts is inappropriate for a couple of reasons; most importantly, child seat anchorages are not rated for adult loads, and secondly, it results in the belts becoming offset from the driver. The OE parcel shelf is a flimsy bit of metal, and requires the use of motorsport grade anchorages and reinforcing plates to mount the shoulder belts correctly. Mounting the shoulder belts on a five door WRX is much more challenging. The 100% correct method is to fabricate a heavy duty bar that bolts between the upper rear OE seat belt anchorages in the “C” pillar. The lower OE seat belt anchorages in the transmission tunnel and base of the “B” pillar are OK to mount the lap belt component of the harness. Be mindful of belts that run over the top of the OE rear seat, as the foam seat back compresses readily in an accident as the driver pulls forwards on the belt, increasing the amount of free-play in the seat belts. In a big accident, the driver could even move forward enough to contact the steering wheel.

Parcel Shelf Reinforcing

OE Seat belt anchorages

Finally, the nylon webbing in a seat belt or harness is designed to stretch in the event of an accident reducing peak G loadings on the driver. Once this stretch has taken place, the harness is useless because the seatbelt will no longer absorb energy, dramatically increasing the shock load on the driver, multiplying the risk of serious injury. Avoid buying second hand harnesses. Some people complain about the cost of competition seat belts, but what price would you put on your safety? Seat belt webbing is also weakened by exposure to UV light. Seat belts are valid for five years after date of manufacture, and all good belts will have its production date printed on a label. Belts that don’t have a production date are definitely past their prime!

21.3.4 Miscellaneous Parts

Some race circuits require the fitment of a crankcase breather catch-can to prevent oil spillage on the road surface. See *Engine Mechanical* chapter for more information.

Small mods such as clutch, brake and accelerator pads can help make heeling and toeing easier for some, but they must be fitted correctly. A poorly mounted brake pedal pad that detaches itself at an ill-opportune time can have disastrous consequences. The position of the accelerator pedal in relation to the brake pedal can also be adjusted to suit your preference. Any competent mechanic will be able to gently massage the accelerator pedal mountings to raise or lower its height. For maximum pub car-park credibility in the cockpit, have a driver’s foot mat made out of thin aluminium alloy sheet and then cover with non-slip material as used on skate board decks. Cut the alloy sheet to neatly fit the drivers foot-well. The standard Subaru floor-mat retainers are perfect for holding it in position. The foot mat or plate will help stop your heels from skidding all over the floor when cornering hard or over bumpy surfaces. Be warned, the rough non-slip finish of the plate will attack your heels like a cheese grater, so leave the crocodile skin shoes at home.

Performance Pedal Pads

Drivers Foot Plate

21.3.5 Tyres

Tyre pressures are important. These must be increased for track days, especially if you intend on driving home on the same set of rubber, rather than leaving it smeared all over the track. There is no magic tyre pressure, you have to be prepared to experiment. Good car clubs, especially dedicated one-make clubs will have base line figures available to use as a starting point. Really serious car clubs will have a tyre pyrometer, or a fancy thermometer for measuring tyre temperature, to better allow you to “home in” on the best pressure. If on-the-spot advice is unavailable, a good rule of thumb is to inflate tyres to around 0.5bar higher than manufactures specs as a starting point. Remember that tyre pressures will increase with temperature. Once the tyres are up to operating temperature, recheck pressures and adjust accordingly.

Tyre Testing

Premium performance rubber is probably the easiest performance handling modification you can do to your car. Ultra-competitive owners even run slick tyres, but these need an entirely different and much stiffer suspension setup to exploit the extra grip capacity. Whatever type of high performance tyre you choose, make life easier for yourself and purchase a second set of rims. These are often available second hand from tyre shops, where someone has fitted aftermarket rims to their WRX. Soft'n'sticky race tyres are great for grip but wear quickly on the street, which is in turn wearing on your wallet.

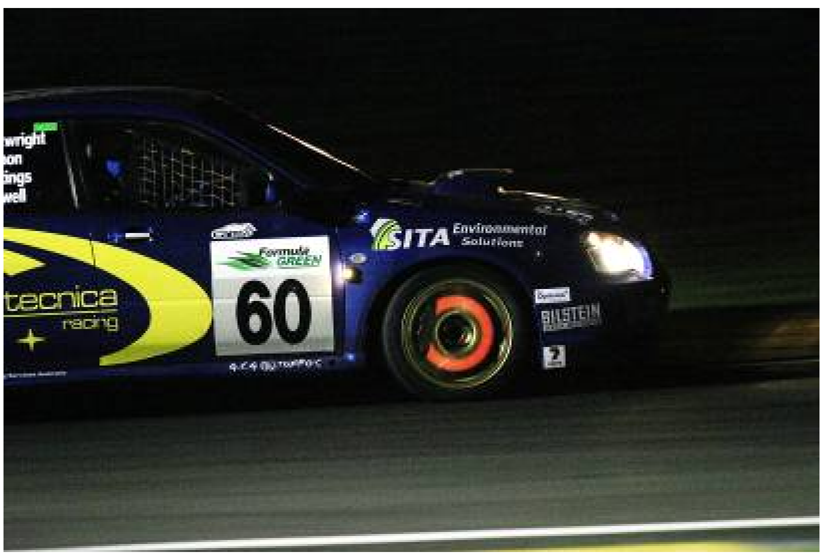
High Performance Track Rubber

21.3.6 Brakes

Consider this: it takes a couple hundred kilowatts to accelerate a car to 100km/h in around six seconds. Engine power has been converted into kinetic energy – the mass of the car is storing this energy in the form of inertia. Braking from this speed back down to rest in a hard stop, most of this energy has to be dissipated by the brakes. The mathematics are scary! On the road, traffic conditions and speed limits give the brakes plenty of time to radiate this energy as heat, before the next braking effort. On the track, the brakes only have a few seconds. End result? Standard brake pads get awfully breathless, and wear out extremely fast. You should monitor the thickness of brake pad material carefully. As a brake pad gets thinner it wears faster, as it has less mass, heating up quicker. Good quality motorsport pads resist fade and wear far better, but can be antisocial in operation, reluctant to operate when cold and have an alarming appetite for brake discs. A set of track pads that you swap out at the same time as your track tyres could make a lot of sense, if you're handy with the spanners.

When going out for the first lap on the track, take some time to pre-heat the pads and discs. Warming (not roasting) the brakes prior to the main event will improve operation and protect components from heat stress. If you don't have time for a warm up lap, at least drive slowly around the pits, gently left-foot braking. Brakes that are heated suddenly from cold will cause uneven expansion resulting in heat spotting, warpage and disc cracking from heat stress, especially with cross-drilled discs. Once all the action is over and your flying lap is finished, allow a cool-down lap. Avoid screeching to a complete stop and then holding the brakes on. This has been known to weld hot pads to the disc.

Worthwhile improvements to brake performance can be gained by ducting air to the brakes via large diameter hoses run from the front of the car. An unexpected bonus is the TOCA like look this air ducts will give to the front of your car! The removal of the pressed metal backing plate between the wheel hub and the brake disc will improve air flow, although there is a risk of foreign objects entering the brakes and getting stuck in the brake disc and pads. Brake balance (see *Stopping the WRX* chapter) is a final area that can be tweaked to take better advantage of increased mechanical grip from sticker tyres and differentials. Normally the rear brakes only contribute to around 25% of total brake effort, but with extra grip, mods can be made to make them work harder for their living. An adjustable bias valve will enable more brake effort to be passed onto the rears. Bias also has an affect on handling attitude, with rally drivers using large amount of rear bias to help un-stick the rear of the car, in order to set it up for a corner. Installing a bias valve is not a DIY job, requiring specialist skills.



Pic Hard Working Brake Parts

21.3.7 Common Brake Problems at the Track

Any track-obsessed WRX nut will tell you, brake fade is the most commonly encountered problem at the track. The word "fade" is normally associated with things that are left out in the sun for too long and is kind of boring waiting for it to happen. Brake fade on the other hand gets your attention pronto-tonto, and refers to an acute loss of braking. In most cases it is cause by heat building up in the brake system faster than it can be dissipated. Brake fade is a general term and encompasses a range of problems such as:

Pad Fade – This is the most common type of brake fade, and is caused by exceeding the maximum working temperature of the friction material and brake discs. Overheated pads and discs will become apparent to the driver in the form of greater and greater pedal pressures required to achieve the same rate of deceleration. Eventually, brake performance will degrade to the point where no matter how hard the pedal is pushed, brake performance is minimal. Competition brake pads or an *Ultimate Brake Package* (See *Stopping WRX Chapter*) will substantially raise the threshold at which brake fade will occur.

Fluid Fade – Occurs when the brake fluid becomes hot enough to vaporise, turning from a nice incompressible fluid into a nasty compressible gas. Symptoms of vaporising fluid become apparent to the driver in the form of a very spongy brake pedal. In extreme cases the brake pedal can go completely to the floor. Once the brake system has cooled, brake pedal feel will recover to an extent, but severely boiled fluid will need to be changed. Fluid fade can be practically eliminated by switching to higher quality brake fluid, or by changing fluid more regularly so as to avoid the problems related with old brake fluid.

Performance Brake Fluid

Anti-Knock-Off Springs

Pad Knock-Off – Symptoms are similar to Fluid Fade, in that the brake pedal goes to the floor without slowing the car. It is caused literally by the pads being "knocked" off the disc rotor. Brake pads normally run very close to the surface of the brake disc, almost to the point of dragging. When the pads have been knocked-off, the first application of the brake pedal is only enough to bring the brake pads to the disc, but without enough squeeze to actually slow the car to any extent. Knock off is predominately a function of wheel bearing problems – a known weakness in the WRX. High cornering loads can cause the bearing to flex slightly on the hub promoting knock-off. Badly warped brake discs, calliper seal problems, bent and seized slide pins can also be a contributing factor.

Prevention is the best cure when it comes to preventing knock-off. Professional drivers make a habit of dabbing the brakes with their left foot towards the end of long straights. This is to reassure them that a nice hard brake pedal is available when it comes time to really stop. Routine maintenance and regular inspection of the brake system and wheel bearings is also important. Anti-knock-off kits are available from STi, comprising of a seal and spring kit that once fitted to the calliper helps keep the brake pads at the right clearance to the disc. Finally, a DIY pressurisation of the brake system can be fitted to help prevent knock-off. This can be as simple as a tyre valve glued into the brake fluid reservoir, inflated by a bicycle pump, although maintaining a good seal with the OE cap can be difficult. Normally 0.3-0.4bar is enough. Don't over-pressurise, as this will cause the brakes to drag, slowing the car and prematurely overheating brake components. Bear in mind that any modifications done to the brake system, however simple, can be potentially dangerous. Get expert help on this one.

Brain Fade – Another very common cause of braking problems on the racetrack. Also known as blowing a sand-shoe. Usually caused by a red mist descending over the driver's vision.

21.3.8 Suspension

A racetrack offers a unique opportunity to test different set-ups, so don't waste the opportunity! Be adventurous, as adjustable shocks, sway bars and camber kits all come into their own in terms of functionality. Follow the lead of professionals and the seriously obsessed. Start a log book and use it to record track and weather conditions, car setup and lap times.

There is no such thing as the 100% correct suspension setup, what is good for one driver can be appalling for another. For example two professional drivers in the same race team, running the same type of car may have major differences in setup. Both drivers may be capable of setting similar times, even though their suspension setup and driving techniques differ widely. Use the advice of others as a baseline, but don't let yourself get talked into sticking with a combination that doesn't suit you. When making changes, make them slowly, one at a time, so that you can recognise if you are moving in the right direction. Remember that settings do interact, for example, changing camber angle will influence toe. Some clubs will have camber and castor gauges available for use by members, while toe requires nothing more than a tape measure, chalk and a (female) assistant (in tight pants). Yes!

21.3.9 Suspension Setup

Revisit the Suspension chapter, as many of the techniques that apply to a road car are easily transferred onto the track, but can be taken to a much more radical extent.

Race Suspension

Camber – Normally 1.5 to 2.0 degrees of negative camber is optimum for high performance street tyres. At the other extreme, getting slick or dedicated racing tyres work to their full capacity will require up to 4.0 to 4.5 degrees negative due to the extreme lateral forces they are capable of generating. Intermediate or grooved slicks slot neatly in the middle at around 3.0 degrees negative. Unless slick tyres are to be used, steer clear of extreme camber angles. Stresses on the wheel bearings and hubs increases greatly, while straight line traction and braking grip can suffer.

Caster – As much as possible, as this decreases the reliance on static camber.

Toe – Front suspension toe is generally set according to driver preference. Zero toe makes the car more responsive to steering inputs, but is at the expense of stability while braking. Experiment between toe in and toe out. Exceeding toe by more than 1.5mm per side is counter productive, and will create too much tyre friction.

Rear toe is a far more important part of suspension tuning. More toe out at the rear promotes oversteer, while toe in promotes understeer. Series production AWD and FWD race cars can use toe out angles of up to 6mm per side to try and overcome the limitations of the standard stabiliser bars. The down side of this is that such large toe values make the rear of the car extremely snappy through fast corners, as well as excessively heating the tyres through friction. Improved suspension parts such as bars, springs and bushes will reduce the need for large amounts of toe at the rear. Between 1.5-2.5mm toe out per side is suitable for a WRX with a standard driveline. Cars with upgraded centre and rear differentials, along with DCCD equipped STi's need far less rear toe, with around 0-0.5mm max per side toe out a suitable starting point.

Sway Bars – Another very important tuning tool for adjusting cornering attitude and overall grip levels. Sway bar rates can be increased for the track, as weight transfer (a function of sway bars) can be exploited to the maximum potential allowable by the tyres, which is the defining factor. Adjustable bars come into their own here for week-end warriors, resetting bars to their maximum setting is generally more than adequate for high performance road rubber. Bar recommendations for slick tyres is a much harder question to answer, but as an indication, bar diameters upwards of 5mm thicker than a high those for high performance road tyres are entirely possible for the track. Some very important caveats; DCCD equipped cars, or WRXs with heavy duty differentials will tend to behave a lot more like powerful rear wheel drive cars, meaning traditional WRX sway bar tuning philosophy (stiffer bars at the rear compared to the front) goes out the window. Very high sway bar rates place extreme loadings on the other OE suspension components, leading to fatigue failures of bar links and mountings, requiring further heavy duty hardware to correct this.

Adjustable Platform Shocks

Spring and Shock Rates – Racetracks are generally far smoother than the road, and do not suffer from speed humps, railway crossings and potholes. Consequently spring and shock rates can be up-rated, particularly when it comes to exploiting the benefits of high performance tyres. Slicks or dedicated race tyres are the extreme example, and need an entirely different (read stiffer) setup to exploit their extra capacity for grip. Spring rates of around 8-10 N/mm (450 – 550lb in the old money) to are required make slicks work at peak efficiency. However, a proper “intermediate” race tyre, “grooved slick” or equivalent generally only requires a spring rate of 9 N/mm at most. Road tyres, even with the fanciest names and claims are still road tyres and are designed with the greatest compromises when compared to racing rubber. They simply cannot generate enough grip to need more than 6-7 N/mm in order to function properly on the track. Don’t even ask how much of a pig a car with suspension setup for slick tyres will be on the road.

Ride Height – Consistency of racetrack surfaces means ride heights can be adjusted lower than would be necessary on the road. This lowers the centre of gravity and reduces the effects of uncontrolled weight transfer. Lowering can be taken too far. It can dramatically change the car's natural roll centre, often for the worst. In addition, the more the car is lowered, the less total suspension travel is available, forcing an increase in spring rate. A suspension system that is set too low will either bottom out or skip over irregularities, ultimately reducing its grip potential. Swapping out springs can be a pain if you forgot to pack your JGTC (Japanese Grand Touring Car) championship team transporter, crew chief and mechanics. Adjustable spring platform shocks are handy in this respect, as long as you invested in a set of quality items that suit your tyres and intended application.

Everything that we have discussed in this chapter to do with suspension tuning for the track, revolves around maximising the quality and appropriateness of the tyres contact with the road. This is the single most important concept that needs to be understood and appreciated, if suspension tuning for the track (or the road for that matter) is to be more than a colossal waste of time and money. For example, getting hung up debating the merits of a particular spring rate in isolation is pointless, when it is the spring rate at the tyre that is important. (even this changes with the tyres used). No doubt you would have noticed how differently the car steers after fitting a set of better stickier tyres and that's because of the difference between the static and dynamic relationship and its translation to handling feel. Therefore, think first about not only the intended use but also the intended tyres. In simple terms, the stickier or grippier the tyres, the more spring rate, roll resistance and overall rigidity you will need to get the benefits from these tyres. And I'm not talking about brand X "High-po" vs brand Y "High-po" radials but the difference between classes of tyres (Road, Intermediate and Slick). Chasing that last 10% of suspension performance is expensive and time consuming, but ultimately rewarding. Save yourself the grief, and take the balanced approach, dealing with reputable suspension tuning companies that have a range of suspension packages to suit your needs.

21.3.10 Engine Set-up

The racetrack (as opposed to the dragstrip) is a true test of how well your engine has been modified. Big power outputs are relatively easy, compared with achieving the same results with reliability, lap after lap on the racetrack. Many engine tuners tailor a mechanical and engine management package with the assumption that WOT throttle can never be held for more than a handful of seconds at a time. This is more than adequate for the road, but dangerous for the track. A professional tuner will factor the rigors of track racing when making engine management and mechanical spec decisions, erring on the side of conservative as opposed to overly adventurous.

Spark Plugs – Stock WRX engines come equipped with No 6 heat range plugs. Moving up to a No 7 heat range plugs is advisable even for stock engines out on the racetrack, while mandatory for enhanced ones. Heavily modified engines running big boost require a No 8 grade plug. Very cold heat range plugs can lead to fouling problems when running on fuels with a high content of toluene on the street – keep a special set for the racetrack.

Track Engine

Engine Management – Engine mapping that has been setup to maximise power outputs with excessively lean fuel mixtures and large amounts of ignition advance have no place on the race track, especially with stock engine internals. Lean air-fuel ratios promote a hotter burn of the air/fuel charge increasing combustion temperatures. Under extended periods of heavy load, combustion chamber and piston crown temperature can rise to critical levels, causing the onset of detonation. Boost pressures are another consideration. An engine running at the absolute limit on the road will quite likely be pushed over the edge on the track. A slight reduction in boost is sometimes prudent.

Fuels – Covered in more detail in the *Engine Management* chapter, the grade of fuel used when going track racing is very important; even a monster tune with all of the good bits will very quickly become expensive scrap if running on the wrong fuel. Always aim to use the best possible grade of fuel you can afford and adjust your engine tuning to suit. In Australia normal 95Ron PULP is good for around 1.1-1.2 bar of boost, while 98-99 high octane unleaded has a safe upper limit of around 1.4 bar (Engine internals permitting!).

21.3.11 Track Racing and the Fuel System

Track racing generates high cornering forces, and while you are out there throwing your car around from side to side, spare a thought for the fuel sloshing around in the fuel tank at the same time. A phenomenon known as fuel surge can occur when enough fuel is forced away from the fuel pump pickup allowing it to draw quantities of air. This sucks! On taking even a small gulp of air, instantaneously fuel pressure drops, leaning the fuel mixture and is bad news for a highly strung turbo car. Fuel surge problems start to emerge as the level of fuel decreases in the tank, and is highly dependant on the degree of lateral and longitudinal G loadings generated. Cars on slick tyres can experience surge as early as 1/2 full, while road tyres can delay the onset to around 1/4 full.

The easiest and cheapest way to defeat fuel surge is to keep plenty of fuel in the tank, although this incurs a weight penalty that more obsessed drivers will find unacceptable. For those with bucks to spare, several options exist; additional baffles can be fitted to the interior of the OE fuel tank, slowing the rate at which fuel moves around. Filling the fuel tank with special fuel cell foam will have the same effect, with the added bonus of improving safety as well. Problem is, both of these methods are labour intensive and complex to achieve a good result. A better solution in the past has been to fit an additional stand-alone fuel pump drawing from a custom made surge tank. Surge tanks are effectively an additional fuel tank or reservoir in the fuel system. Normally a surge tank of between 1.5-2.0 litre capacity is enough to ensure an uninterrupted supply of fuel to the engine. Installing all of the associated plumbing is time consuming and requires specialist skills. The risk of fuel leakage and subsequent fire is an extremely serious consideration; surge tanks should never be located in the passenger compartment unless separated by a liquid and flame proof bulkhead.

If this sounds all too difficult, salvation is to hand. STi fit a modified surge pot to the OE fuel sender and pickup assembly on selected JDM models. Its greatest attribute is simplicity, and is a benefit for even highly strung road cars. There is one catch, the STi part is hard to source and expensive at around A$1,600. An alternative is an improved copy of the STi unit manufactured by MRT, costing around A$790 including a 3.5LPM high flow fuel pump.

MRT Fuel Sender Surge Pot

21.3.12 Engine Lubrication System

Using engine oil with a higher viscosity rating is recommended for track use. The 5W-30 grade engine oil suggested by Subaru should be changed to 20W-50 grade engine oil. This increases the strength and durability of the film of oil that protects engine bearings and other parts from damage. Oil cooling becomes more of an imperative for serious track racers.

Engine with Competition Sump

Exactly the same forces that play havoc with the fuel system apply equally to the engine lubrication system. See *Engine Mechanical* section for detail on baffled high capacity oil sumps.

21.3.13 Monitoring Equipment

While punting around the racetrack your car's engine will be under extreme stress. This makes additional gauges, a good idea to warn you of impending doom. There isn't a lot of time to glance around the cabin while trying to shave those extra 10ths of a second off your lap time, so they must be easily seen to be of any benefit. Although it is nice and neat, mounting them in the centre console or glovebox is next to useless, as well as being well out of the drivers line of sight. Don't depend on gauges with a memory recall. If there is a problem, they will only tell you at what pressure or temperature your engine croaked. Shift lights are also a good idea. See *Interior and Miscellaneous Improvements* for more information.

21.4 Track Racing Maintenance Requirements

Maintaining your car for track racing does not mean that it has to be torn down into a million pieces after each track day, but components will wear faster and so maintenance must be stepped up. After each outing get into the habit of inspecting the car for any fluid leaks and loose components. Pay particular attention to brake pads, discs and flexible hoses. If the type of racing you do is extremely hard on brakes, have your brake system flushed and refilled with competition grade Dot 5.1 fluid. Good practice is to give the brake system a quick bleed after every track day as part of preparation for the next event. As little as 3-4 good pumps at each wheel is sufficient.

In The Pits

Racing hugely increases loads on the drivetrain. Check wheel bearings after every meeting. When fitting new wheel bearings, use high quality synthetic bearing grease such as NEO on re-assembly. Standard transmission oils should be replaced with high quality synthetic. A well run-in engine can be changed over to synthetic engine oil, respecting previously mentioned viscosity ratings when used for track racing.

Hard charging operators will change both the engine oil and transmission oil after every single outing.

21.5 Conclusion

The racetrack is the great leveller, with all of the normal bullsh*t and posturing so prevalent on internet forums blissfully absent. Lap times speak for themselves. A successful track racer doesn't have to be measured on the amount of money spent, but more on: a) The amount of enjoyment had. b) Being able to circulate for the whole day with the minium of fuss. c) Spending the minimum amount of time under the car fettling sickly equipment, and finally. d) Keeping out of the crash repair shop.

But then there are those that winning is an all-consuming passion, and will go to extreme lengths to make this a reality. Do not fear, for a last word on track racing, we will hear again from Brendan Helsham. He is living proof that even the most serious track addiction can be kicked! Part of his rehabilitation currently consists of engaging in the automotive equivalent of basket weaving and macramé;

Kicking the habit - the Boy Racer Grows Up

Brendan Helsham – June 2005

After providing the Foreword for the first edition of Training WRX, following that up with my story on 'Track Days' in the 2nd Edition, I have been asked to bring you up to date on what I have been doing with my WRX for this new book. The answer is nothing! Times have changed and I have moved on.

My old heavily modified Version IV WRX racetrack "special" was sold late in 2002. Late in 2004, my road going Version VI STi was also sold. Where does that leave me now? Well, driving a new Liberty 3.0R Auto Sedan. Yes, that's right, an automatic and a non-turbo! Its funny how things change; when I bought that first WRX back in 1996, I was single and had no kids. Now I am happily married with three kids and have different priorities as I approach the big 40.

Being the "fastest kid on the block" was no longer important to me, so the Liberty was the perfect choice. It's not slow by any means, but compared to the WRX/STi, it is a little pedestrian. I also opted for the automatic transmission purely as I had only ever owned and driven manual cars for the 20 years I had been driving. It was time for a change and I am glad I made the decision to go that way. Who knows, in another five years when I replace this Liberty, I may very well go for a manual again.

The new Liberty has everything I want and need in a car today. The engine has more than enough grunt for pottering around Sydney and the car comes standard with lots of creature comforts on the inside for me. I would have to say that 6 months into owning this car, I still love it.

I don't miss the STi per se, but when I see one on the road, I feel a satisfied sense of "been there, done that". With this satisfaction comes the knowledge that I was privileged to be part of what will inevitably become motoring history. Good on you Subaru for making such a great car that will inevitably become the cult car of the 90s and beyond.

Appendix

Glossary

2WD
Short for Two Wheel Drive. Can either be FWD (Front Wheel Drive) or RWD (Rear Wheel Drive)

4WD
Short for Four Wheel Drive. This is what makes your Subaru really shine in difficult conditions. Engine Power and Torque are transferred to the roadway by all four wheels.

AVCS
Short for Active Valve Control System. Subaru's very sophisticated electronically camshaft phasing control system. Controls intake camshaft position on some WRX's and all Version VII and later STi's.

AFM
Called an Air Flow Meter, but to be 100% correct is actually an air mass meter and reads the actual weight of the air entering the engine. This is the device immediately downstream from the Airbox that sends information to the ECU. It can be affected by an over-oiled air filter element. See Chapter 11 for details.

API
American Petroleum institute, an organisation purported to represent the interests of both petroleum industry members and energy consumers in North America.

AWD
The name given to Subaru' s constant four-wheel drive system.

BDC
Bottom dead centre – describes the lowest point of piston travel in the cylinder bore.

Bevel Gears
See also *Straight-Cut Gears*. Bevel gears have cogs cut at less than 90 degrees to the axis of rotation. This allows easier engagement and quieter operation, but at the cost of reduced strength.

Brake balance Bar
A more expensive and better alternative to the proportioning valve; this is a true mechanical way to control "balance" as opposed to a valve that is based on a theoretical pressure that allows best balance.

Bump
Is the term used for describing the compression of a suspension unit and bump-rate describes how the shock absorber is set up to behave in its compression (up) stroke.

Bump Stops
These are rubber or polyurethane pads located at the top of the shock absorber rod. When all suspension travel is used up, the bump stop contacts the damper body, and prevents further travel. At this point further shock energy is transferred directly to the car body via the bump stop itself.

Camber
This is the angle of the face of the wheel in relation to the vertical axis. If at the top of the wheel it leans in towards the centre of the car, this is negative camber. Therefore, if the wheel leans outwards at the top, it is said to have positive camber. Negative camber is common on a WRX

CAN
Short for computer area network. A specific computer communications protocol that allows a form of multiplexing for communication between different electronic control units in a vehicle.

Castor
Imagine the wheel assembly of a shopping trolley, it is the relationship between the centre of the wheel axis and its anchor point which highlights castor. A shopping trolley has negative castor, this helps the wheels always follow the direction of travel. In a motor car generally the suspension is set up with positive castor in mind. Positive castor is common on a WRX

CE
Check Engine light. The idiot light that becomes illuminated when the engine ECU detects an abnormality in either the engine electrical system or emission control system.

CHRA
Centre Housing Rotating Assembly – an acronym used to describe the bearing core of a turbocharger.

Clevis (strut)
Lower part of the strut that bolts up to the wheel hub mounting boss.

Crankcase
An old industry term for the section of the engine block that houses the crankshaft. On the WRX engine it is the section to the two cylinder block halves that the crankshaft fits into.

DBW
Drive-By-Wire throttle control. A system whereby the drivers right foot is no longer connected to the throttle body of the engine. Instead, the driver "requests" a desired

throttle position, which is then processed by the ECU. Depending on prevailing conditions the ECU will then command an actual throttle position.

DCCD
Short for Driver Controlled Centre Differential. Latest incarnation of Subaru's electronically centre differential. Diver can choose between either Automatic torque split or manually selectable via a thumbwheel.

Detonation
Or pre-ignition is the condition that occurs when the fuel-air mixture in the combustion chamber spontaneously ignites before the spark plug fires. This creates an unwanted extra flame front to form in the combustion chamber. The characteristic metallic rattling that can be heard is caused by the two flame fronts colliding. This results in an extreme peak in cylinder pressure and can hole pistons, break rings and blow head gaskets.

22.1.1.1 Dog Gear Sets

Found almost invariably in motorsport, where strength and speed are the most critical factors, dog gearboxes or gear sets dispense with *synchromesh* rings and engage directly with their matching cogs. This makes them stronger and faster, as the synchro rings are weaker and slow down the change from one gear to another. The downside of dog gears is the extra precision required from the driver. Double-declutching and similar techniques will be required to avoid "crunching" gears or missing shifts altogether. See *Synchromesh Gear Sets*

Double Acting
This describes shock absorber operation and describes a shock absorber that controls both the bump and rebound operation of the suspension. Most cheap original units are single acting and only control the rebound stroke of the shock.

Disc Thickness Variation
A variation in thickness between two points on the friction surface of a disc rotor (usually caused by poor manufacture, poor machining or rubbing of the rotor against the calliper when the brakes are "off").

Discard Thickness
Alternative term for Brake rotor/drum Minimum Thickness.

Dual Circuit Brakes
Safety design incorporated on modern cars ensuring there are two largely independent hydraulic brake circuits. Some dual circuit systems are more sophisticated than others. Usually the two systems operate on diagonally opposed wheels so that if one circuit fails, the car will still brake in a straight line.

EBC

Short for Electronic Boost Controller. Comes in all-sorts of shapes, sizes and flavours, including elaborate display screens and interface panels. An aftermarket device marketed by multiple manufacturers. Automatically regulates turbo boost pressure to the desired level electronically as set by the Driver.

ETC
Electronic throttle control. Sinking your boot through the floor boards passes on a request to the engine ECU – which then decides the actual throttle output to be commanded at the engine.

FIA
Federation Internationale DE L'Automobile. The FIA is the Governing body responsible for the administration of major international / national motorsport championships.

FMIC
Acronym used to save wear and tear on your mouth, shortening Front Mount Intercooler into one word.

GC, GD
These are Subaru chassis types. The GC is the original chassis Version I to VI. The GD is the new shape Version VII and beyond.

Geometry
This can best be explained as the camber, castor and toe angles that the suspension has been designed to maintain throughout a variety of ride heights and cornering conditions. Geometry will also dictate how the car feels and responds to the driver's inputs.

Glazing
The process whereby a brake lining or disc rotor becomes smooth and glossy due to excess heat.

GTP
Grand Touring Production. An Australian production racing series. See also Showroom Class.

Heat Spots
Shiny dark areas on a rotor caused by extreme heat.

Helical Gears
See *Bevel Gears*

HVAC
Heating, ventilation and air conditioning.

JDM
Short for Japanese Domestic Model. A popular acronym used in modern day car-speak to describe spec levels etc. for the Japanese market, often these spec levels are not available in other parts of the world.

LHD
Left Hand Drive

MAP, MAP Sensor
This sensor measure the pressure of air in the engine manifold, that is to say, post-turbo. It is a key input to correct fuelling and is the main reason why an externally-venting BOV screws up the fuelling. See Chapter 12 for details.

MBT
Minimum Best Timing, industry jargon for the minimum amount of ignition advance the engine requires in order to make maximum power. Very dependant on fuel quality and engine load.

Minimum Thickness
The thickness at which a disc rotor must be discarded. Through wear and machining a disc rotor becomes thinner over time; as a result it becomes less able to dissipate heat and more prone to warping and other problems. The vehicle manufacturer usually determines the minimum thickness.

Monster Tune
Not a widely used term. Used in this book to denote a full spectrum enhancement, requiring internal engine changes. As the cost of 'dropping' the engine is thousands of dollars in labour alone, the monster tune is a significant purchase. From A$6,500.

Non-Asbestos Lining
Friction material which uses no asbestos, thereby being easier on public health (breathing asbestos dust can cause the disease Asbestosis). Sometimes non-asbestos linings can be more abrasive, accelerating rotor wear.

Nitriding
This is a process for improving the surface hardness of steel and cast iron. It is commonly performed on engine crankshafts to improve the bearing surfaces' resistance to wear. Nitriding involves immersing the metallic component in a bath of metallic salts and then heated for a period of up to 3 days, depending on the depth of hardness required.

NVH
Noise, vibration and harshness.

OBD II

This is an industry-standard "On Board Diagnostic" plug that allows workshops to troubleshoot ECU problems without the necessity of acquiring the official Subaru diagnostic computer. Originally developed to suit Californian clean air legislation, now has become somewhat of an un-official worldwide standard for Electronic control unit diagnosis.

OE or OEM
Original Equipment or Original Equipment Manufacturer. Denotes either the original factory part, as produced by Subaru, or a manufacturer that builds parts used by Subaru in the original build process, or as genuine spares and accessories.

Original Equipment
Industry term for a component supplied with a new car or as an official replacement part. Known as OEM or "Original Equipment Manufacturer" parts, they are not necessarily produced by the carmaker in question, but will carry its warranty and seal of approval.

Out-Of-Round
Effect where a disc is no longer true to its original shape, as a result of either warping, inconsistent wear or other damage. This can cause pulsing, grabbing, additional noise and lowered performance.

Parallelism
A term which refers to the relationship between the two friction surfaces on a disc brake rotor. It is critical that the surfaces are parallel, particularly with ABS, as the slightest shudder can confuse the antilock system.

Pillow Ball
See Rose Joint

PCD
Short for Pitch Circle Diameter. Used in measuring wheel nut spacings in a wheel. Calculated by drawing a circle that intersects the centre of each wheel stud. The diameter of this circle is the PCD.

Pogoing
Where the body of a car continues to oscillate up and down after hitting a bump. Similar to someone using a pogo stick. Symptomatic of worn shock absorbers.

Pointy Heads
Tongue-in-cheek term for those with an appreciation of the science behind why things work the way they do.

Power
In the Oxford Dictionary, power is stated as being "The rate at which work is done" Power is a direct function of **Torque** and Engine RPM's.

Preload
A term to describe the process of applying a carefully measured load to either gears or bearings, to ensure correct mesh or accuracy of operation.

Proportioning Valve
Hydraulic control designed to stop the rear wheels from locking up (rear wheels become "light" under heavy braking and therefore more likely to skid). This valve reduces the brake fluid pressure at the rear wheels.

Pulling
Tendency of a vehicle to veer to one side (or another) under braking.

PULP
Premium Unleaded Petrol. Australian term for 95 Ron fuel, and middle of the range as far fuel quality goes in this country, the lowest being 92Ron and 98Ron the highest octane pump petrol available.

Pulsing
Uneven or stutter-like force transmitted through the brake pedal during braking, usually caused by problems with disc rotors or linings. Generally caused by Parallelism problems. Not to be confused with ABS pulsing which only occurs under extreme braking conditions.

R&D
Research and development. The investment in expertise, time and money needed to produce new and improved products.

Reservoir
Chamber connected to the master cylinder (usually by hoses) and used for storing hydraulic fluid.

RHD
Right Hand Drive

Rotor
Alternative name for brake disc.

Rose-Joint
Specific style of suspension joint or coupling commonly used in motorsport, effectively a ball a socket design that transfers suspension loads directly with no compliance, but also allows rotation in relation to itself.

Run-Out

Rotors that are warped or out-of-true have excess "run-out", meaning the surface varies or wobbles as it rotates around a fixed axis.

Rebound
Describes the extension of a suspension unit and the rebound-rate is how the shock absorber is set up to behave in its extension (down) stroke.

Roll Centre
The imaginary axis about which the car rolls on its suspension, under cornering loads. Alterations to the suspension geometry can change the height of this axis, making a huge difference to the handling of the car.

Roll Stiffness
Is a measure of to what degree the suspension is set up to resist the body roll generated when cornering.

RPM
Revolutions Per Minute, or the number of times your engine rotates completely in one minute.

ROM
Read Only Memory, a special type of computer chip that once programmed stores information permanently. Even when turned off and the power disconnected.

Rose Joint
Motorsport style of bushing that uses Teflon coated inner that is press fitted into a bronze raced outer, allowing low friction movement. Commonly used in high performance suspension applications. Also known as a pillow-ball type joint.

SAE
Society of automotive engineers, and as the name suggests is an industry based organisation advocating industry interests and needs. Also responsible for a system of grading standards for certain products such as oils etc.

Showroom Class
A class in GTP racing in which the WRX can compete. Restrictions on modifications are very strict. GTP Showroom-class race cars are not ideal examples of performance enhancement as extreme measures must be taken where the rules permit.

Solid Rotor
Disc rotor with solid metal between the two friction surfaces.

Spongy Pedal
Pedal which feels spring-like, perhaps due to the presence of air in the hydraulic system.

Spring Rate
Determines the loading required to compress the spring through a given distance. A spring with a high rate is a spring which will require a great deal of force to compress it.

Sprung Weight
This is the weight of the car, less the weight of the unsprung components (see definition below). It is useful because it is the ratio between sprung and unsprung weights that determines optimum performance. In general low unsprung weight is good, a lot is bad. But the key is the ratio between the two. This concept is developed in more detail in the chapter on wheels and tyres

Squish
Industry speak describing a particular style of combustion chamber design that makes use of extremely tight clearances between the piston crown and parts of the combustion chamber at TDC. Used to improve fuel efficiency and emissions.

Stand-Off
Describes a phenomenon that occurs in the intake manifold of an engine when the intake valve closes at the end of the intake cycle. This causes a fast moving column of air in the inlet tract to that cylinder to suddenly stop moving. As this column of air still has a degree of inertia, it then proceeds to “bounce” back out of the intake port and back into the intake manifold. This is not a desirable trait, as it can interfere with the cylinder filling process of the next cylinder on its intake stroke.

Static Wheel Loading
The amount of weight on each road wheel in a stationary car, as a result of a car's (usually uneven) weight distribution.

Straight-Cut Gears
See also *bevel gears*. Straight gears have cogs cut at 90 degrees to the axis of rotation. This allows faster engagement and greater strength, but at the cost of considerable gear whine.

Swept Area
Total friction area contacted by the pads during one revolution of the rotor.

Synchromesh Gear Sets
Fitted to almost all manual transmission road cars, synchromesh rings between individual cogs in the gearbox provide a braking action, equalising the rotational speeds between the gear to be selected and its opposing number. In plain English, synchromesh makes it

easier to change gear without crunching and other misbehaviour. See also *Dog Gear Sets*.

TDC
Top dead centre, describes the upper most point of piston travel in the cylinder bore.

TMIC
Another fine Acronym. Describes Top Mounted Intercooler.

Toe
Toe is any variation from the parallel alignment of a pair of wheels in the yaw plane. In essence toe describes how a wheel points in relation to straight ahead. If a wheel toes out, it means the front of the wheel is pointing away from the centreline of the vehicle. If the wheel has toe in, it is pointing in towards the centreline of the car. Static toe describes exact alignment with the centreline of the vehicle, and is said to point straight ahead. Toe in or zero toe is common on a WRX

Toe, Dynamic
The deflection of the wheel in the yaw plane, under acceleration, deceleration and cornering. This can create passive steering conditions that can affect agility and handling.

Torque
Again Dryly defined by the Oxford Dictionary as “A Force that causes Rotation” In the case of your engine, Torque is the actual “twisting” force exerted by the engine.

Turnbuckle
A special threaded rod that has a combination of left hand and right hand threads and lock nuts that allow the easy adjustment of suspension locating arm length.

Turn In
How quickly the car responds to steering inputs.

USDM
United States Domestic Market – acronym used to describe North American spec Subaru’s.

Unsprung Weight
This is the weight of the wheel, brake rotor and calliper, hub and suspension components that move relative to the rest of the car. Ideally these should be as light as possible (hence the benefit of inboard disks, which the WRX does not have), reducing the inertia of the wheel and suspension parts, allowing it to follow the contours of the road more closely.

Wear Sensor

In the WRX a special "squeal pin" in the pads provides clear notice that it's replacement time. This is easily mistaken for regular brake squeal (see above). A quick check of the brake pads will resolve this issue.

Wheel Sensor
The device which electronically monitors the speed at which a wheel is rotating. Usually it forms part of an antilock braking system, though nowadays wheel sensors increasingly supply information for traction control systems as well.

Windage
A term used to describe the friction generated within the crankcase of an engine as the crankshaft, conrods and other rotating parts fight their way through oil in both liquid and gaseous form that is constantly sprayed around within an engine's innards. Significant amounts of power can be recovered by minimising the amount of windage within an engine.

WOT
Or Wide Open Throttle. Planting the accelerator pedal through the floor-boards is WOT!

WRC
World Rally Car. The governing body of world Motorsport's (FIA) premier category for rally cars. These vehicles really are the Formula One's of the Forrest. Featuring exotic materials and some of the most sophisticated automotive electronics around.

Yaw
Describes the rotation of the vehicle's body through a corner around its centre point as viewed from above. Normally associated with finely calibrated electronic "G" sensors that can determine if the vehicle is understeering or oversteering when used in conjunction with lateral G and steering wheel angle.