REPORT

Re-tuning factory ECU's to suit lower octane 95 RON fuel

In July 2004 MRT traveled to Hobart, Tasmania to retune several cars at the local Sti Dealership. The aim was to set the cars up to suit the locally available low octane Fuel, with higher octane 98 Ron fuel not being available at roadside pumps. At present the only solution is for owners to purchase the higher octane brew from specially ordered 44 gallon (202 litres) drums.

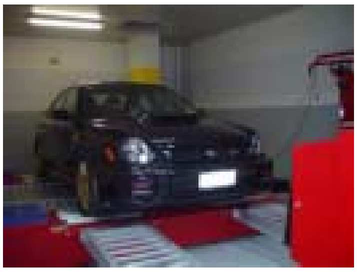
SAVINGS

The local supply of 98 Ron fuel, (from a 44 gallon / 202 litre tank) costs AU$1.80 per litre, when typically the same fuel on the Australian mainland is around AU$1.10/L, and local 95 Ron fuel is only AU$0.98/L (effectively a $0.70c/L premium!!).

Naturally clients were enthusiastic to see if we could save them some money and achieve the same performance on 95 Ron fuel! With a custom tune, dyno time and base re-programming costs taken into account, it will only take just over 6 mths to recover the cost in fuel savings alone. After only 6 mths, the owners will be saving a small fortune on a weekly basis, not to mention that isn't bad when you consider the added fun in driving a car that is all round much better!

CARS in this report

- 2002 Impreza STi (Unmodified)
- 2004 Forester XT turbo 2.5 Litre, virtually standard, with only inner guard mod and std airbox.



PEOPLE

- Brett Middleton *and*
- Paul Fisher :

EQUIPMENT

- EcuTeK Delta Dash Data logging and test software
- Dyno Dynamics “Possum Bourne Limited edition” 4wd rolling road dyno.
- Dyno Dynamics Wide band lambda. (Sensor in tail pipe)
- Dyno Dynamics Boost pressure logging. (From inlet manifold)
- Dyno Dynamics Air inlet temp sensor. (In air intake.)
- M & W Wide band Lambda Uega Sensor and display logger. (Sensor also in tail pipe)
- EcuTeK reflash Software “Flash 01” and “Flash 04”
  Including interface from factory sensors listed as:
    - Fuel mixture in exhaust, via O2 sensor behind turbo.
    - Boost via factory Map sensor.
    - Air inlet temp via AFM sensor.
    - Knock detection via factory knock sensor.



Method:
Testing the standard cars

On the Friday (30th July) the STi was tested on the dyno to check the car and Dyno.
As supplied by the owner it had 98 Ron fuel and this was to be removed prior to the tuning session (Saturday), however we were able to use this as a benchmark to check the car with a known program that we use in Sydney.

The outcome was compared to the usual results achieved on 98 Ron fuel in Sydney, with the car performing with similar results. This proved the car was not outside anticipated/expected results and that there were no other issues which needed attention first. As a result the testing and outcomes after the retune on 95 Ron fuel could be compared to a similar car (and dyno graph) with 98 Ron fuel.

Preparation

On the Saturday morning, the Impreza STi was then drained of 98 Ron fuel and the tank filled completely with 95 Ron Fuel. The Forester XT was delivered by the owner with a full tank of 95 Ron fuel. Both cars were road tested to ensure they were ok, and data logged the results with EcuTeK Delta Dash. http://www.ecutek.com.au/delta-dash.htm

Each car was to receive 2-3 hours of custom tuning on the dyno. During their individual runs, each one was tied down on the dyno front and back, and connected to all relevant equipment (refer to the list at start of document for full details).

As a backup three fuel mixture devices were used to constantly check the cars fuel mixture.

- Two in the rear section of the exhaust
  - M & W system (Wide band)
  - Dyno Dynamics system (Wide band)
- The OEM system (Narrow band) via the Delta Dash / EcuTeK PC Interface

The blower fan on the dyno was adjusted for maximum air flow to suit the Subaru radiators and Top Mount Intercooler design. For the Forester XT, the fan was also raised to maximize airflow to the scoop to suit the higher bonnet level.

TUNING

The aim of the trip was to first achieve a safe retune to suit the local lower RON fuel. Of secondary importance was to gain more performance but if we could get both it would be a win win situation!! ☺

Subaru state (on the petrol tank access flap) that the

- Impreza STi model should “use 98 Ron fuel”.
- Forester XT model should use “Premium Unleaded Fuel Only" (whilst the actual owner's Manual reads "Minimum Octane Number 95").

Obviously it was expected that the STi would react more favorably to the tune than the Forester, given that the STi was required to run on (min.) 98 Ron fuel only, whilst the Forester was tuned by Subaru for the lesser 95 Ron fuel to start with.

BASE POWER RUN

A base dyno plot was completed on both cars prior to any changes being made. This proved a valuable base to compare to as future changes were made. The runs on each car were completed for accuracy as quickly as possible, as air supply to the Top Mounted Intercoolers (TMIC) was not perfect. A period of time was allowed for between each run to ensure stable and constant air intake temperatures to ensure repeatability and consistancy.

AIR INLET CHARGE TEMPS.

It should be noted that any chassis Dyno, without a dedicated high volume air supply to cars with top mounted intercoolers, can be susceptible to massive heat soak (and resultant power loss). Typically front mounted air blowers have little charge air passing through the bonnet scoop to the TMIC. At the end of a single power run, the air inlet charge rises rapidly as the intercooler struggles to cool the compressed (boosted) inlet charge (Turbo compressor outlet temps are often well above 100 deg C).

If a second power run is begun too soon after the first, the TMIC will have little or no time to “recover” (from the first power run) resulting in alarming inlet temps, often resulting in a lower power and torque reading. Any more runs after this and its simply a waste of time.

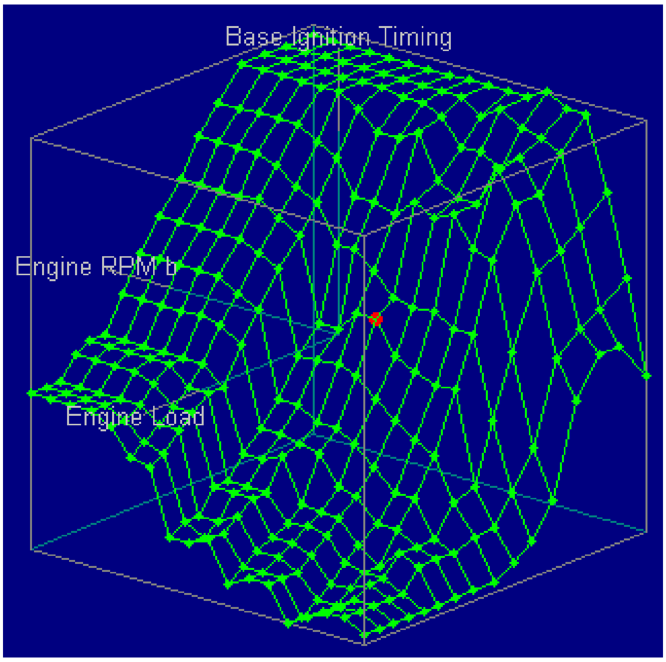
As the cars were slowly increased in spec and adjusted to suit the fuel, more power and torque could be gained. Boost was also adjusted to suit.

Power runs were constantly done, this allowed knock, boost, etc to be checked.

Rate of ECU learning, maximum threshold of ignition advance, boost control, peak boost, in gear boost and more were adjusted. Although it sounds complex, this is actually a very simplified description of the many adjustments that were made..!

At the completion of the dyno session both cars were again tested for final dyno plots, plus adjusted on the road for an additional 30 minutes.

(For more data on “Ron” and “Mon”, etc refer end of this document.)



Comments from Paul (The Tuner):

"The Subaru ECU is very intelligent, it can work with or against modifications as it constantly monitors inputs (Knock, fuel mixture, boost, etc) as well as outputs (injector duty, spark, boost, etc).

An example - if you fit, say an external boost controller, you may get factory standard power plus 10kw, but the potential with that boost increase is far greater when the ECU is correctly tuned. Why? The ECU will protect the engine when it gets feedback that it knows is not within its standard parameters. This means if the ECU was "tuned" or reflashed to suit the new external boost controller and NO other changes made, the car will be quicker for the same given boost.

A good example of the ECU protecting the engine is when the car hits "boost cut" or "fuel cut" due to high boost". This is one of the more obvious ones, however what a lot of people don't realize is there are many other hidden settings that can dramatically limit performance of the vehicle (E.G. Ignition and fuel control if knock is detected, etc).

What we do is work with the ECU and adjust the settings to allow the ECU to work WITH the new modifications, not against them!

With these cars we have been tuning today (where there were minimal or no modifications), we have worked within the ECU's abilities and settings to ensure it takes advantage of every possible gain with the low octane fuel. In doing this one of the things we have done is to adjust the maximum settings of the ignition tables, along with the rate at which the ECU adds and subtracts the timing through one of the many knock control tables.

All in all some great results working within the potential of the standard setup. As with some of the reports you may have read on other more modified models, retuning the factory ECU to work within its particular environment (whether standard with low RON fuel, mildly or wildly modified with good fuel, etc, etc) is one of the best ways to get the best possible performance AND drivability!"

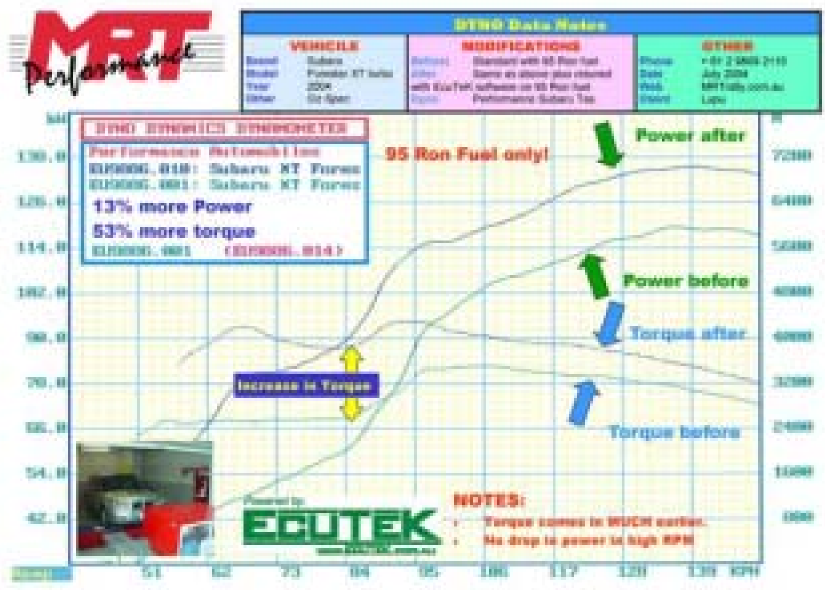
Results

For dyno graphs refer here in the main folder
ftp://ftp.mrtrally.com.au/Dyno-graphs/

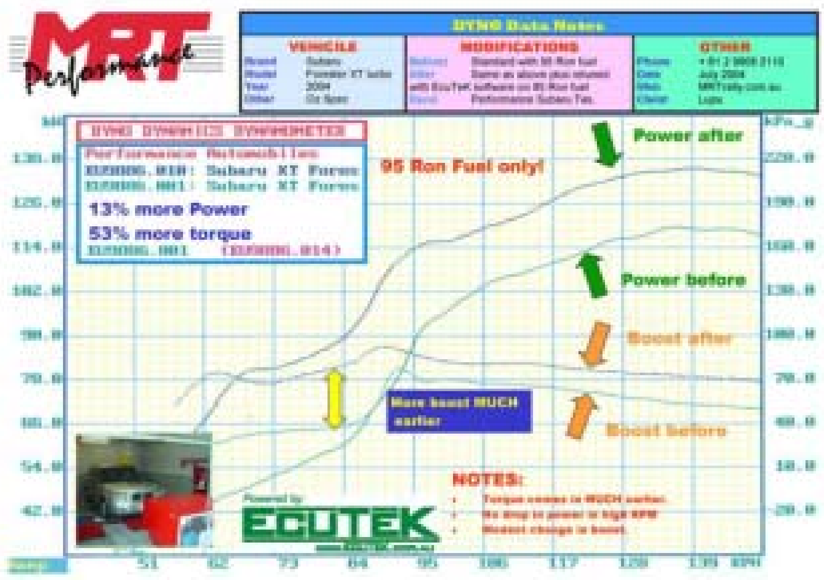
Forester

This car was a challenge as it is not required by Subaru to run on 98 Ron fuel, so its fair to assume the car is running well when we started!.
Note the massive increase in torque at low rpm's.
The same power as the car started with was achieved with the retune 30 km/h earlier !

Forester XT Power and Torque
ftp://ftp.mrtrally.com.au/Dyno-graphs/MRT-Forester-XT-2004-2500cc-turbo-95RON-fuel-std-Vs-plus-ecutek.jpg



Forester XT Power and Boost.
This map shows how the car comes on boost much, much earlier than standard, and how the overall boost was only changed by a very modest amount.
Also note that the boost plot is much flatter and constant than standard.
ftp://ftp.mrtrally.com.au/Dyno-graphs/MRT-Forester-XT-2004-2500cc-turbo-95RON-fuel-std-Vs-plus-ecutek-boost-plot.jpg

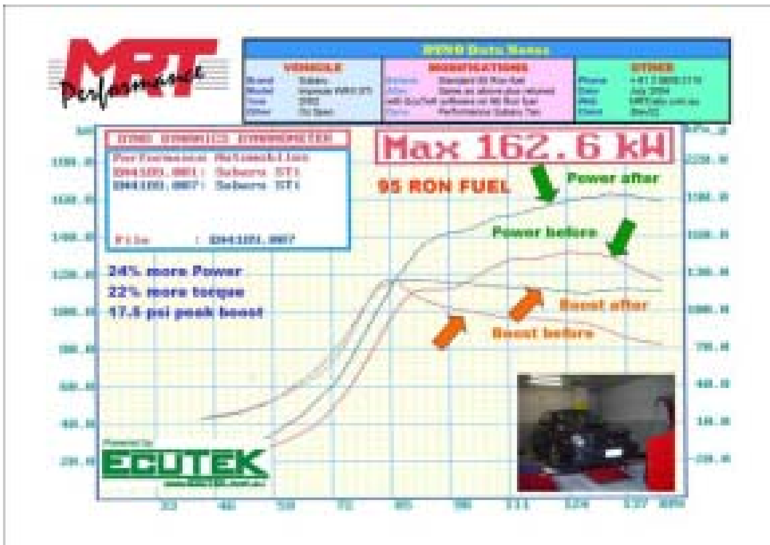


Impreza STi

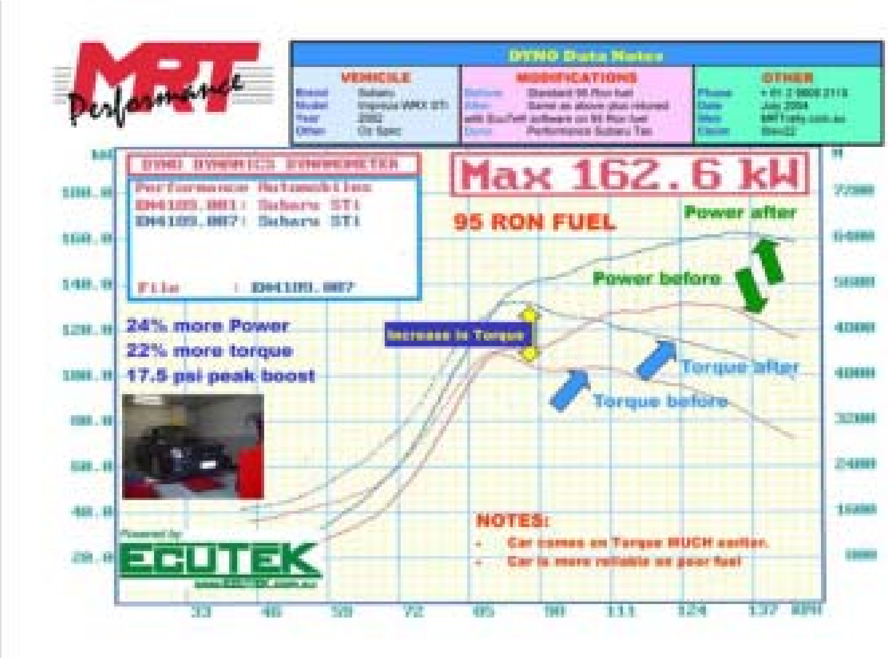
Boost Levels
Its important to note that we have not gained the power by simply winding up the boost. Look closely, you will note that peak boost is the same as the factory standard peak boost however the boost curve is flatter and more constant. The more consistent boost curve will be especially notable when driving the car as the vehicle will keep accelerating at a much stronger rate as it has much more torque.

Drivability
A common complaint of owners of 2001 onwards STi's is the disappointing lack of torque at low rpm. This is most notable when starting on a steep hill. The revised program (as shown) dramatically improves this weakness!! ☺

Impreza STi Power and boost (top graph)
ftp://ftp.mrtrally.com.au/Dyno-graphs/MRT-Impreza-STi-2002-95-RON-fuel-Std-vs-plus-ecutek-boost-plot.jpg



Impreza STi Power and Torque (middle graph)
ftp://ftp.mrtrally.com.au/Dyno-graphs/MRT-Impreza-STi-2002-95-RON-fuel-Std-vs-plus-ecutek.jpg



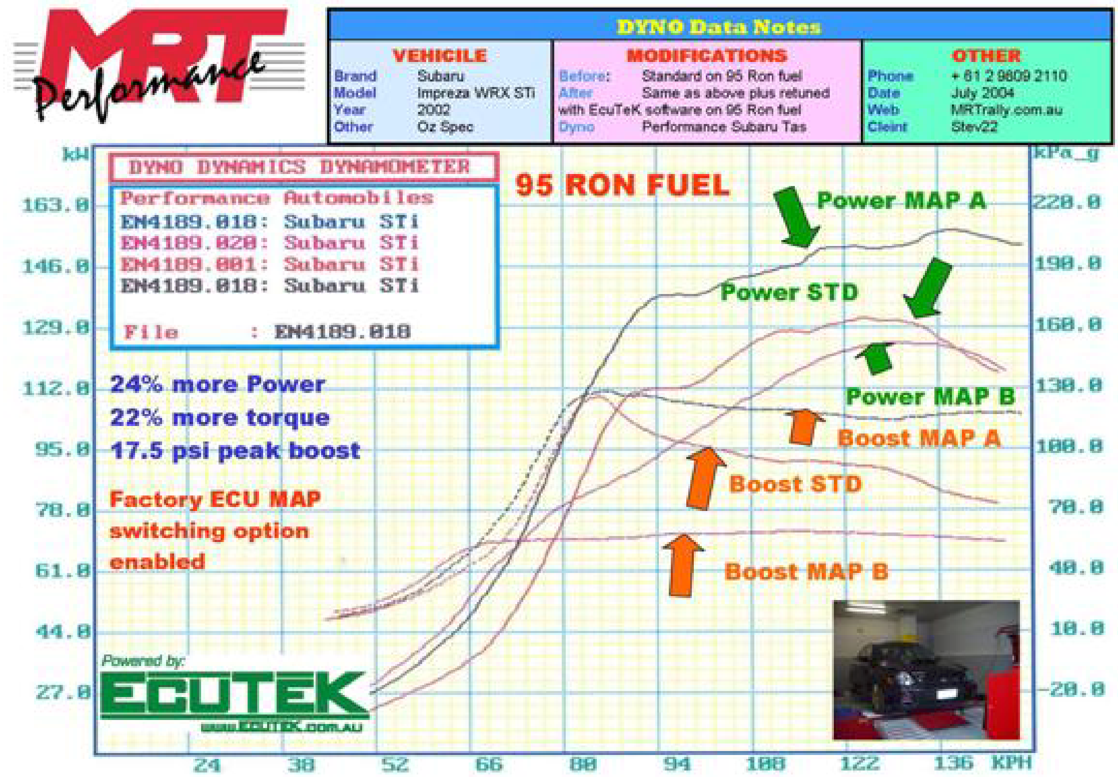
MAP SWITCHING

The customer also made the additional request for us to enable Map Switching, so that they could easily run two optimized maps (in this case one for high boost and one for low boost, although they could also have run one map to suit high octane fuel and one to suit lower octane fuel if they wished).

The graph below shows the two new power and boost plots compared to those of the standard car. Map A shows the new highest boost setting, with Map B the lowest boost setting and standard boost also mapped for comparison purposes.

For more info on MAP switching, refer here. (And the best part is no wiring mods are required!!)
http://www.ecutek.com.au/delta-ecu_repro.htm

ftp://ftp.mrtrally.com.au/Dyno-graphs/MRT-Impreza-STi-2002-95-RON-fuel-Std-vs-std-plus-ecutek-MAP-SWITCH.jpg



The Forester XT owner had the following to say (quoted from our forums)
http://www.mrtrally.com.au/forums/topic.asp?TOPIC_ID=18063

Gentlemen
Please accept my thanks for your opinions and experiences. Without all of your posts I wouldn't have been informed enough to take the step to have the Ecutek 2 installed.
To Brett and Paul of MRT: boys, you have performed magic!
First impressions are overwhelming. As all of you are enthusiasts, I am sure you can relate to my excitement. The XT is an absolute street jet! It now gives a massive shove in the back... It now spins the wheels if I'm not careful with the loud pedal... The engine now sings a song that makes my blood boil...
I will post some details of the dyno runs later but, for now, how does a tractive effort improvement of 50% down low sound? Yeah, I know... But wait, there's more!

He then later added…..
Gentlemen, from the hard copy dyno sheets I have done some simple calculations of the improvements gained following the EcuTek 2 upgrade. All figures are relative to the "before" baseline and partly explain the real life seat-of-the-pants feel on the road
At the respective speed points Km/h 51, 62, 73, 84, 95, 106, 117, 128, 139 and 140
the tractive effort increased by 37% 50% 56% 41% 29% 16% 14% 13% 15% and 14% whilst power ATW has lifted by 43% 50% 64% 50% 30% 15% 16% 15% 13% and 15%
How's that? Before starting down this road I was hoping the EcuTek could also deliver more down-low performance rather than just screaming power at the top end. Well, it certainly can!
In the 0-60 km/h or 0-80 km/h traffic light drag race nothing beats it, then again I haven't yet come across anything carrying the WRX or STi badge. In the Hobart wet weather hi-po 2WDs or hard-hitters like V8 Bombodores or Falcons don't stand a chance. Regardless of that, the XT now feels massively strong, with outstanding flat-out as well as in-gear acceleration.
I'm keeping an eye on the fuel consumption and will let you guys know what I find. It's early days but the average last week came to 12.5 l/100km, including the hours spent on the dyno and Paul's test drive... Not bad, considering... Best I ever got before EcuTek was 10.0 l/100 km and worst 13.0 l/100km
Next in line are new sway bars (F & R) and the F strut tower brace. Smilingjack is right about gravel roads - just perfect, but with tighter body control via the swaybars I expect same tidy dynamics to be achieved on tarmac as well
Cheers

Resources

www.EcuteK.com.au
www.MRTrally.com.au
Discussion page on topic
http://www.mrtrally.com.au/forums/topic.asp?TOPIC_ID=18148

Overall the end result was several very happy clients!

Brett Middleton
www.MRTrally.com.au/shop

For further data on RON, MON, etc, please read on!

MON RON PON Road Octane??

The following was copied from
http://www.motorcycle.com/mo/mcnuts/fuelron.html

At the beginning of the 20th century, engineers were perplexed by aircraft engines that were self-destructing for no apparent reason: One day, they would run fine, the next, the engine would hole a piston. Soon, they figured out that fuel detonation was the culprit, tracked the problem down to varying fuel qualities, and it became apparent that a standard fuel rating system was needed.

At the time, batches of fuel that weighed and seemed identical were not--there was a great difference in quality, even amongst ones that came from the same factory.

So the fuel manufacturers tried to rate fuels by through a series of chemical tests, which proved unreliable in determining which blend would "knock," or detonate, once used in the real world.

Consequently, special single-cylinder engines with variable compression ratios were developed as a standard test platform--all you had to do, theoretically, was crank the compression up until the fuel being tested began to knock, and then record it's High est Useable Compression Ration (HUCR). These engines were distributed to different fuel labs, and a standard was born.

Or so they thought.

After testing at different sites, it was found that the exact same fuel would produce different HUCR numbers, depending on the atmospheric conditions. It was then decided to pick two pure, readily available substances to calibrate all the test machines/si tes. Presumably, pure substances would give predictable, constant performance by which a standard "low" and "high" rating could be set.

The two primary reference fuels, **I**sooctane (2,2,4 trimethyl pentane) and *n*-heptane were arbitrarily chose and, again arbitrarily, assigned "octane" numbers of 100 and zero, respectively. Then, all test engines could be "zeroed" in with *n*-heptane, while an upper range could also be quantified with **I**sooctane.

Octane, by the way, turned out to be a poor name since the "octane rating" of the molecule *n*-octane (**C**8**H**18) is actually -17!

A fuel's "octane" rating is found by comparing it's knock characteristics with various mixtures of *n*-heptane and **I**sooctane. For example, a "octane" rating of 92 means that the fuel being tested, under standard conditions and running in a sta ndard engine, performs the same as a mixture that is 92 parts **I**sooctane, and eight parts *n*-heptane. Numbers higher than 100 simply specify the potential to perform better that pure **I**sooctane.

But since those early days of fuel standardization, the testing procedure has fragmented into several testing procedures, the most relevant being the Research Octane Number (RON), Motor Octane Number (MON) and the Pump Octane Number (PON).

The RON and MON tests use the same single-cylinder, variable-compression engine, but differ in that the MON test specifies a higher test RPM and inlet

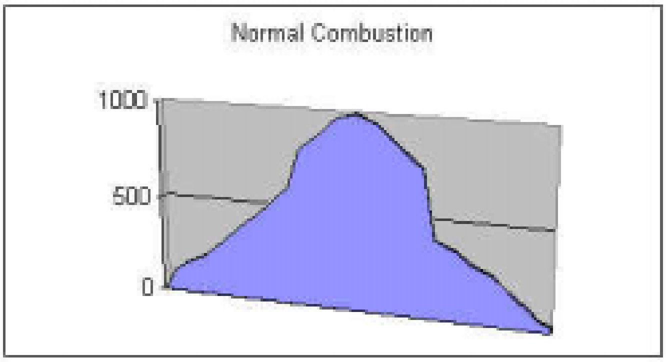
The following was copied from
http://www.shell.ca/code/motoring/encyclopedia/info/jargon.html

RON, MON and Road Octane:

RON stands for a fuel's Research Octane Number. This value is measured under fairly easy test conditions. The **MON**, or Motor Octane Number, is a tougher test measured at higher engine speed and temperature. And the **Road Octane Number** - the octane number that relates most closely to actual driving conditions - is the average of these two values, i.e. Road Octane = (RON + MON)/2. The Road Octane Number is more frequently referred to simply as the octane number. Always be sure that the octane number a vendor advertises is its Road Octane value, not its RON

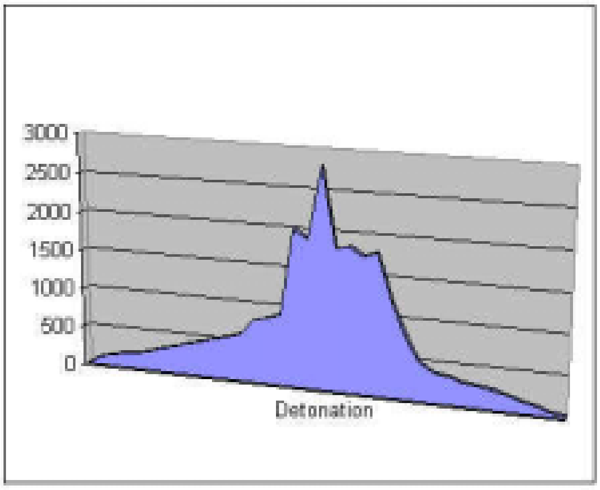
The following was copied from
http://www.ozsuperkart.net/TechArticles/Fuels.htm

The octane rating of a fuel is what most people are familiar with, but there seems to be a lot of confusion surrounding it. In simple terms the octane number you see at the pump is the average of two octane numbers; the Research Octane Number (RON) and the Motor Octane Number (MON) or (RON + MON) / 2. This final octane number is sometimes referred to as the Anti Knock Index or AKI. This pump octane number is a measure of the anti- knock characteristics of a given fuel.



MON and RON are determined by standardized ASTM laboratory tests. The details of the tests are not as important as what they mean in terms of performance. Low to medium-speed knock characteristics are determined by the Research (RON) method, while high-speed and partial throttle heavy load knock characteristics are determined by the Motor (MON) method. MON testing is conducted under more stringent conditions with the timing on the test engine advanced and run with a higher inlet air temperature, so the MON number tends to be lower but also more valid for high-performance applications. There are a number of more valid tests that have been developed to determine the anti-knock characteristics of fuels used in high performance engines, but the aren't in general use at this point so we are stuck with the old reliable pump octane number.

So what's that knocking sound coming from my engine?



The Knocking sound you hear when your engine is in trouble are the result of abnormal combustion. The most common combustion problems are detonation and pre-ignition. In simple terms detonation is the uncontrolled burning of the fuel in the combustion chamber, while pre-ignition can be defined as the starting of the burning process by any source other than the spark plug usually before the plug has fired.

To truly understand what detonation is, its important to understand that if you raise the temperature of any combustible mixture high enough, it will ignite on its own. This is sometimes called the "spontaneous combustion point" or the "auto ignition temperature". Detonation is a rapid uncontrolled rise in cylinder pressure caused by all or part of the fuel mixture reaching this auto-ignition temperature.

Following the ignition process through a cycle should help complete the explanation. As the piston rises and compresses the trapped mixture the pressure and temperature begins to rise. The spark plug fires somewhere before the piston reaches Top Dead Center (TDC) and starts burning the compressed mixture in the cylinder and as a consequence raises the combustion chamber temperature. While this burning is taking place, the piston is still rising and still compressing the air/fuel mixture which raises the cylinder pressure, and combustion chamber temperature even higher.

At this point, the pressure rise in the cylinder is very rapid, but it generally proceeds at a fairly even controlled rate. The remaining unburned mixture and the end gases at the edges of the combustion chamber are being raised to extremely high temperatures as the advancing flame front compresses and heats up the mixture directly in front of it. This activity before the flame front reaches the end gases at the edge of the chamber are sometimes called **pre-flame reactions**. The longer it takes for the complete burning to take place the greater the chances that these pre-flame reactions will force the end gases to reach the auto ignition point and cause a rapid uncontrolled pressure rise, along with a huge increase in cylinder temperature. If brought to the auto ignition point the end gases of the combustion chamber can cause a pressure and frequency rise that is high enough to be audible.
That's the KNOCK or PING that you hear. Ideally, the burning of the mixture will be completed before any of these end gases have an opportunity to reach the point of auto ignition. If the ignition timing is set correctly this should happen around 15-20 degrees After Top Dead Center (ATDC).

It's hard to visualize the immense pressures we are talking about in the combustion chamber. In a normal combustion cycle the pressures can easily reach 100 times the trapped compression ratio, that's 800-1300 psi banging away at the piston crown and cylinder head and bearings. Once an engine starts to detonate the pressures can reach 3 to 4 times that high. The pressure rise during detonation can be almost instantaneous, so it's easy to see why the edges of the piston can be broken away during these cycles. It's like having a small bomb go off in the engine.

As you may have guessed from the earlier discussion of octane numbers, high octane fuels have a considerably higher auto ignition temperature to keep these pre-flame reactions from causing sudden uncontrolled pressure rises. If the charge burns fast enough or the fuel is resistant enough to auto ignition (high octane) then all is well and the pressure rise isn't too extreme. Hopefully it should be fairly clear that if you can shorten the burn time (10% to 90% burned) enough then the octane requirement of the engine will be reduced. As a general rule, the first half of combustion 0-50% burned, speeds up in direct proportion to rpm, while the 50-100% burned time speeds up exponentially with rpm. So all other things equal, the faster you spin an engine, the faster the charge will burn and the more knock resistant the engine will be. Small bore, high rpm motors are by design, very knock resistant.

We defined pre-ignition previously as the starting of the burning process by a source other than the plug. This has the same effect as advancing the timing. This causes the engine to be subjected to huge amounts of heat, because the piston and cylinder walls are subjected to the burning process for a longer period of time, this in turn raises the combustion chamber pressure. It's possible for pre-ignition to melt the top of pistons because of the extreme temperatures that this advanced timing causes. Keep in mind that any time you raise the temperature in the cylinder you get a corresponding rise in pressure , or conversely raising the pressure also raises the temperature. So it's easy to see how pre-ignition and detonation are very closely linked.

So it pretty much boils down to this. If you can control the pressure and temperature in the combustion chamber , things will go along with out too many problems. But once you cross that temperature/pressure threshold a number of interrelated actions can take place that causes all hell to break lose. High octane fuel is one way to keep the carnage in check.

How much octane do we need?
Cylinder pressure is one of the key factors in determining the octane requirement of an engine. Intake valve closing time on four-stroke engines, and exhaust timing on two-strokes will have a major influence on the dynamic cylinder pressure . It's a commonly held misconception that higher Octane fuel slows down the flame speed which keeps the engine from knocking. Flame speed is a function of fuel chemistry, not the Octane rating. The component make up of the fuel will determine the flame speed whether it's a high octane fuel or not. . Racing fuels designed for high rpm applications tend to have higher flame speeds than normal to help reduce burn time. There isn't much time available to complete the combustion cycle at 10,000rpm, so choosing the right fuel can really make a difference. Choosing a faster burning fuel will allow you to run less ignition advance, and ultimately make more power at higher revs.