The Benefits of the Saturday Car Talk Meetings
~ or where does the Hp. go? !

By Bob White

At the July Saturday "car talk" get together, one of the coffee (or was it lemonade) drinkers asked, " …. on the Bugatti Veyron there's a Hp gauge , but does it only show 1000 Hp at the car's top speed? " The answer, to get ahead of ourselves a bit, is no. Still it is a good question, or at least a prelude to the real question which is, where does the Hp go, and when.

So I will try to answer the question and some if its corollaries such as:

….. when should you shift for max performance.

….. why do (and the new 997 PDK is of this type) some cars have a higher top speed in a lower gear, i.e., 6^{th} rather then 7^{th} as with the PDK .

….. what consumes the Hp?

….. etc.

For the mathematically challenged I will try to avoid " math " as much as possible but if you see an equation don't stop, just skip over it and keep reading and looking at the figures. The example used to answer the questions and illustrate the results is a generic 997S. However, you can use any vehicle you wish, such as your Porsche, or for that matter any other car. One caveat, though, is that you need to know something about the whole "car". Fortunately for most PCAers your car's Owners Manual together with information from the Porsche.com web site under technical information can supply what is needed.

So let's start with the most basic question of where and how the engine Hp is used when driving your car. Imagine you go out to your car and it won't start so you decide to push it out of the garage. You push (you actually apply a force to some point on the car) and it moves (you hope).

The force you apply must overcome, in no particular order, the resistance or friction of the tires, any slope you push the car up or down, any forces due to the air flowing over the car, the inertia of the weight (the engineers will please excuse my not using mass here) due to acceleration, and friction in the bearings etc. The latter is usually lumped in with the tire friction.

Putting this in some kind of "equation" form gives

The applied force = aerodynamic force + tire and bearing friction force + any acceleration force + up or down hill forces against gravity

Each of these is can be expressed in a form that allows the calculation of their numerical value. As an example let's say you are driving your 997S at a steady 100 mph on a flat road. Then the force required would be (no acceleration since steady speed and no hills)

F, in pounds = rolling + aerodynamic = 58.14 pounds + 156.32 pounds = 214.46

Those of you who want do some calculations for their particular car or are just interested in the details of how these numerical values are calculated will find information at the end of the article.

The Hp now = F, in pounds x car speed in feet/sec divided by 550
= 214.45 x 146.666/550 = 57.2

Making this same calculation for a range of speeds gives the results show in the figure below.

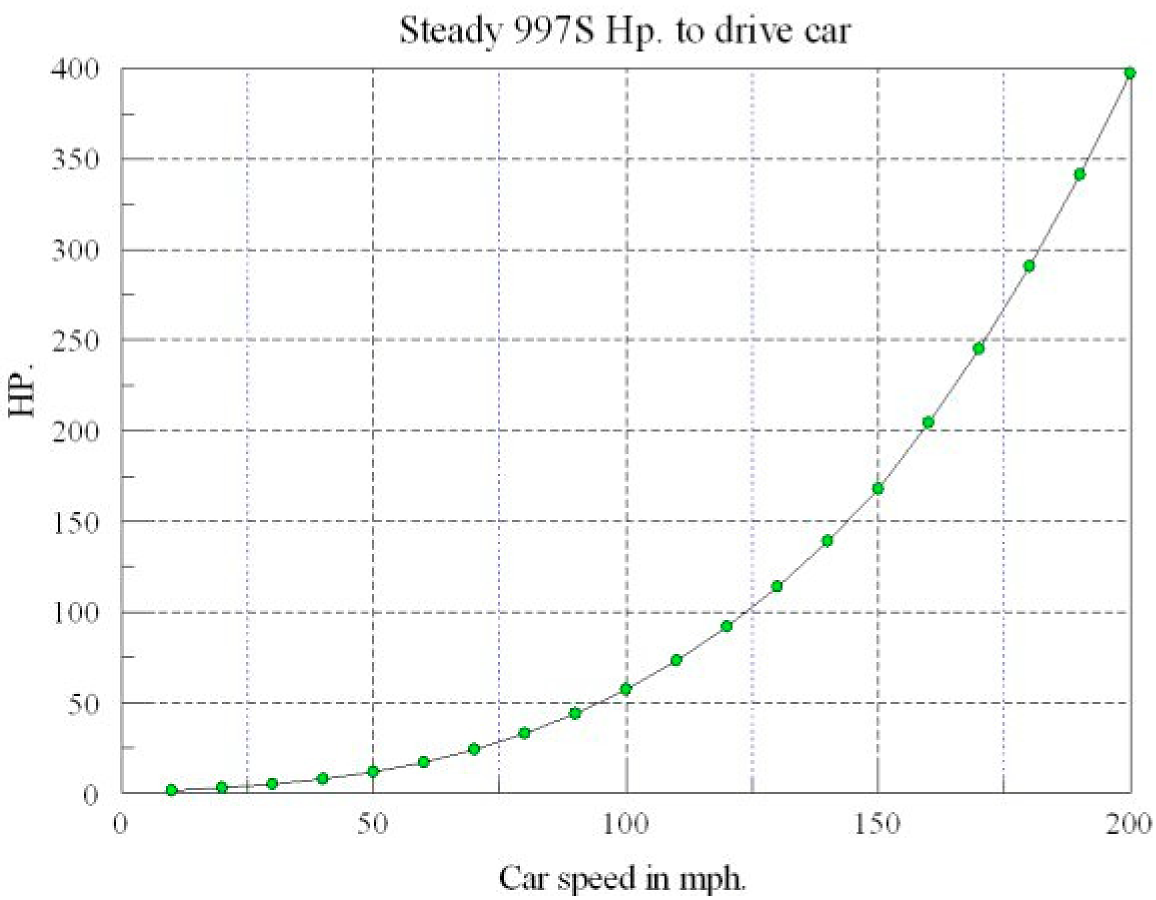

Figure No. 1 Required Hp to drive the car at steady speed

You can see from this figure that the Hp to drive the car goes up VERY quickly (with the cube of the speed actually) as the speed increases. You can also see that a 997S with its 355 Hp should be able to get to about 190 mph. The factory says 184 or so and I will explain later that this is due to the final gear ratios and the speed is engine rpm limited. It is also interesting to note that it only takes about 57 Hp to go 100 mph. The remaining 298 Hp is available for accelerating the car and is what gives the car the great passing and hill climbing capability on the road.

You may ask why such a large reserve. The answer is the cars weight. For performance weight is the enemy. A quick example tells the story. If you are driving 35 mph in first gear and stomp on the gas (there's a Corvette next to you?) a 997S will accelerate at about 0.9 gees. The force required and power can be calculated from one of Sir I. Newton's (1642 to 1727) Laws, i.e.

Force = Weight x accel in gees

So F = 3470 x 0.90 = 3123 pounds and Hp = 3123 x 51.23/550 = 291 Hp !!
Also note that the steady Hp at 35 is only 6.5 Hp,

How important is weight? Pretty obvious from the above but in human terms it means watch your weight. If I weighed 250 instead of 160 the extra 90 pounds would increase the above to 298.4 hp or an extra 8.5 Hp. Think about that when you look at what it cost to up the power output of your car. It is possible get an extra 8.5 Hp by changing the exhaust system for something like $1000 to $1500.

The remaining part of the question that needs to be looked at is how does the engine power get to the wheels and the magnitude of the other power consuming terms, i.e. the inertia and uphill/downhill requirements. The engine Hp at any rpm is known from the factory Hp and torque curves published in the Owners Manual.

For the 997S this is

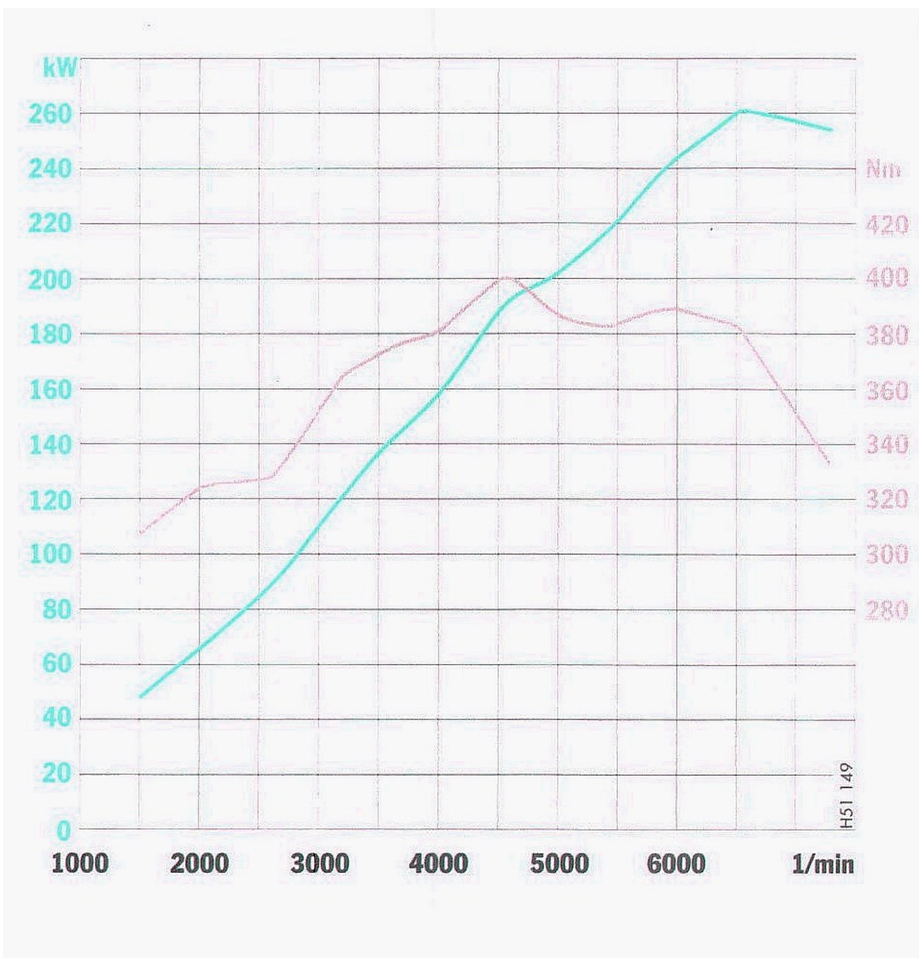

Figure no. 2 Engine Hp and Torque from the Owners Manual

The factory values are in the metric system so to convert to English units divide kW by 0.745 to get Hp and multiply Nm by 0.7374 to get foot-pounds.

For the engine power to get to the wheels it must pass through the transmission/differential and axle/tire to the ground. Some of the older Owner's Manuals included curves showing the car speed in each gear (for a given differential ratio) as a function of the engine rpm. If your manual does not have such a diagram it can be calculated from the gear ratios and tire diameter. For the 997S the gear ratios are given below.

Transmission Ratios 2007 997S

Differential Ratio 3.44 to 1 Manual Transmission

Gear	Ratio	Overall Ratio (ratio x diff. ratio)
1 st	3.91	13.45
2 nd	2.32	7.98
3 rd	1.61	5.54
4 th	1.28	4.40
5 th	1.08	3.72
6 th	0.88	3.03

Tire Size Rear 295/30 ZR 19 (100Y) XL, effective radius 1.067 Ft.

Using this information one can calculate the transmission engine rpm versus vehicle speed relationship shown in the next figure. Note that these are straight lines and can be extended to higher rpm values.

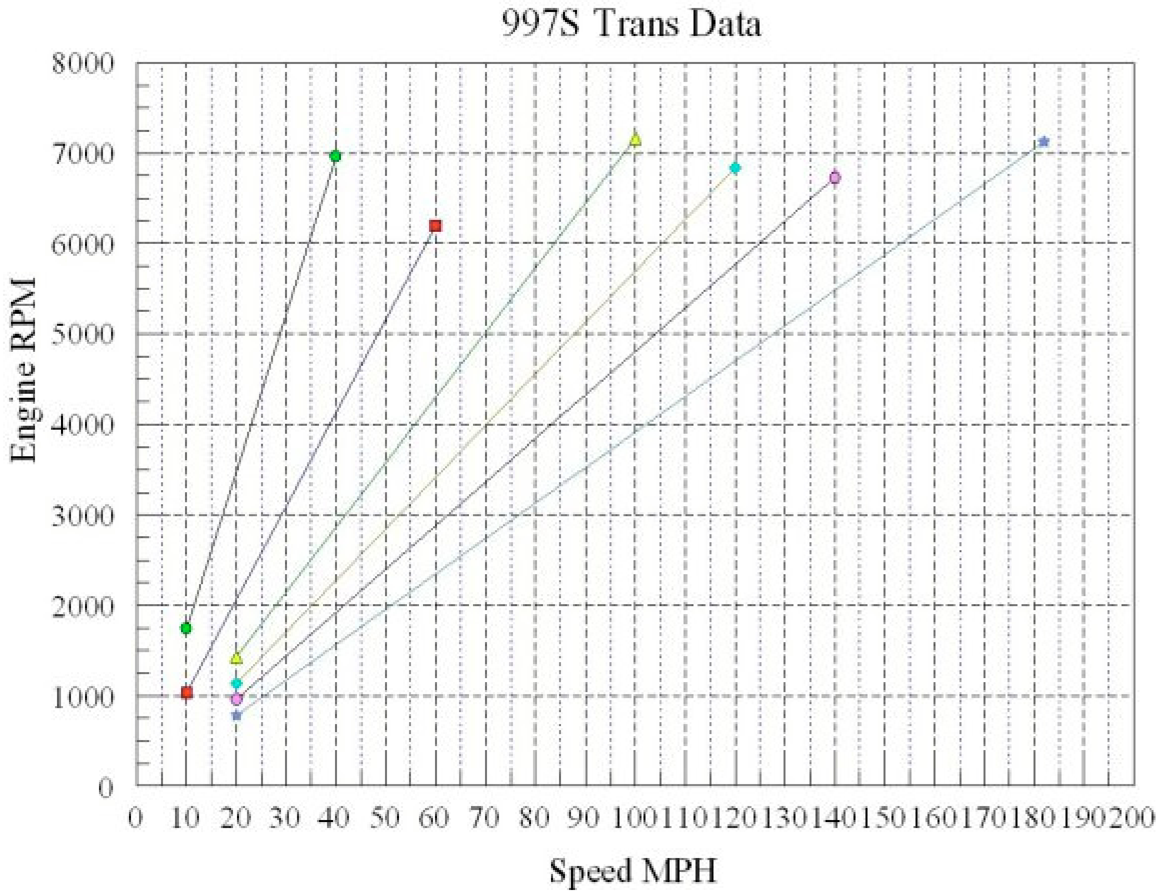

Figure No. 3 Engine Rpm and Vehicle Speed for Each Transmission Gear Ratio for a Given differential Ratio (in this case 3.44:1).

All of the information needed to answer the questions above is included in the figures above. It is only necessary to “pick off” the appropriate values and plot them into the Hp versus car speed plot, Figure No. 1. This is a process that is actually very straightforward so don’t be alarmed. The steps are:

> Go to the engine Hp graph and find a Hp at a rpm
> … at 1500 rpm you find 64.3 Hp (after conversion from kW)
> Next go to the transmission data curve and find the speed at the same rpm
> …. At 1500 rpm you find 8.4 mph for 1st, 14.8 for second, and so forth
> You now plot these points into Figure no.1, Hp versus car speed.
> Now do the same at 2000 rpm and so on to max rpm plotting each value.

This results in a new version of Figure No. 1 with the Hp available in each gear compared to that required to drive the car. The next figure shows this modified plot.

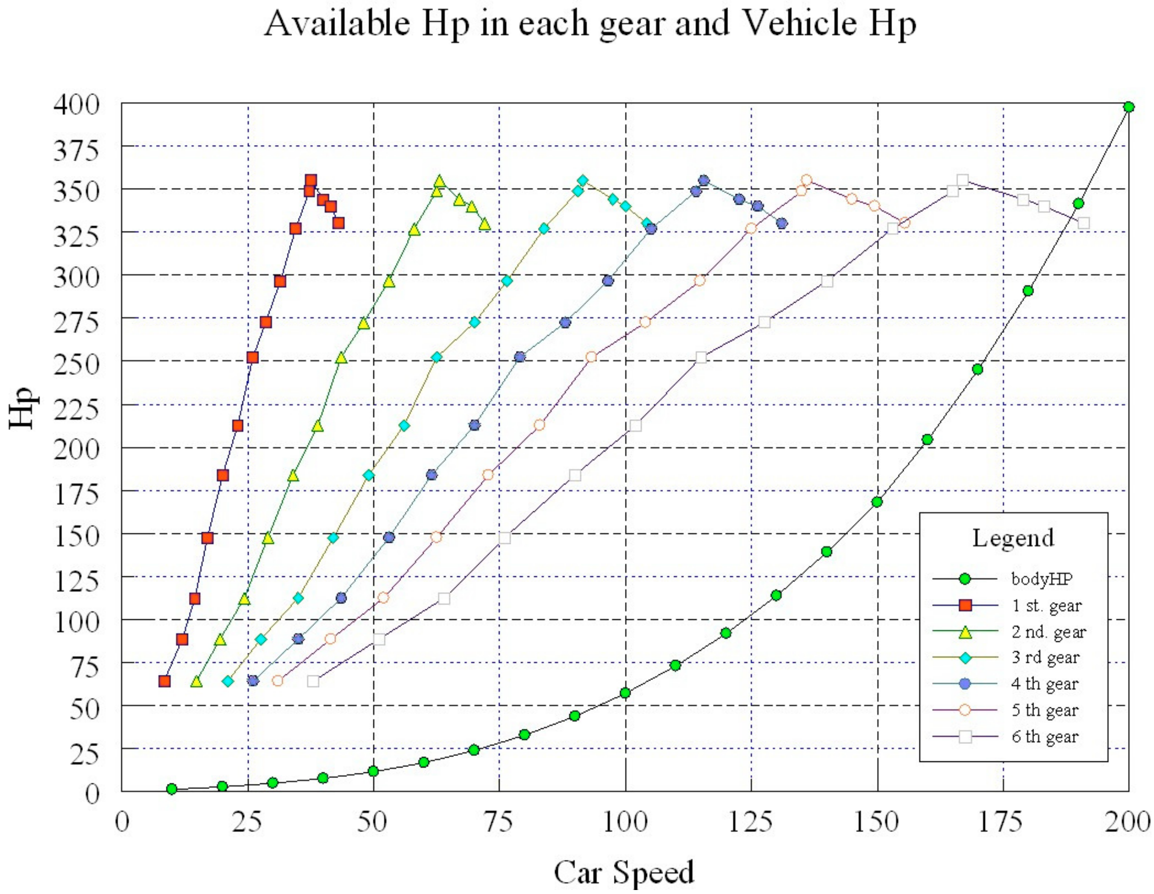

Figure No. 4 Hp Available in Each Gear and Hp to Drive the Car at Any Speed

This figure contains all of the information needed to answer the questions following the first paragraph. Let's start with "when should I shift gears for maximum acceleration?" Looking at Fig. no. 4 you can see that in 1st gear there is always more Hp available, the difference between Hp in first subtracted from the bodyhp, than at any speed if you shift into 2nd. For example, if you are in 1st at 25 mph you have about 250 Hp available but if you shift into 2nd you would only have about 120 Hp. So when accelerating from a stop you don't shift from first to second until you are at the redline for maximum performance. The same is true for 2nd gear since the second gear available power curve does not cross over that of 3rd.

Third (3rd) and 4th just touch the body power curve at the redline so nothing is to be gained by shifting sooner. However, 4th and 5th cross so shifting a few 100 rpm lower than the redline would make available more Hp in 5th rather than 4th. Fifth (5th) just touches 6th, as in 3rd to 4th, so the shift point is back to the redline.

In 6th there are no additional gears so the intersection with the bodyhp curve determines the top speed. Note that this occurs below the redline. Further, the Hp at the maximum speed point is LESS than the maximum available from the engine and the top speed is limited by an rpm slightly below the redline. If a 6th gear were chosen such that the engine maximum Hp occurred at the cross over point the maximum speed would be about 3-1/4 mph higher. At these speeds the difference between 188 and 191 mph is somewhat academic unless you are specifically trying for maximum speed. However, the current ratio will provide better acceleration in the normal highway speed range. The transmission table above shows that the current overall ratio is 3.03. For maximum top speed 6th gear would need to be changed to 0.762 from the current 0.88 giving an overall ratio of 2.62:1 This means that the rpm at top speed would be 6600 rather than the current value of 7350, a substantially lower value. This shown in Figure No.5

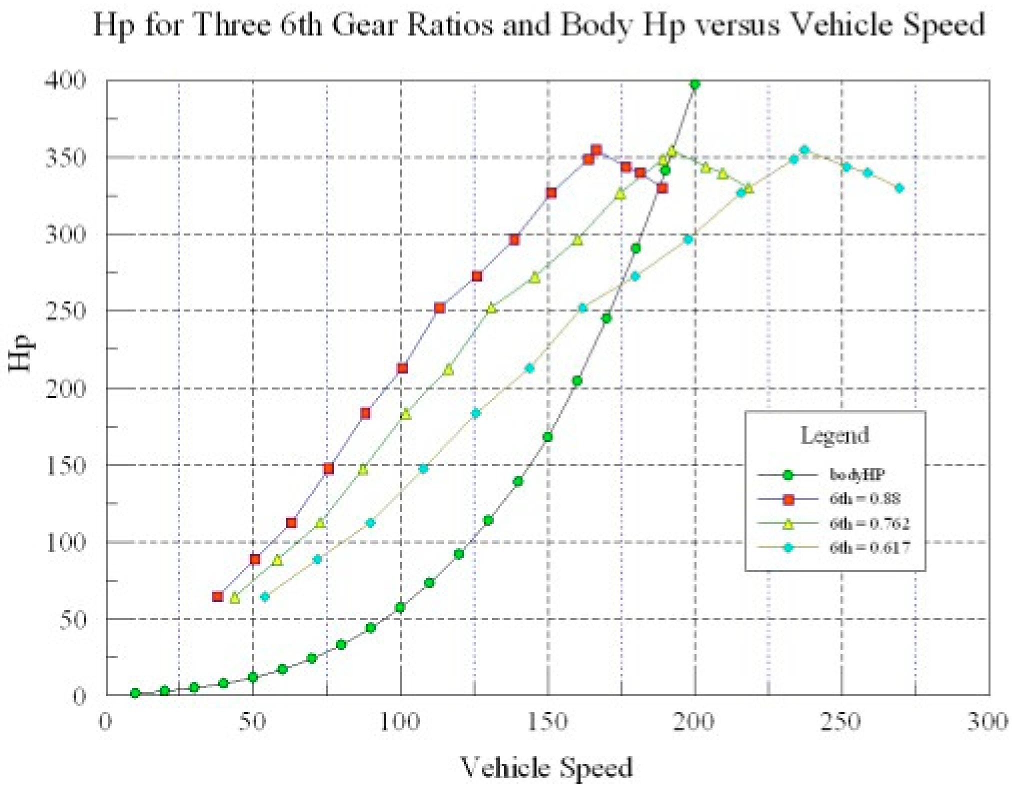

Figure No. 5 A comparison of the Effects of Final Transmission Ratios

A seventh gear as in the new PDK, which has a lower numerical ratio of 0.617 instead of 0.88 as in the manual gear box, gives an overall ratio of 2.12 which reduces the engine speed and fuel consumption, noise, and wear but would reduce the vehicle top speed. Again see fig. no. 5 above. Acceleration would also be reduced. The following table clearly lists these effects for top speed and acceleration power at 75 mph.

Comparison of Acceleration Potential and Top Speed For Three Different 6th or 7th Gear Ratios.

6th or 7th Ratio	Hp available at 75 mph.	Top Speed
0.88	121	188.0
0.762	93	191.3
0.617	63	175.0

The reduction in top speed is 13 mph compared to the standard ratio 0f 0.88. However, the rpm at a cruising speed of 75 mph drops from 3000 rpm to a remarkable 2090, two thirds of the standard value. The power available for accelerating (without a down shift) is only 63 Hp, however, compared to 121 Hp. Depending on the fuel injection, and with the new direct injection as on the new 997 leaner mixtures are possible, this would give better fuel economy and thus reduced emission per mile as required in Europe.

So enough is enough, and this is probably more than you wanted to know. It was my intention to include sample calculations for those interested in the details. However, as I wrote them up it became evident to do them clearly would add several pages. Consequently, anyone who would like detailed examples of the calculation process can email me at r-white1@illinois.edu and I will send them to you and will also answer questions the same way. I have also written a computer program to do the calculations and have a second one which also calculates the entire acceleration curve etc. and am willing to provide them on request. However, these require some knowledge about how to use computer as a computer and not just as a gaming machine, word processor, or means of surfing the internet.