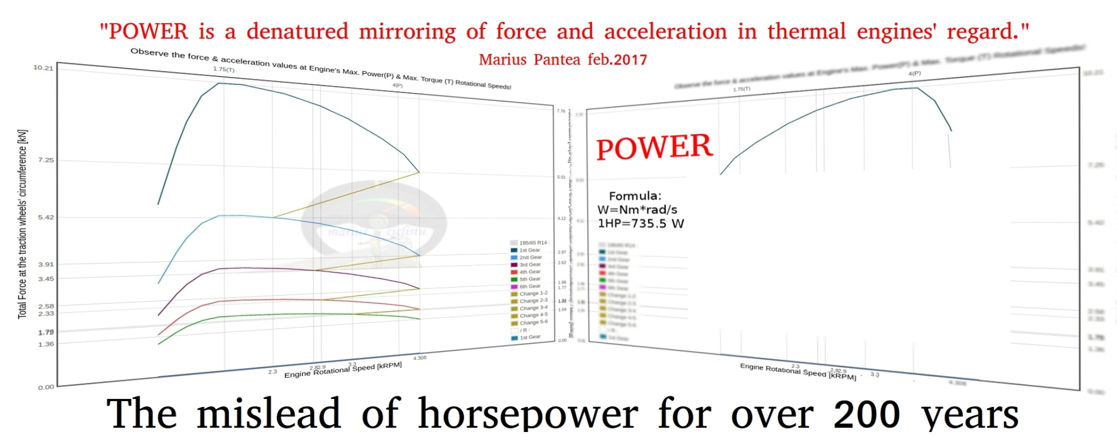
Chapter 5 – The power's mislead in thermal engine's regard

The disappointment experienced in the last rally made me expand the simple online tyre size calculator I had made in the past, by developing free online calculators and comparators for:

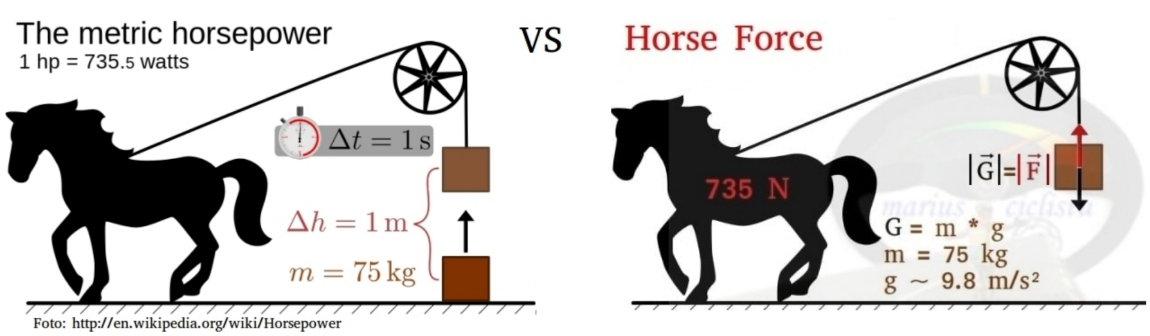
- car, motorcycle and bicycle transmissions;
- tyre friction force based on its treadwear;
- car cost per kilometer;
- fluid resistance (including air friction force);
- power, rpm and torque relation;
- torque, force and arm relation.

The reason was that I wanted a way to compare, in an objective manner, the accelerations of two cars or of the same car with different wheels diameters, as the maximum power or maximum torque in relation with the car's mass comparison was not so clear.

By February 2017 my conclusion was clear: **"Power is a denatured mirroring of force and acceleration in thermal engines' regard."**



And now let me explain how I draw this conclusion. I found out the origins of the horsepower. James Watt patented a steam engine in 1781 and defined the horsepower as the work done by a horse in a second while lifting a mass of 75 kg, 1 meter from the ground. Toking that hypothesis and the fact that power is synonymous with force outside physics, so some people perceive it as force, I defined the horse force required to lift 75



kg at a constant speed. The constant speed means 0 acceleration, 0 acceleration means that the sum of the forces that act upon the load is 0, so the horse force is 735 N while horsepower is 735.5 W. Taking into account that:

ENERGY[J] = WORK[J]

and

WORK[J] = FORCE[N] * DISPLACEMENT[m]

and

POWER[W] = WORK[J] / TIME[s],

that means:

POWER[W] = FORCE[N] * DISPLACEMENT[m] / TIME[s],

so for translation movement:

POWER[W] = FORCE[N] * SPEED[m/s]

and for rotational movement:

POWER[W] = TORQUE[Nm] * SPEED[rad/s]

but in both cases:

POWER[W] = ENERGY[J]/ TIME[s],

so putting *powerful car* in the same sentence with *fast car* is like saying that an *employee makes many toys* because it has a *big salary.* A big salary does not guarantee that the worker will produce many toys. Let's say his salary is 5000 euros per month. Does that tell you how many toys does he make in one month? No, you must look at the toys and count them in order to know that. You can just assume he makes many toys, but how many exactly?

When talking about thermal engines, each one produces a certain amount of rotational force measurable with a dynamo-meter. That rotational force is not the same on all the rotational speed range, so a graph is made representing the "number of toys" the engine is producing. For my Lancer, that curve is the green one from the graph below.

The power graph is calculated, pay attention, not measured, but calculated from the torque graph with the formula **POWER[W] = TORQUE[Nm] * SPEED[rad/s]**. **That power represent the energy[J] per time[s] that is transformed into torque [Nm].** For example at maximum power of 55 KW the engine has 6000 rpm and the torque is 87.54 Nm. In translation, at 6000 rpm, in each second, the engine is transforming 55 KJ (euros) into 87.54 Nm (toys).

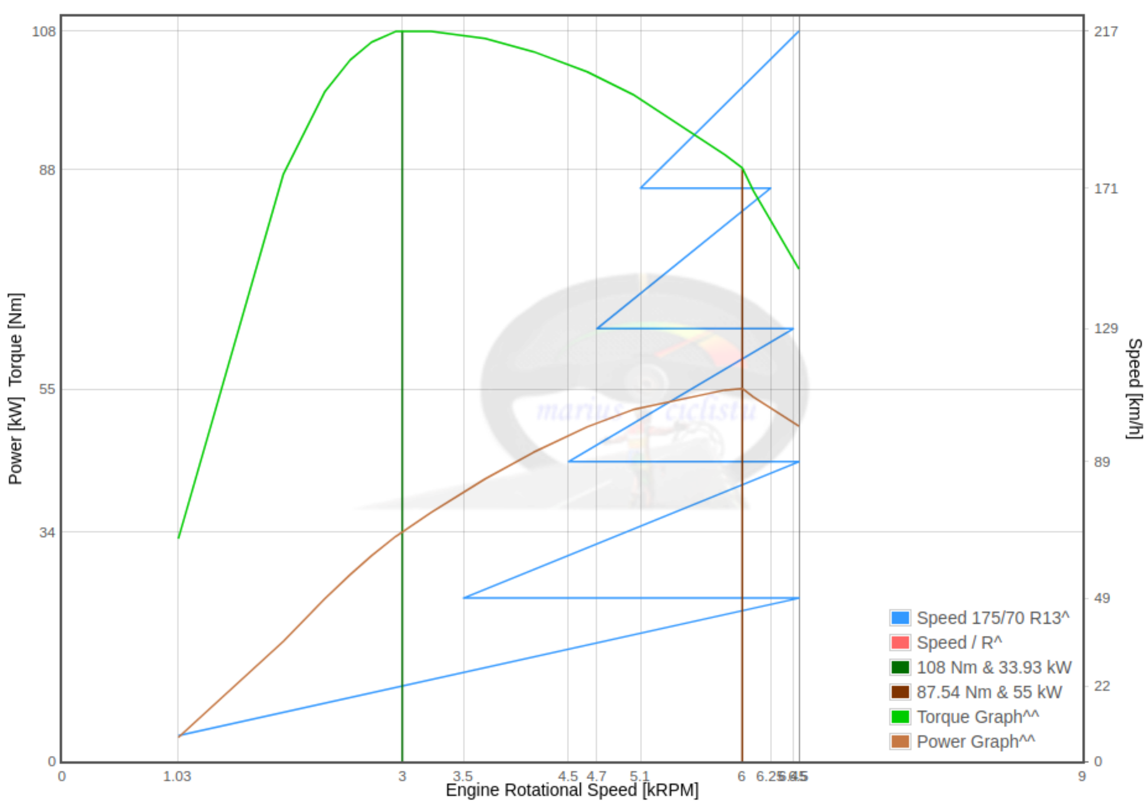
Now let's see the result at maximum torque of 108 Nm. At that torque and its rotational speed, the power has a value of 33.93 KW. In translation, at 3000 rpm, in each second, the engine is transforming 33.93 KJ (euros) into 108 Nm (toys).

It is worth mentioning that the calculated power via torque and rpm does not represent the entire amount of energy per time consumed by the thermal engine to produce that torque, as the thermal engine efficiency is under 30% in most cases. So if we assume a 30% efficiency of transforming energy to torque, you can clearly see that at 3000 rpm the productivity is higher (108 "toys" with 33.93 "euros" meaning a theoretical overall cost of 113.1 "euros", resulting 1.05 "euro/toy") than at 6000 rpm (87.54 "toys" with 55 "euros" meaning a theoretical overall cost of 183.33 "euros", resulting 2.09 "euro/toy").

As we are discussing about a perfect environment, the losses generated by the friction in the transmission, tyres etc. are neglected. That means that the power calculated at the engine's flywheel is the same as the power at the traction wheels.

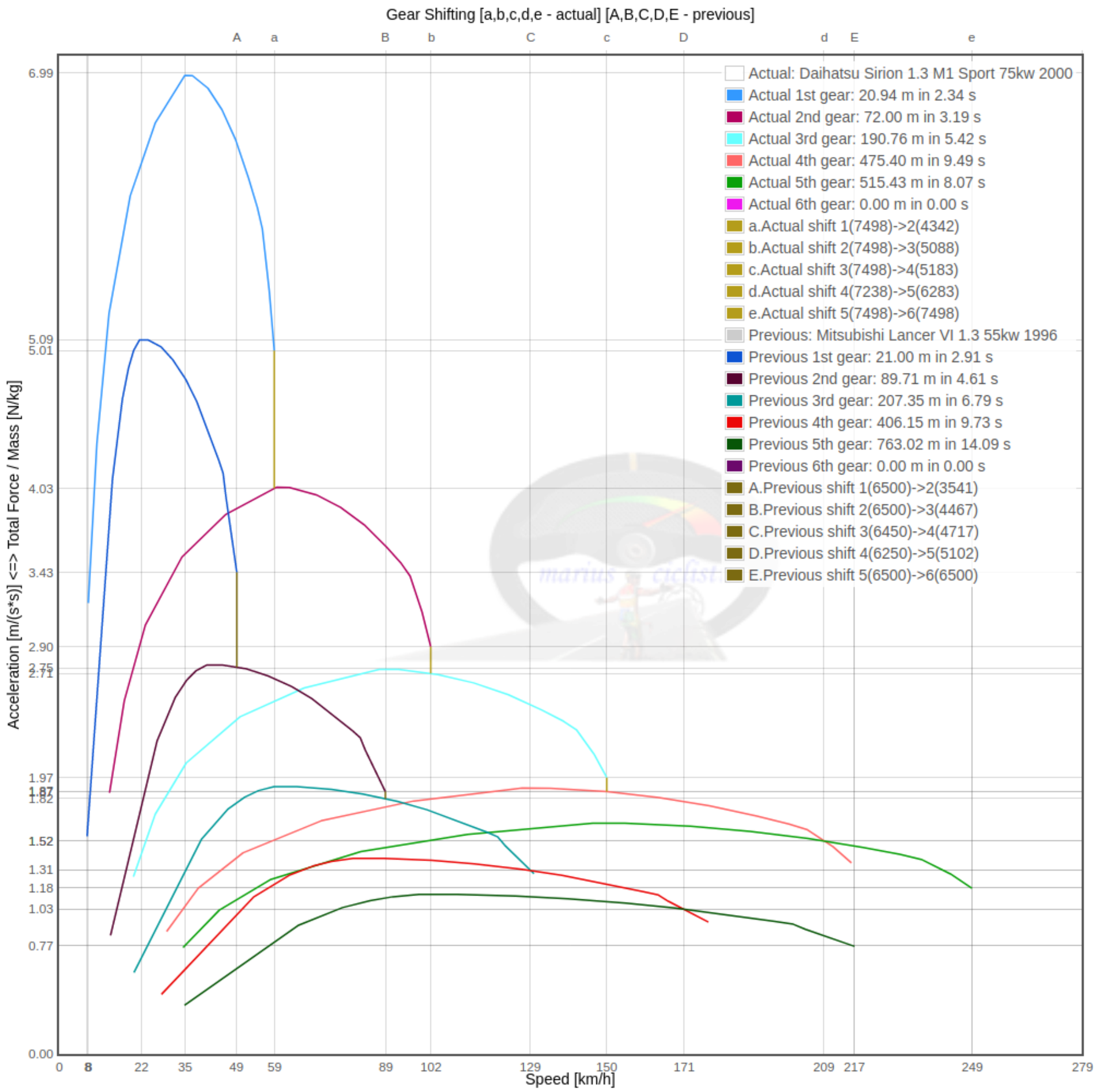
The torque however, is not the same in these two spots but it will always be directly proportional with the force generated by the engine through the transmission at the traction wheels' circumference. Pay attention that in theory, if the car has 2wd, each wheel will have a half of that force at its circumference and for a 4wd car each wheel will have a quarter of that force at its circumference.

The acceleration is force divided by mass so as **force is directly proportional with the torque**, **the acceleration will also be directly proportional with torque** meaning that if we want to compare the accelerations of two cars, we look at the torque's graph, not at the power's one. You will reply by saying: "*But power is also directly proportional with force as it is a multiplication of rotational force and rotational speed*", but bear in mind that **the torque varies with that rotational speed** resulting three rpm intervals: idle rpm – maximum torque's rpm, maximum torque's rpm – maximum power's rpm and maximum power's rpm – electronic limitation's rpm. In the graph below these intervals are between 1025 and 3000, 3000 and 6000 respectively 6000 and 6500 rpm. In the first one the torque is rising and the power is rising. In the second one, the torque starts to drop as the power is still rising, so here the two are indirectly proportional. In the last one the torque continues to drop while the power is also dropping. Does this prove that **power is not directly proportional with force**?

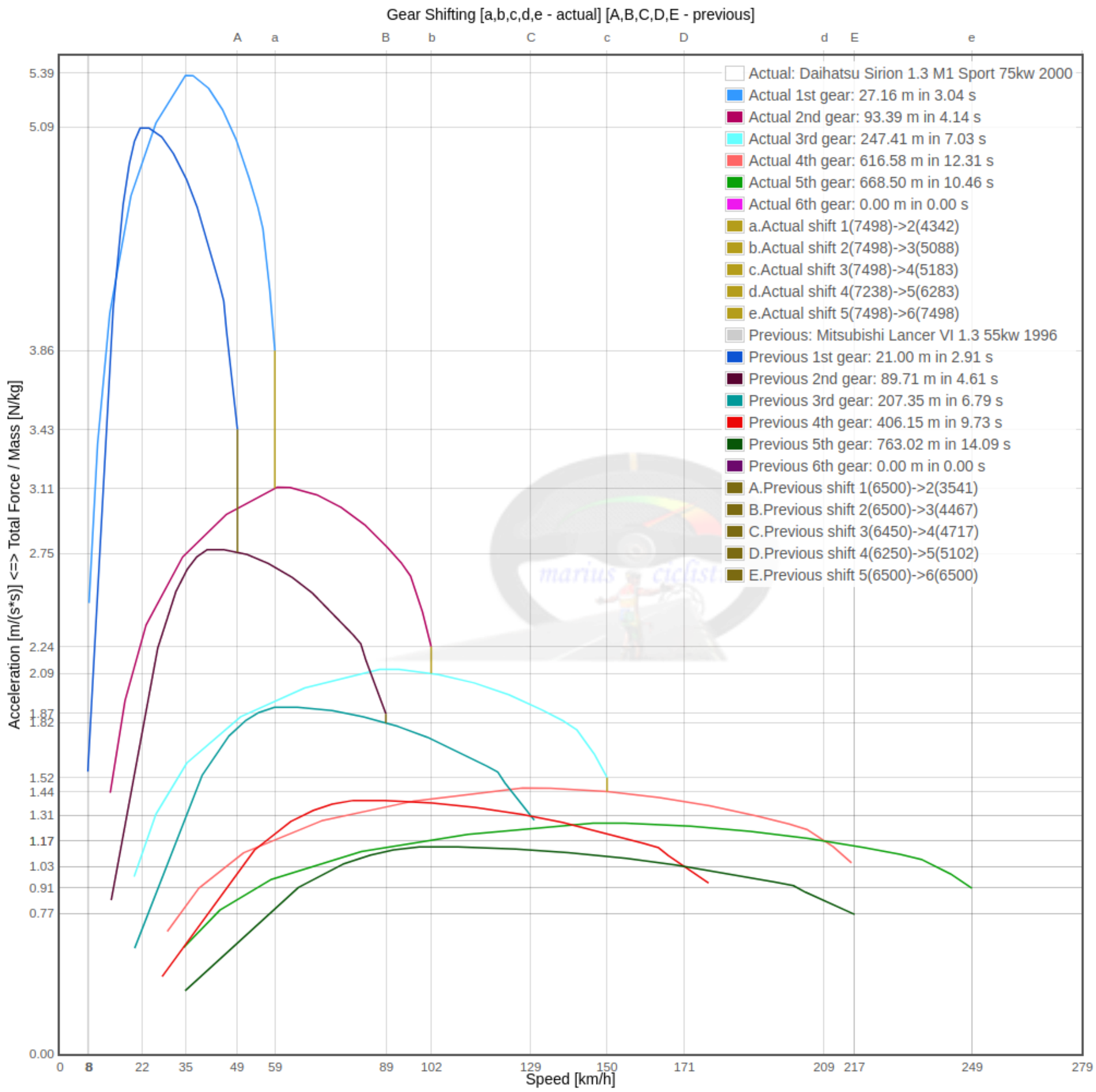


Now let's see how the gear ratios from the transmission act when the car is accelerating to answer the question you just thought about after reading my above explanation: “***How do you explain that a car with higher horsepower accelerates faster that one with smaller horsepower?***”.

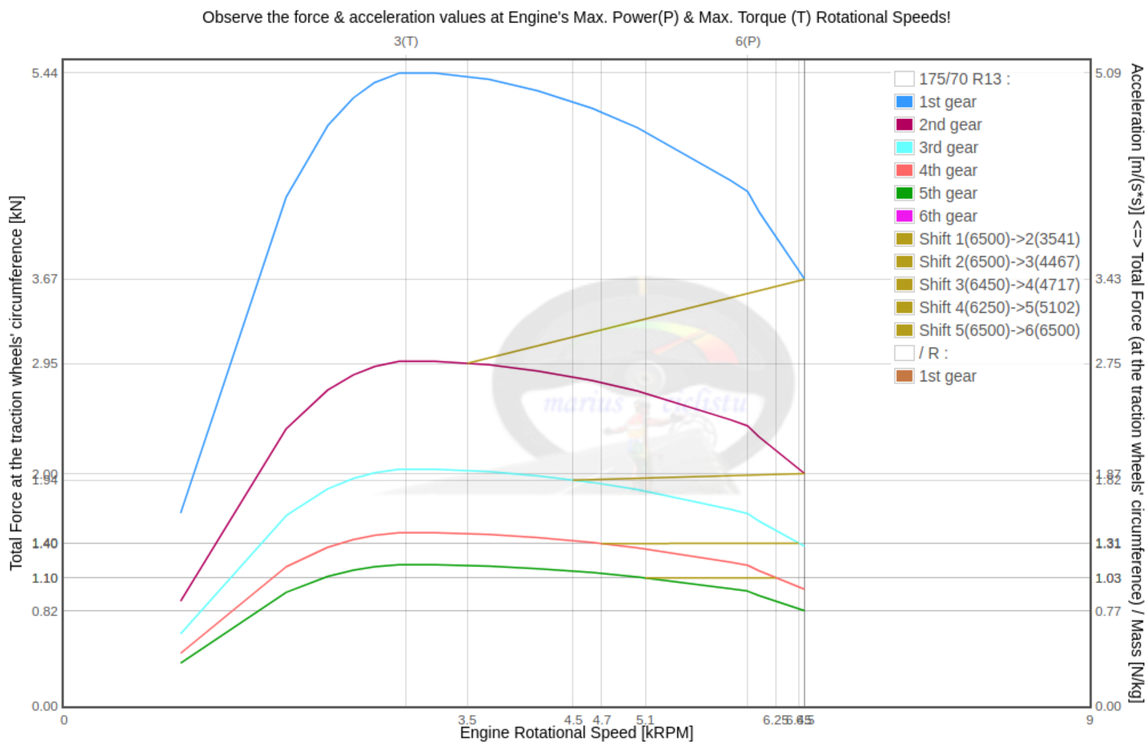
In the graph above, the blue line represent the speed while going through the rpm range in the most efficient way for obtaining the best acceleration: 1025-6500 in 1st, 3541-6500 in 2nd, 4467-6450 in 3rd, 4717-6250 in 4th and 5102-6500 in 5th. Notice how all the rpm intervals include the maximum power’s rpm (6000) and that in 3rd, 4th and 5th gear the intervals are smaller. That is the effect that the transmission's gears has on the behavior of the engine, making it run mostly around the maximum power’s rpm, not around the maximum torque’s rpm. Below is an example of 825kg with 75 KW @ 7000 rpm and 120 Nm @ 4400 rpm VS 1070 kg with 55 KW @ 6000 rpm and 108 Nm @ 3000 rpm.



The Sirion covers 1274.54 m approximately 6 seconds faster than the Lancer does but if the Sirion would had also 1070 kg, then it will be only approximately 3 seconds faster. In the graph below you can see the acceleration's comparison for each gear. I'll explain the distance over time calculation a bit later.



Now let me open your eyes to see why **maximum horsepower is a very vague way of looking at a car's best acceleration** and why **the rotational speed at which the maximum power occurs has nothing to do with the best gear shifting rpm values for each gear, when we want the best possible acceleration.** I say horsepower because it produces more mislead than the watt does, in fact both being units of measure for power or for energy over time to be more specific.

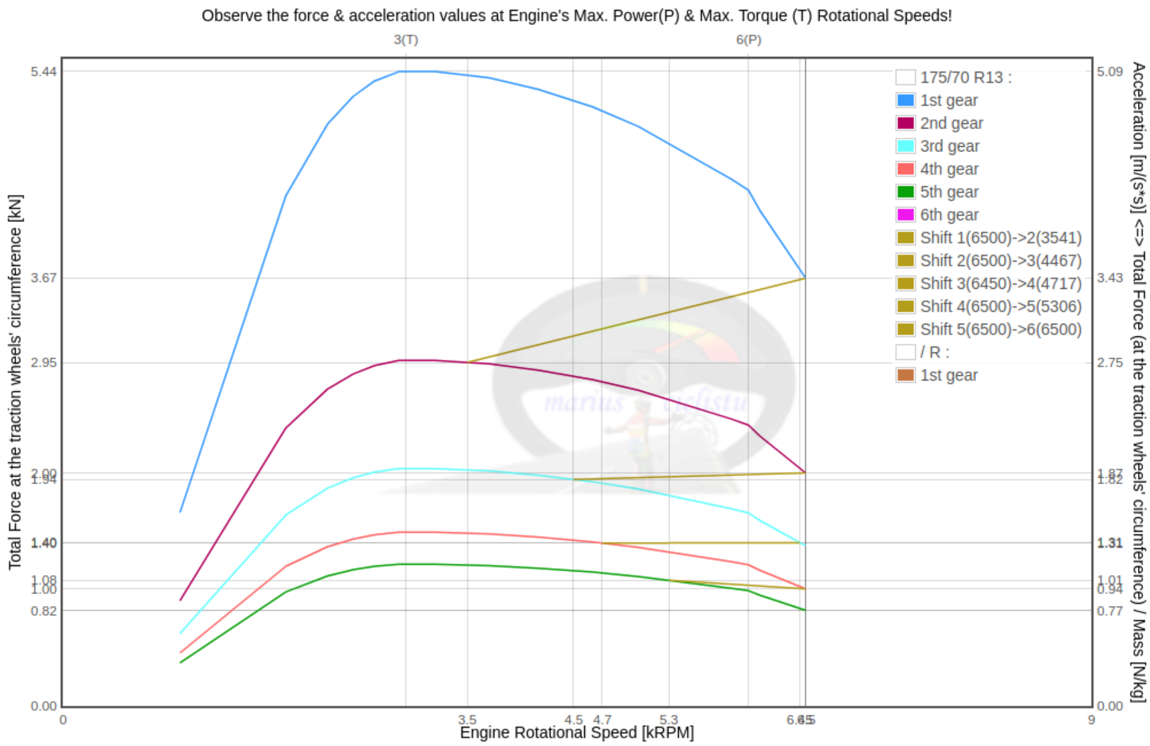


The graph above displays the force at the traction wheels' circumference and the acceleration generated by that force when acting upon the car, as I already explained that the two are directly proportional, depending on the rotational speed of the engine.

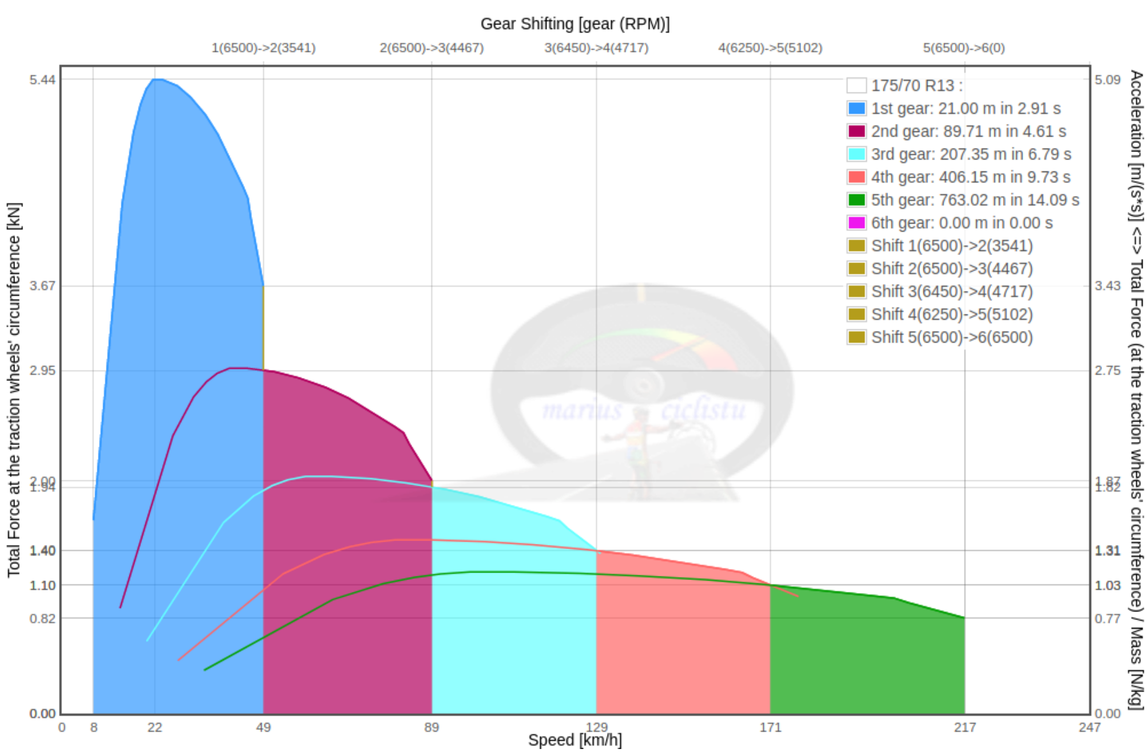
If you want to better understand the force's unit of measure from the left axis, you can transform the kilo-newton in horse force. For example 5.44*1000/735 = 7.40 horse force that means the equivalent of 7,4 real horses in front of the car at maximum torque (3000 rpm) in 1st gear. As a comparison, the force value at maximum power (6000 rpm) in 1st gear is 4.41*1000/735 = 6 horse force, **so the maximum power generates 1.4 horse force less that the maximum torque.**

Looking at the blue line, the engine starts from 1025 rpm and revs up until 6500 rpm, then the second gear's brown line takes over and revs up from 3541 to 6500 rpm and so on. You may notice the gold colored lines between 3rd,4th and 5th gears are horizontal and that the optimal gear change rpm is neither the end of the rpm range, as it is in 1st and 2nd gears' case, nor the maximum power's rpm. If you still wonder why, just think about it.

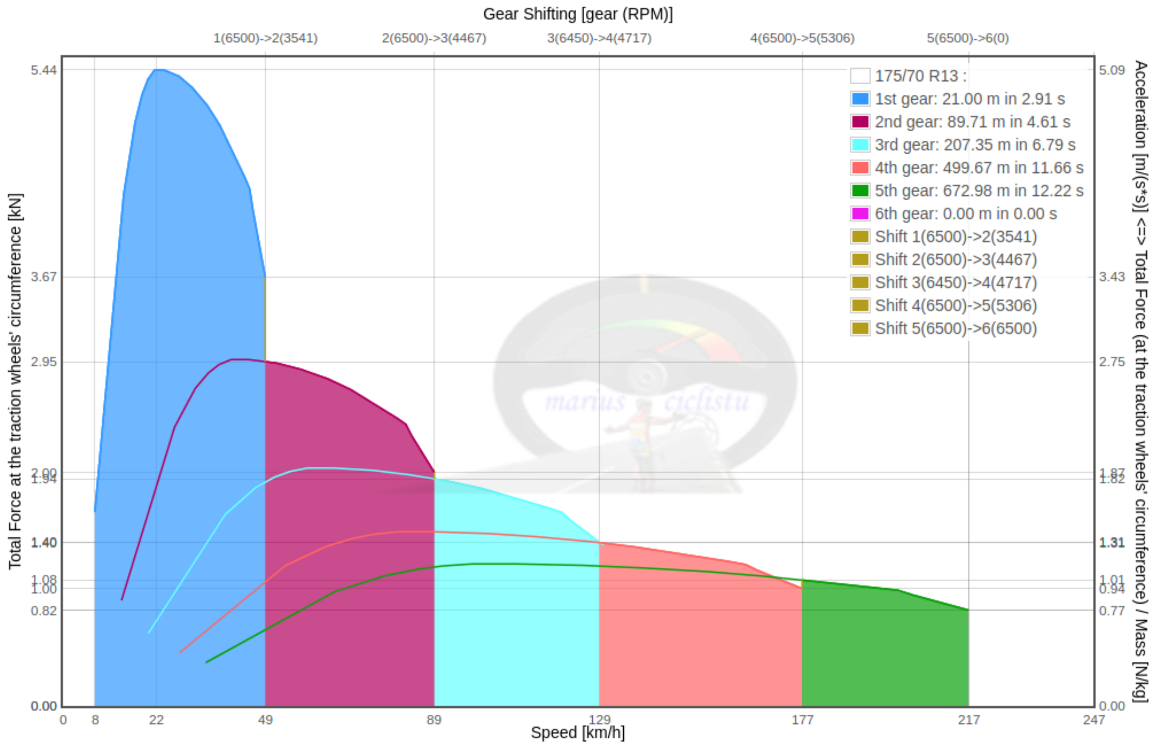
If in 4th gear for example, you go over 6250 rpm to 6500 rpm, the acceleration before changing into 5th (**0.94 m/s^2 seen in the graph below**) and the one from 5th just after the shift (**1.01 m/s^2 seen also in the graph below**) would be less than it would had been in both gears if you would had shifted at 6250 rpm (**1.03 m/s^2 seen in the graph above**).



But let's see that acceleration difference by changing the rpm with the speed on the horizontal axis. This is the graph while changing from 4th to 5th at 6250 rpm:

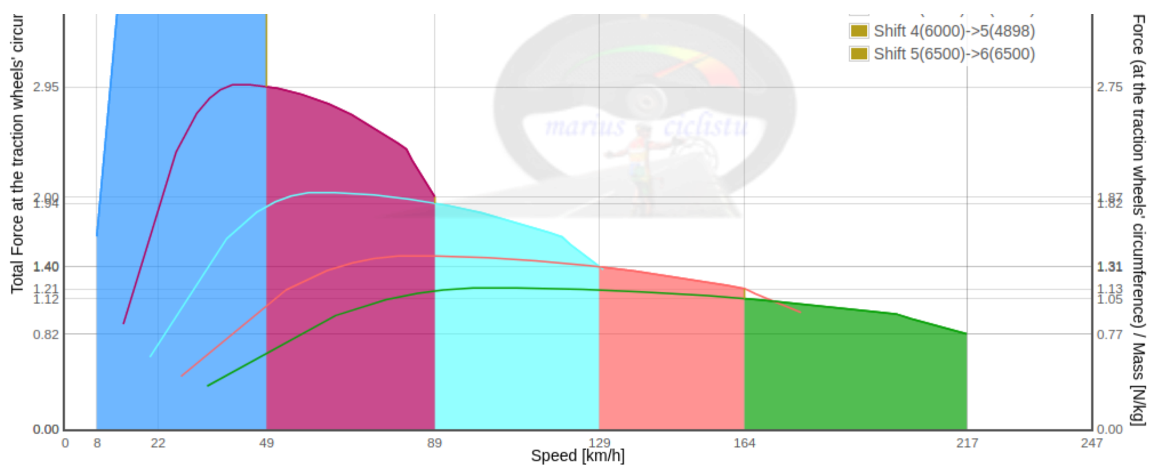


And this is the one while changing from 4th to 5th at 6500 rpm:



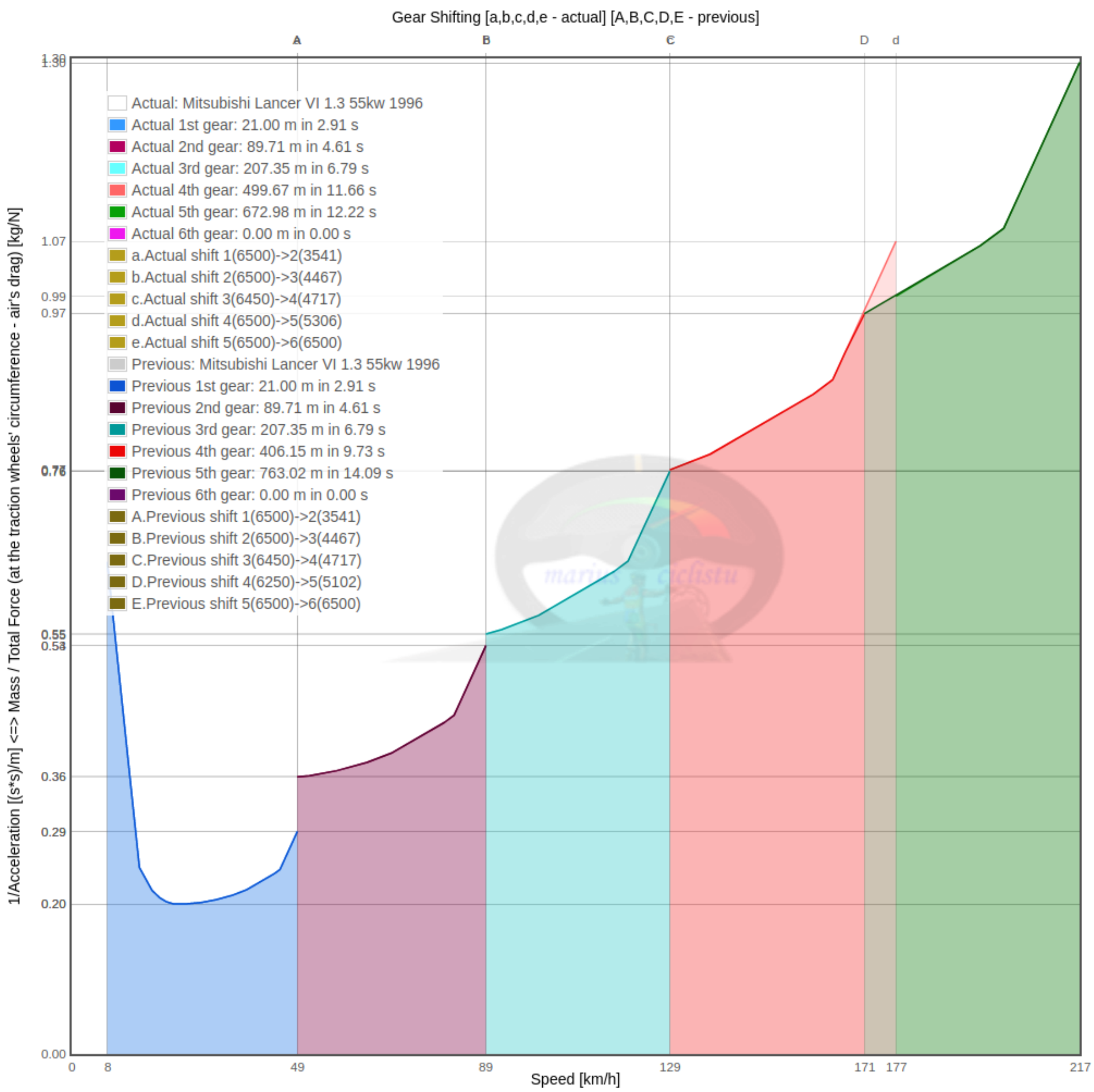
The filled areas represent the values of the acceleration, the higher the better. Observe the area between 171 and 177 km/h from the above two graphs and the values of the acceleration from the right side (bear in mind the air friction and other losses are excluded).

The same is valid if the gear change from 4th to 5th would be made at the maximum power's rpm (6000) as it can be seen in the graph below:



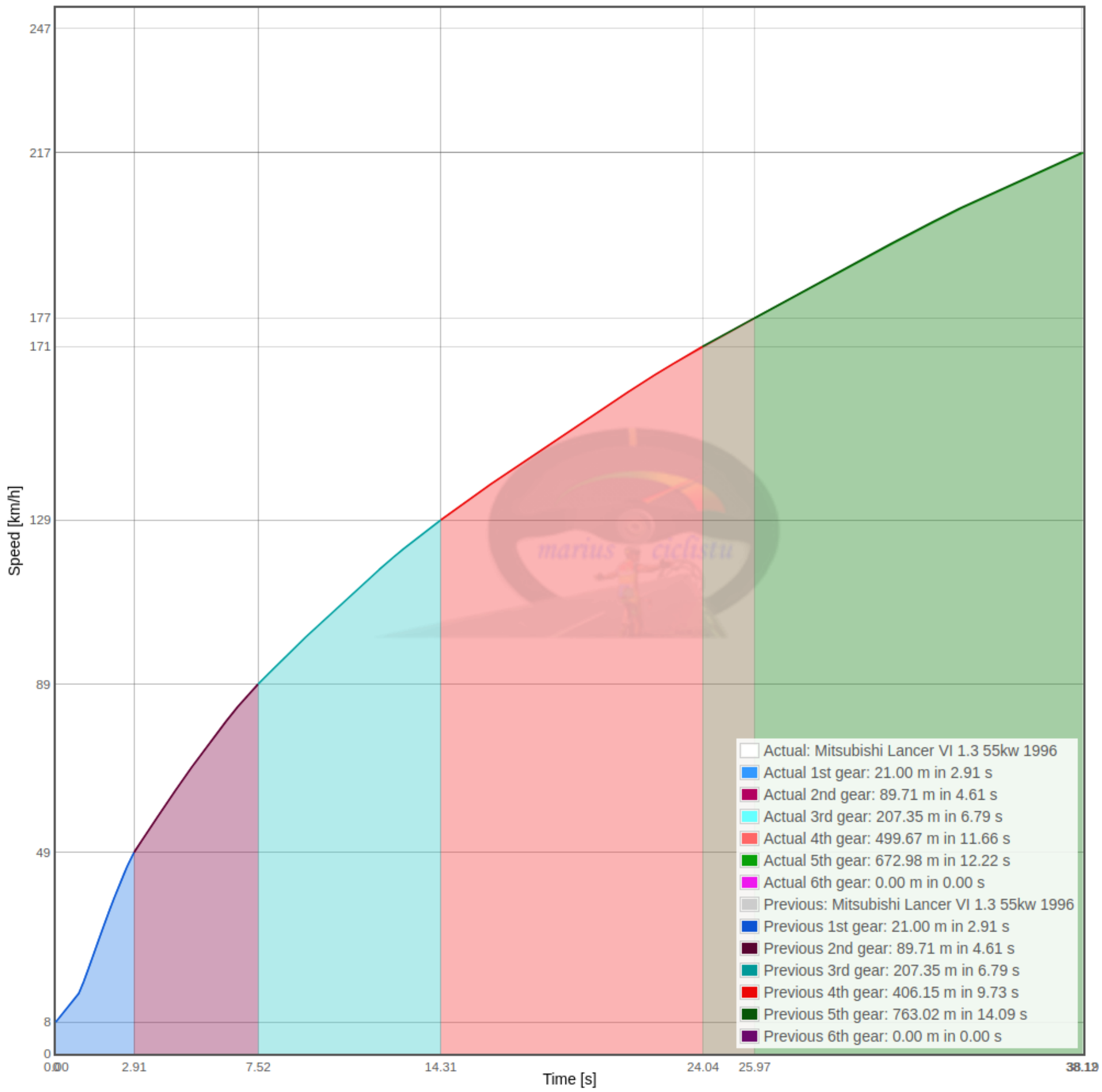
In the above two graphs that white triangle represent the lost acceleration.

If you are still not convinced about the irrelevance of power’s rpm when dealing with gear shifting when looking for best acceleration, let’s look at some more graphs.



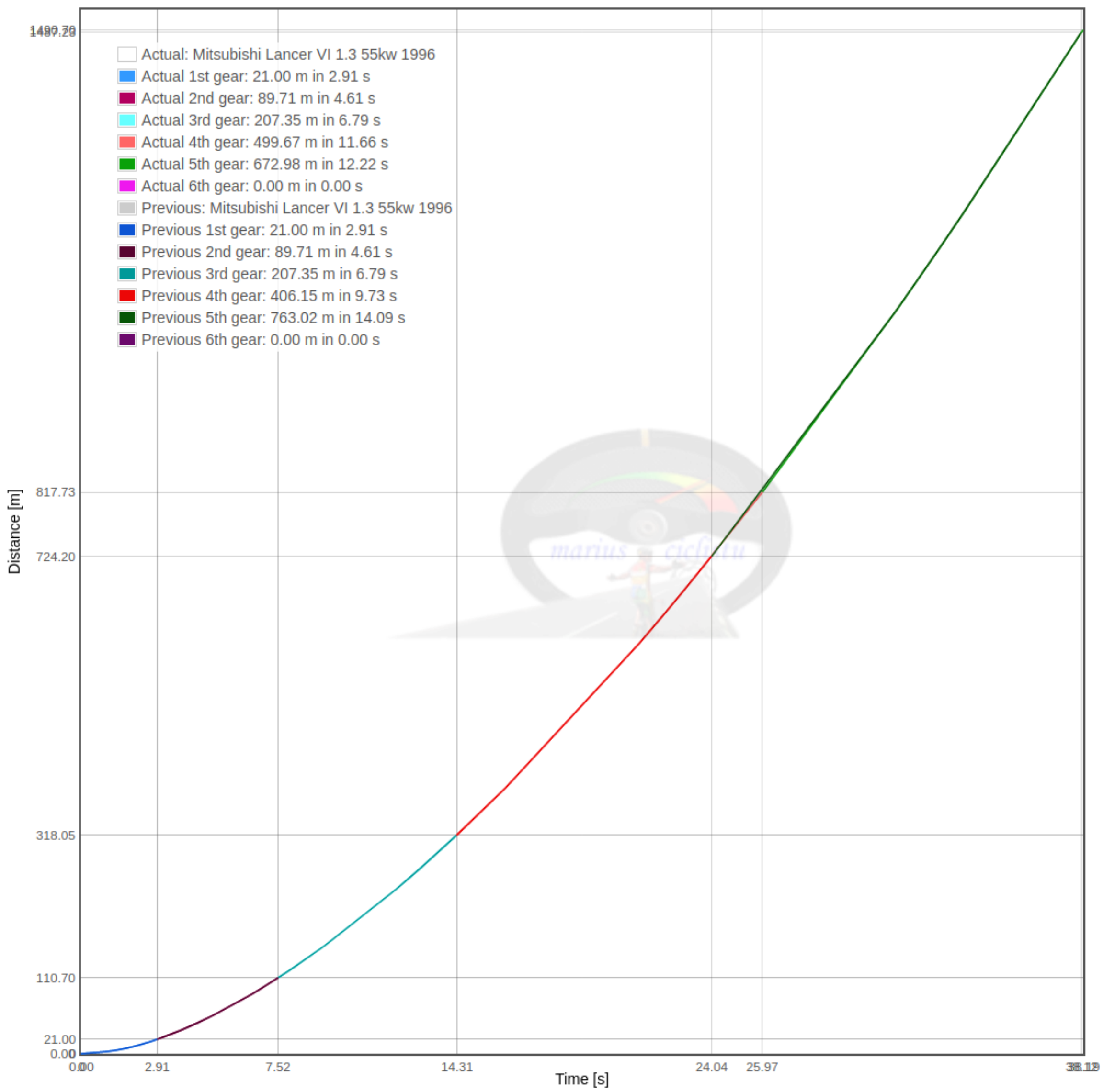
The filled areas from graph above represent the time spent in each gear while accelerating (the time needed for shifting gears is considered to be 0). If you look in the legend at 4th to 5th gear shift you can see that the previous calculation is the one with optimum gear shifting and the actual calculation is the one in which the 4th gear is changed only at 6500 rpm. Again, between 171 and 177 km/h you can see a pink triangle that increases the filled overall area (time) between 8 and 217 km/h.

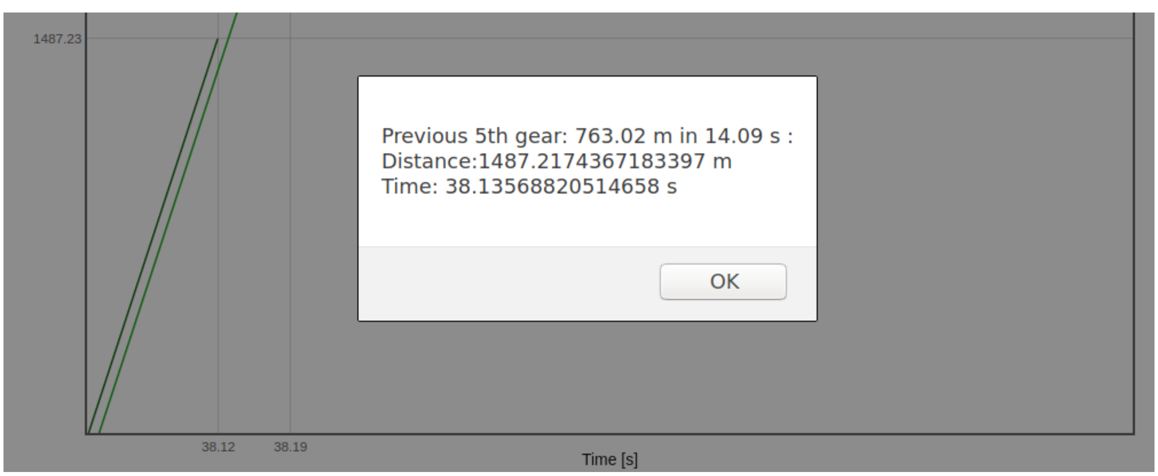
Moving on to the next graph of speed variation depending on time, the colored areas below each graph line represent the distance covered (the time needed for shifting gears is also considered to be 0). Here the difference is hard to notice between 171 and 177 km/h but keep in mind the respectively time values of 24.04 and 25.97 seconds.

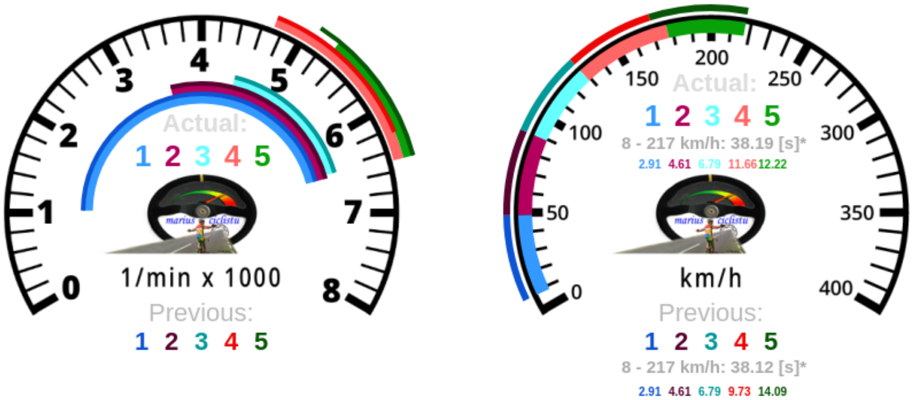


The distance covered over time, while starting at 8 km/h and accelerating until 217 km/h with the gas pedal floored, again without losses and with instantaneous gear shifting for this example, is represented in the next and final comparison graph. You can see there that with optimal gear shifting, the car reached 217 km/h after 1487.23 meters in 38.12 seconds, with 4th gear change at 6500 rpm after 1490.70 meters in 38.19 seconds and if we take a closer look at a virtual finish line placed after 1487.23 meters, the time for 6500 rpm shift would have been 38.14 seconds.

So to conclude, when starting from 8 km/h, with the gas pedal floored, 0 seconds gear shifting time, without losses and after 1487.23 meters, a less than optimal 4th gear change at 6500 rpm instead of 6250 rpm will result in +0.02 seconds time gap and if we consider a speed of 217 km/h that is equivalent with 60.277 m/s, the distance gap would be 1.205 m.


Actual: Mitsubishi Lancer VI 1.3 55kw 1996
Actual 1st gear: 21.00 m in 2.91 s
Actual 2nd gear: 89.71 m in 4.61 s
Actual 3rd gear: 207.35 m in 6.79 s
Actual 4th gear: 499.67 m in 11.66 s
Actual 5th gear: 672.98 m in 12.22 s
Actual 6th gear: 0.00 m in 0.00 s
Previous: Mitsubishi Lancer VI 1.3 55kw 1996
Previous 1st gear: 21.00 m in 2.91 s
Previous 2nd gear: 89.71 m in 4.61 s
Previous 3rd gear: 207.35 m in 6.79 s
Previous 4th gear: 406.15 m in 9.73 s
Previous 5th gear: 763.02 m in 14.09 s
Previous 6th gear: 0.00 m in 0.00 s
Distance [m]
817.73
724.20
318.05
110.70
21.00
0.00
0.00
2.91
7.52
14.31
24.04
25.97
Time [s]


1487.23
Previous 5th gear: 763.02 m in 14.09 s :
Distance:1487.2174367183397 m
Time: 38.13568820514658 s
OK
38.12
38.19
Time [s]



After this long explanation the conclusion is that **for best acceleration,** the maximum power's rpm does NOT influence the shifting rpm. **The shifting rotational speeds in each gear depends ONLY by the gear ratios in the transmission and the engine's torque graph.**

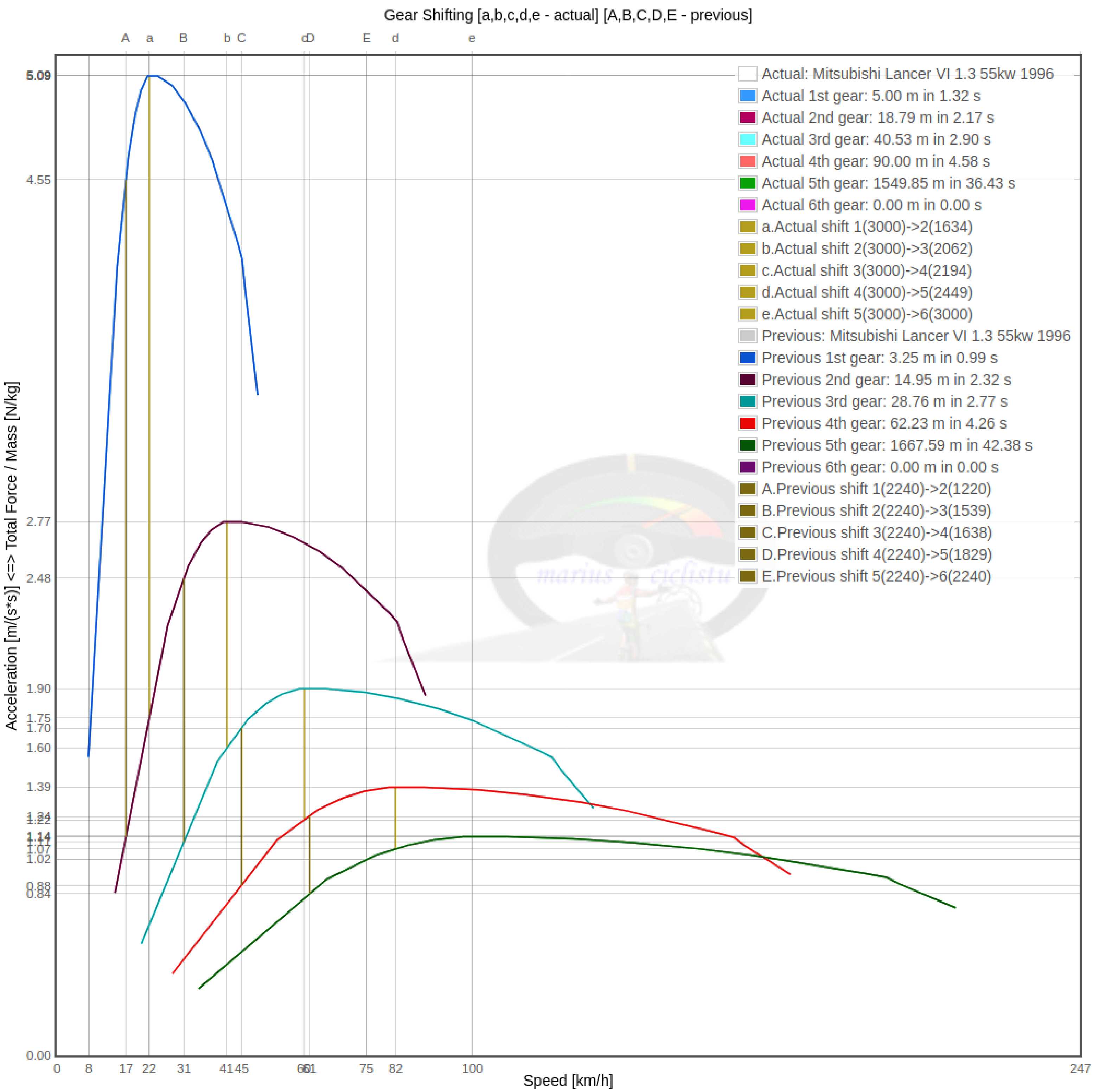
Also, if at maximum power the acceleration is not the highest and in order to obtain the best acceleration, the rotational speed at which that maximum power occurs does not influence the shifting rpm in neither gear, then **what is the power good for? Well, the maximum power is good for a vague way of guessing an economic way of driving.** Even if the power we are talking about is calculated by measuring the force generated by the engine with the gas pedal pushed 100% (we assume the fuel and air mixture to be "energy" and the gas pedal to be a valve that controls the "energy flow" into the engine), **if we push the gas as little as possible and patiently wait** for the car to gain speed while revving the engine from approximately 1000 rpm until the power half's rpm (22.5 kw/2240 rpm in this example) or until half of the maximum power's rpm (3000 rpm in this example) we will obtain a **small fuel consumption.**

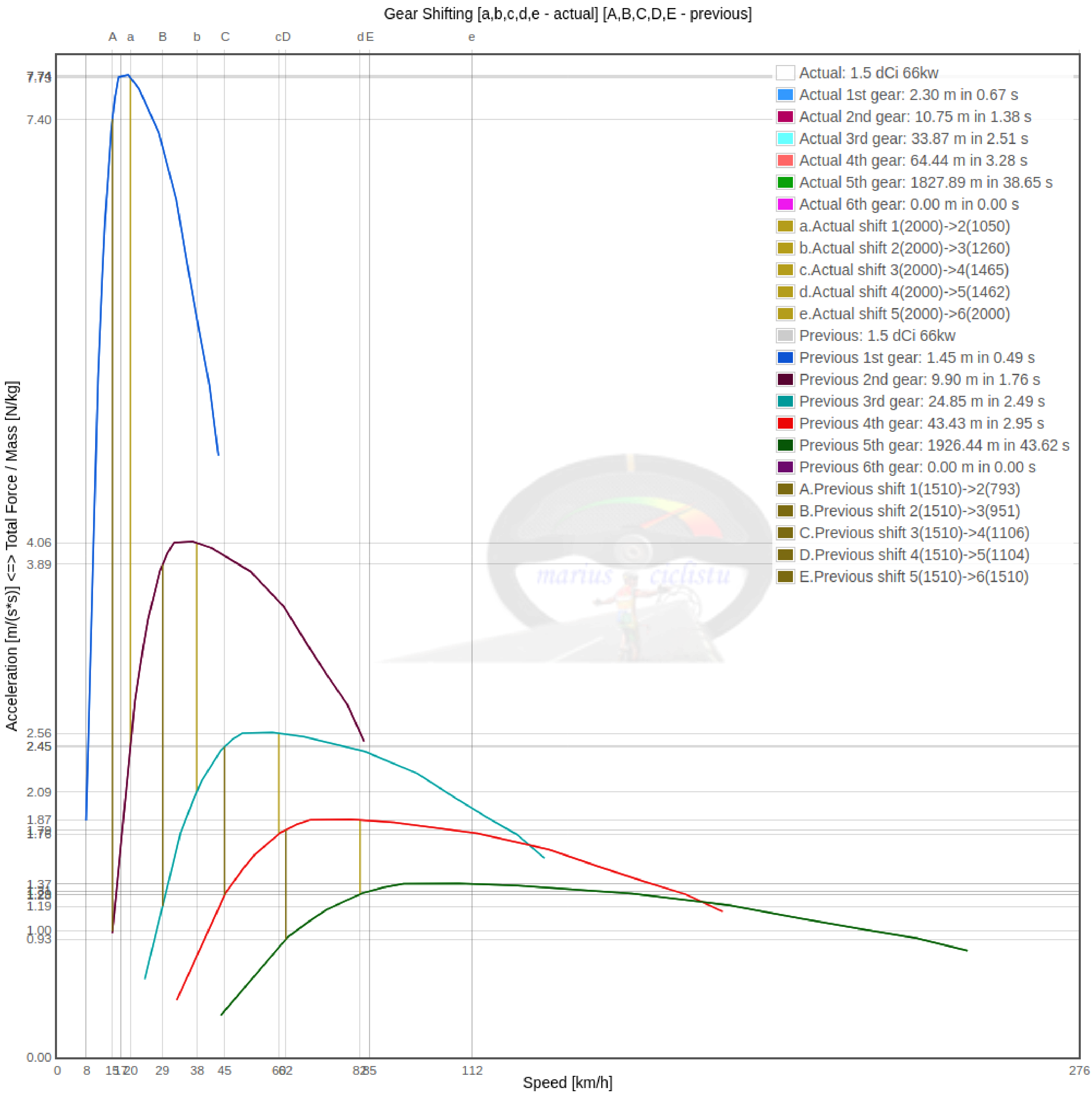
From my experience, while driving my Lancer from Cluj-Napoca to Oradea and back by using 2240 rpm as gear shifting rpm, the engine consumed an average of 4 l of petrol over 100 km and by using 3000 rpm as gear shifting rpm, 5l of petrol over 100 km.

With the diesel company car I drove, I managed to obtain an average of 2.8 l over 100 km from Cluj-Napoca to Sebeș and back in two consecutive days while using approximately 1510 rpm as gear shifting rpm. While shifting at 2000 rpm the average fuel consumption was around 4.5 l over 100 km. But the funny thing about diesel engines is that if you drive them like that they will "eat" your money because the injectors, high pressure fuel pump and turbo will fail quicker than if you would drove it at much higher rpm. As you've already read, the high pressure fuel pump from my company car needed to be replaced even if I drove it while shifting gears at over 4000 rpm, so...

The comparison between these rpm gear shifting values can be seen in the following two graphs. You can ignore the values from the vertical axes as they are in reference with the gas pedal pushed 100%.

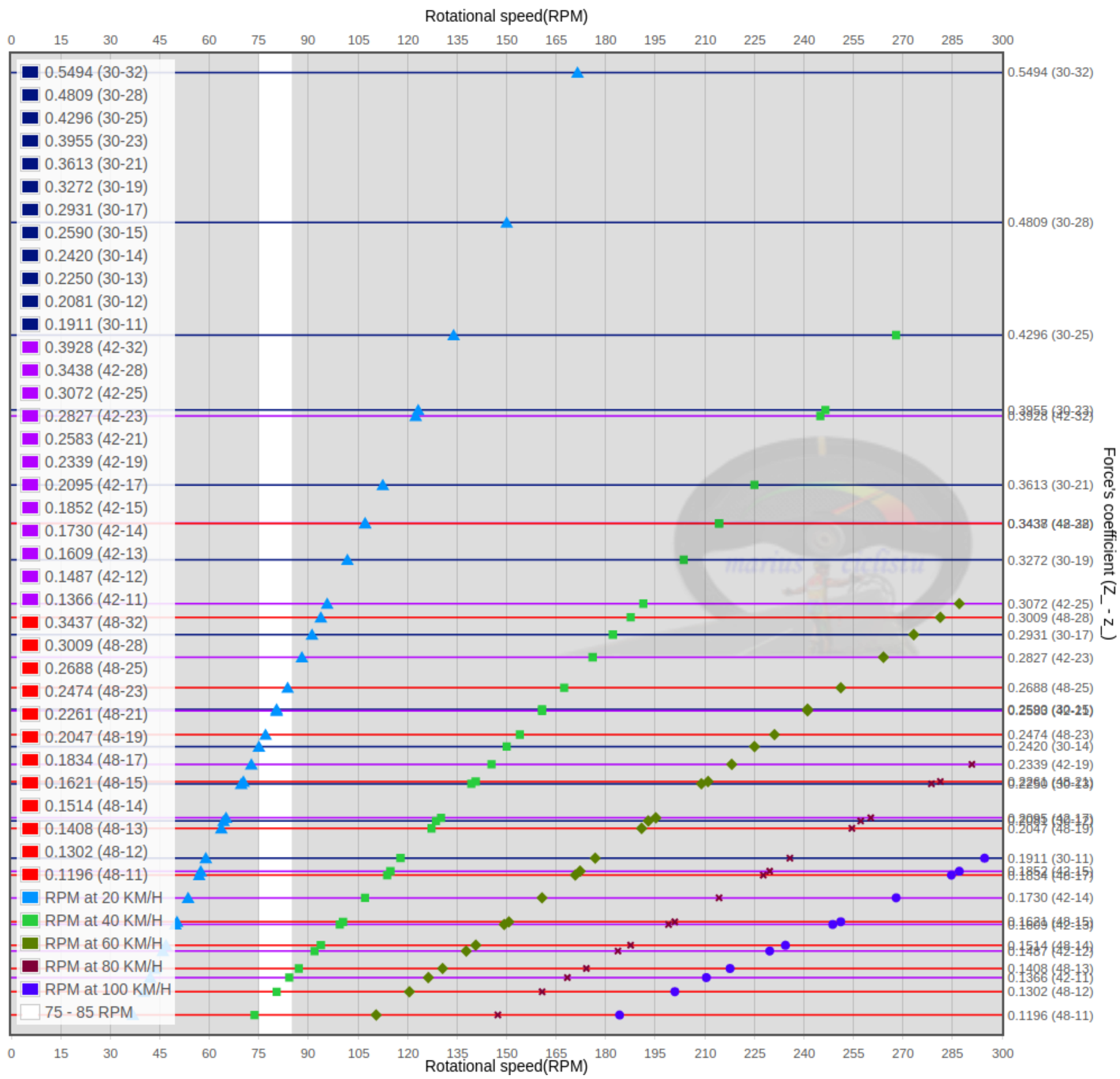
The same theory applies to motorcycles with the observation that the throttle must be twisted in such a way that the rider and bike don't backflip!


Gear Shifting [a,b,c,d,e - actual] [A,B,C,D,E - previous]
A a B b C cD E d e
Actual: Mitsubishi Lancer VI 1.3 55kw 1996
Actual 1st gear: 5.00 m in 1.32 s
Actual 2nd gear: 18.79 m in 2.17 s
Actual 3rd gear: 40.53 m in 2.90 s
Actual 4th gear: 90.00 m in 4.58 s
Actual 5th gear: 1549.85 m in 36.43 s
Actual 6th gear: 0.00 m in 0.00 s
a.Actual shift 1(3000)->2(1634)
b.Actual shift 2(3000)->3(2062)
c.Actual shift 3(3000)->4(2194)
d.Actual shift 4(3000)->5(2449)
e.Actual shift 5(3000)->6(3000)
Previous: Mitsubishi Lancer VI 1.3 55kw 1996
Previous 1st gear: 3.25 m in 0.99 s
Previous 2nd gear: 14.95 m in 2.32 s
Previous 3rd gear: 28.76 m in 2.77 s
Previous 4th gear: 62.23 m in 4.26 s
Previous 5th gear: 1667.59 m in 42.38 s
Previous 6th gear: 0.00 m in 0.00 s
A.Previous shift 1(2240)->2(1220)
B.Previous shift 2(2240)->3(1539)
C.Previous shift 3(2240)->4(1638)
D.Previous shift 4(2240)->5(1829)
E.Previous shift 5(2240)->6(2240)
Acceleration [m/(s*s)] <=> Total Force / Mass [N/kg]
5.09
4.55
2.77
2.48
1.90
1.75
1.70
1.60
1.39
1.24
1.22
1.14
1.11
1.07
1.02
0.88
0.84
0.00
0 8 17 22 31 41 45 60 61 75 82 100 247
Speed [km/h]
marius ciclistu

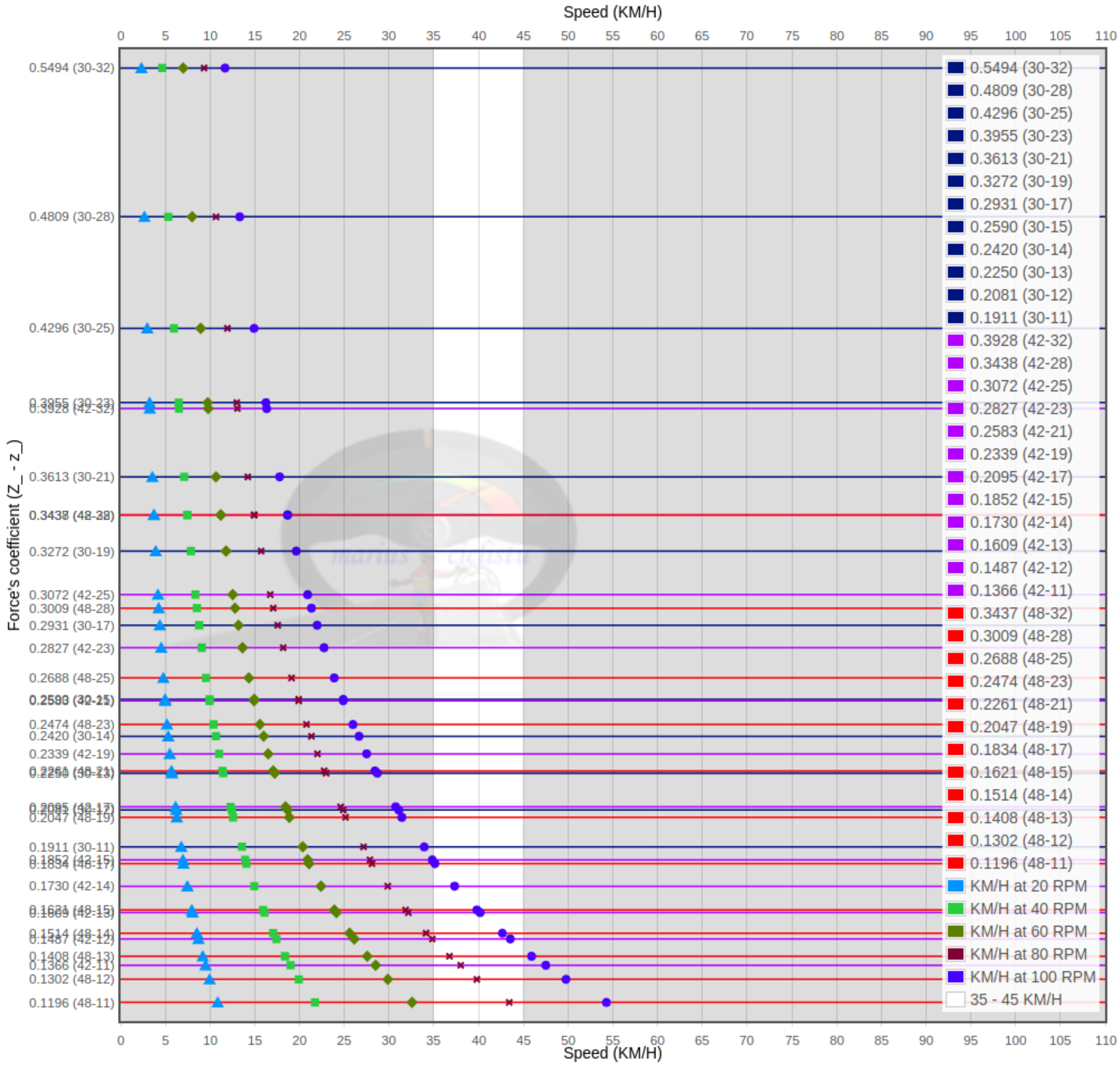


Gear Shifting [a,b,c,d,e - actual] [A,B,C,D,E - previous]
Acceleration [m/(s*s)] <=> Total Force / Mass [N/kg]
Speed [km/h]
Actual: 1.5 dCi 66kw
Actual 1st gear: 2.30 m in 0.67 s
Actual 2nd gear: 10.75 m in 1.38 s
Actual 3rd gear: 33.87 m in 2.51 s
Actual 4th gear: 64.44 m in 3.28 s
Actual 5th gear: 1827.89 m in 38.65 s
Actual 6th gear: 0.00 m in 0.00 s
a.Actual shift 1(2000)->2(1050)
b.Actual shift 2(2000)->3(1260)
c.Actual shift 3(2000)->4(1465)
d.Actual shift 4(2000)->5(1462)
e.Actual shift 5(2000)->6(2000)
Previous: 1.5 dCi 66kw
Previous 1st gear: 1.45 m in 0.49 s
Previous 2nd gear: 9.90 m in 1.76 s
Previous 3rd gear: 24.85 m in 2.49 s
Previous 4th gear: 43.43 m in 2.95 s
Previous 5th gear: 1926.44 m in 43.62 s
Previous 6th gear: 0.00 m in 0.00 s
A.Previous shift 1(1510)->2(793)
B.Previous shift 2(1510)->3(951)
C.Previous shift 3(1510)->4(1106)
D.Previous shift 4(1510)->5(1104)
E.Previous shift 5(1510)->6(1510)
marius ciclistu

When not rallying in 2016, I was riding my trekking bicycle for a total of 900 km, the most I've rode in one year since 2009. Suspecting that something is not ok with the power being used in cycling, I studied a way of convincing myself that what I had understood about the power and thermal engines is or is not valid also for rider and bicycle. As the force with which the rider is pushing the pedals is multiplied by a coefficient in each gear ratio to result the force at the back wheel's circumference, the answer were two graphs with that coefficient depending on the pedals' rpm and on the speed of the bicycle.



In the case of a car's transmission, at a given speed, the force has the highest value in the lowest possible gear. When talking about the bicycle's "engine", a rider's torque curve varies because it depends mainly on fatigue, so it can't be taken into consideration, while the force's coefficient remains always the same in a given gear ratio.



So if a rider wants to go with 40 km/h and the maximum pedals' rotational speed he feels comfortable with is 80 rpm, then by studying the two graphs from above, it can be seen that the best gear ratio he can use for having the highest force coefficient value is 0.1302 with 48-12 chain gearing. That means that if he pushes the pedals with a force of 98 N the equivalent of 10 kgf (the force that you can feel when holding 10 kg in your hands), the force at the back wheel's circumference is 0.1302 * 98 = 12.76 N that means 1.302 kgf. I did not tried a power meter when riding my bicycles, but my guess is that it would be more interesting to use the torque rather than the power it displays. In that way we can see the force's values and decide objectively how to use the chain gearing, even if it would be close to impossible for a rider to remember all this information. But we never know what the future brings. Maybe you or someone else will develop an automatic transmission also for bicycles, that could adapt the gearing according to the force that the rider puts in the pedals for obtaining the maximum force at the back wheel's circumference.