The influence of wheel and tire aerodynamics in WLTP

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Abstract

The geometric shape of passenger car wheels can have a large influence on the aerodynamic drag of a vehicle as it has been shown already in different publications. In combination, tire and rim cause approximately 25% of the overall drag. Until now, the challenge for aerodynamicists is to find the rim / tire combination with the best aerodynamic characteristics, which then is used for the official c_D-value of the vehicle and for the determination of fuel consumption according to NEFZ regulations.

With the introduction of WLTP this procedure is going to change. To determine the fuel consumption of a vehicle every varying part of the equipment (standard or optional) has to be considered, so that every sold vehicle can have its own consumption value. Alternatively the worst case of all configurations can be used, but this would lead to a higher fleet consumption.

For this reason, the aerodynamic characteristics of wheels and tires gain more and more importance and especially the interaction between different rims and tires has to be considered. This paper will show some possibilities to influence the aerodynamics of passenger car wheels and their effect at WLTP.

1 Introduction

With increasing fuel costs and an increased environmental awareness, fuel consumption has become one of the most important development targets for passenger cars. Standardized driving cycles help to compare the fuel consumption of different vehicles on a common basis and form the foundation for determining the official fuel consumption. Of cause, every standardized cycle is only a modelling the real world driving and can never cover every single on-road situation.

With the currently used NEDC cycle, the gap between cycle consumption and the real world consumption of a vehicle has been increasing over the last years, as average speeds on the roads are increasing and manufacturers are using the entire margin to optimize the consumption especially for this driving cycle. For this reason, a new official cycle (WLTP) is about to be introduced, which has stricter boundary conditions and is adopted to today’s average traffic situations. With this new cycle, the focus for different parts of driving resistance is shifted and topics like aerodynamics, that are strongly dependant from the vehicle speed, gain more importance.

2 Standardized Driving Cycles

Standardized driving cycles are the basis for judging fuel consumptions and emissions for different vehicles and are important when it comes to comparing different vehicles on a common basis. A driving cycle is basically a simplification of real world driving. It will never be able to determine the fuel consumption of every individual driver on the road and every traffic situation. However, when it comes to official consumption figures, its purpose is to build a common basis. With the ongoing vehicle development (e.g. in recent years the average power of a vehicle has been steadily increased), also the driving cycles have to be adopted.

2.1 NEFZ

The New European Driving Cycle (NEDC) was introduced in the year 1992 and is mandatory since 1997 for the determination of the fuel consumption of passenger cars in the EU. It consists of two different stages: The Urban Driving Cycle witch is repeated four times and the Extra Urban Driving Cycle (see **Figure 1**). The length of the cycle is around 20 min.

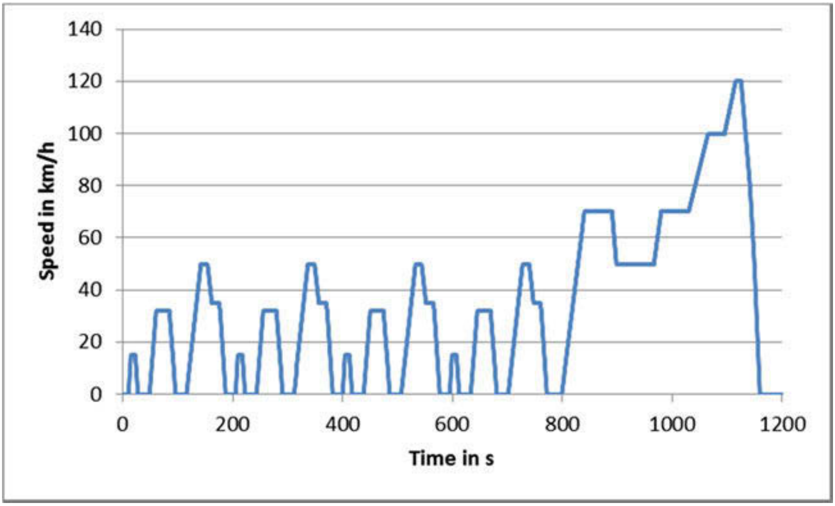

Figure 1: NEDC Driving Cycle [1]

The NEDC cycle nowadays is often reported to be no longer representative for the typical vehicle usage on European roads, which can for example be seen in **Figure 2**, where official NEDC values are compared with reported results from real world driving. One reason for this discrepancy is the low average speed during the cycle. The influence of aerodynamic drag for example, is proportional to the squared velocity and at an average speed of 33.3 km/h it has only minor effect. With roundabout 25% of idle-phases during NEDC, stop-start systems are highly effective in this cycle and are typically overrated compared to real world driving.

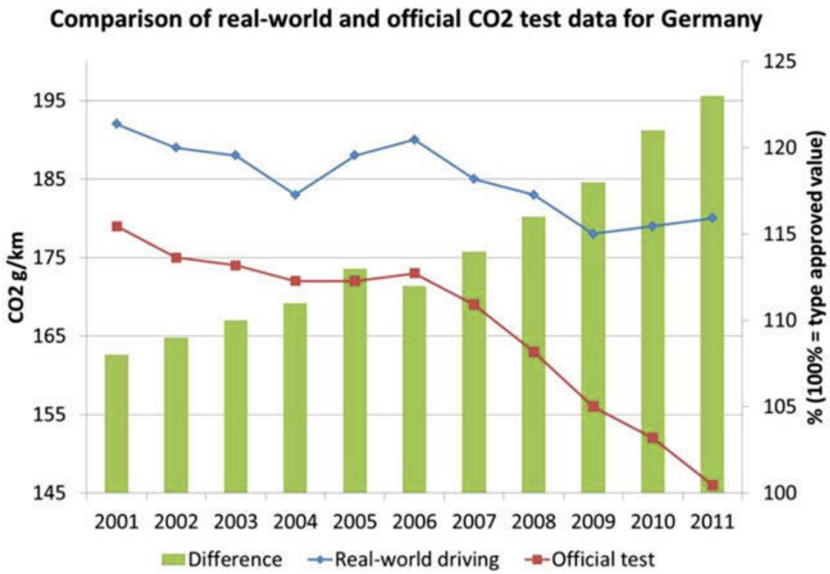

Figure 2: Comparison of NEDC results with real world driving [2]

Another reason for the discrepancy between real-world driving and the NEDC results can be found in the relatively tolerant boundary conditions of the cycle, allowing car manufactures to optimize their vehicle and testing conditions for minimal fuel consumption and minimal emissions. For example, most of the auxiliary loads can be switched off for the cycle and there is no need to recharge the battery during the cycle.

The determination of aerodynamic drag is carried out in a coastdown test, where for example all the gaps of the vehicle can be sealed to optimize the aerodynamics of the vehicle. Also, the aerodynamic drag is determined only for one vehicle configuration and optional equipment, such as larger tyres or roof rails is not being considered at all. Therefore, large aerodynamic effects are often neglected in the NEDC driving cycle.

2.2 WLTP

With the increasing gap between NEDC results and the real world driving emissions, the NEDC cycle is no longer able to represent the average passenger car usage in the EU. Therefore a working group by UNECE was founded to create a global standard for determining CO_2 emissions and fuel consumption. The result is the “Worldwide Harmonized Light Vehicles Test Procedure” WLTP, which is being developed at the moment. The test procedure covers a wide range of vehicles, put in different vehicle classes, including passenger cars (class 3b).

The cycle, defined for class 3b vehicles is plotted in **Figure 3** and consists of four parts:

- Cold start and low speed phase (589 sec)
- Medium speed phase (433 sec)
- High-speed phase (455 sec)
- Extra-high-speed phase (323 sec)

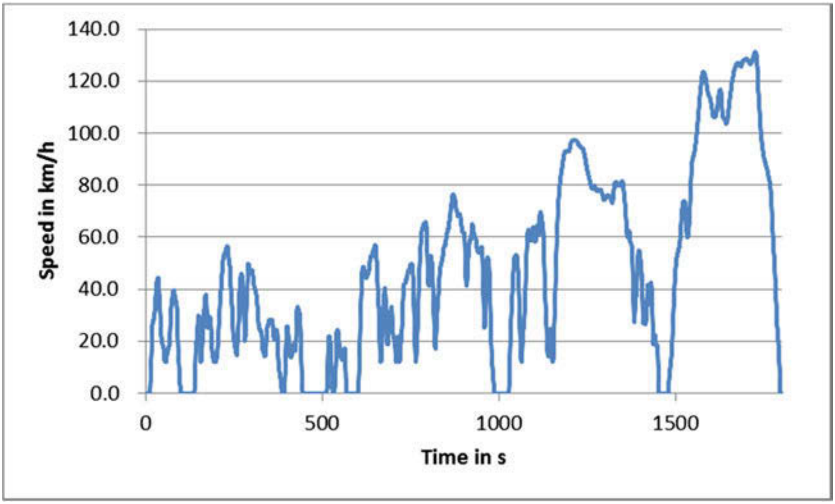

Figure 3: WLTP Class 3b Driving Cycle [3]

2.3 Comparison of NEFZ and WLTP

When comparing both cycles, it is obvious that the WLTP is much more dynamic with higher acceleration requirements and much shorter idle phases than the generic NEDC. Figure 4 shows the basic facts of both cycles compared to each other.

	NEFZ	WLTP
Duration in s	1181	1800
Length in km	10,92	23,27
Average speed in km/h	33,3	46,5
Max. Speed in km/h	120	131,3
Idle in %	24,9	13,1
Max. Acceleration in m/s²	1,04	1,67
Max. Deceleration m/s²	-1,39	-1,5

Figure 4: Comparison of WLTP and NEFZ [1, 3]

Not only is the maximum and average speed increased but also idle phases are reduced by 50%. These facts already result in an increased influence of aerodynamic drag in WLTP by roundabout 50% compared to NEDC [4].

Additionally the boundary conditions of WLTP are much more regulated, resulting in fewer possibilities to optimize the vehicle for the cycle run. It is therefore expected that WLTP will result in higher fuel consumptions and emissions than NEDC, especially when the vehicle uses techniques that are highly effective in the NEDC cycle.

When it comes to aerodynamics, the most important fact is that not only the basic vehicle is evaluated, but also the influence of optional equipment has to be considered. This can either be done by considering only the worst case, but this makes no sense since it would lead to a higher fleet consumption and could therefore result in penalty taxes. It is therefore important to consider the aerodynamic influence of each optional equipment available to the customer.

3 Influence of Tyres and Rims

Tyres and rims are responsible for around 25% of the aerodynamic drag of a vehicle [5]. Most of this influence is caused by the overall shape of the wheels, which can – for obvious reasons – not drastically be changed. But still, also the shape of both the rim and the tire that can be modified by the manufacturer results in quite a large influence to drag. For WLTP this influence is getting more and more into focus, because it will result in different CO_2 emissions and fuel consumptions for the specific vehicle.

3.1 Rim Influence

When buying a new car today, customers often have the possibility to select more than 10 different rim sizes and designs for their vehicle. In medium-class the range often varies from 15” wheels to 18” or 19”. Additionally the width of the rims also changes. While the smaller 15” and 16” rims often have a width of only 6”, the larger ones often are manufactured in widths of 7.5” or even 8”.

Figure 5: Selection of different wheels (15”-19”) for the VW Golf [6]

Figure 5 shows part of the variety in rim sizes and designs for the VW Golf. It can be seen that not only the size varies, but also the design of the rims is quite different. While some wheels are nearly closed, which is typically good for aerodynamics, especially the larger ones have very thin spokes and they are often preferred by the customers.

With NEDC, this does not matter for the official fuel consumption of the car, because there is only one type approval necessary for each vehicle type. But with WLTP this is going to change. The fuel consumption has to be declared for each configuration chosen by the customer and this means, the aerodynamic influence has to be known for each set of wheels.

3.1.1 Aerodynamic Drag

When it comes to the aerodynamics of rims, it is typically beneficial to have a completely closed rim with a flat surface.

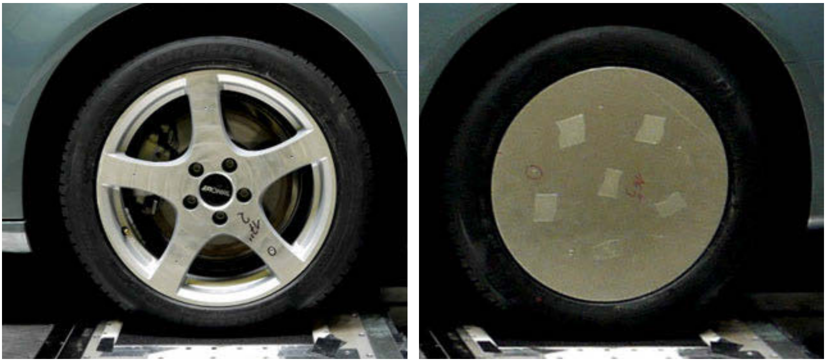

Figure 6: 17” open aluminium rim (left) and completely closed rim (right)

To investigate the magnitude of this influence, a 17” rim with an already smooth surface (see **Figure 6**) was compared to a completely covered rim in the IVK wind tunnel of University of Stuttgart. For this measurement, all 4 wheels of the vehicle were modified. The results show, that the aerodynamic drag of the vehicle is reduced by over 5% when covering the openings in the rim.

This influence gets even higher, when the aerodynamic characteristic of the baseline rim is worse than in the example above. Steel rims without wheel covers, for example, typically result in high aerodynamic drag. For a 16” steel rim, aerodynamic drag is typically reduced around 5% when a standard production wheel cover is attached. With a completely closed, flat wheel cover this influence can even be doubled (Figure 7)

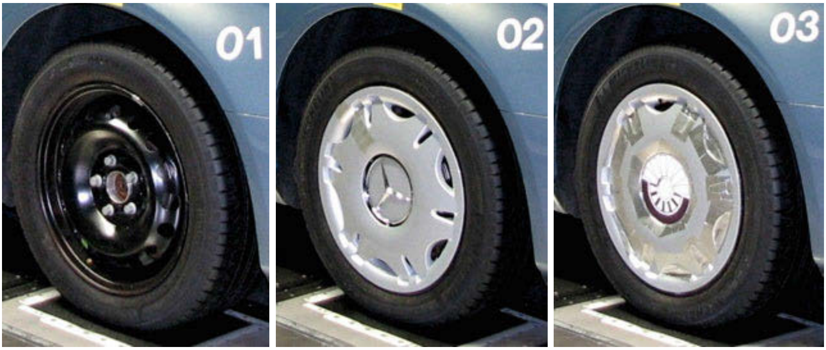

Figure 7: 16” Steel wheel with different wheel covers [7]

This means, with an aerodynamically optimized wheel, the aerodynamic drag can be reduced or on the other hand, if the customer chooses a large wheel with worse aerodynamic characteristics, he will not only get higher fuel consumption on the road, but also higher fuel consumption at WLTP.

3.2 Tyre Influence

In difference to the rim, the possibilities in designing a tyre are much more restricted. Additionally, the design specifications for a tyre are mostly driven by topics as handling, rolling resistance, brake performance, noise etc. and the aerodynamic characteristics so far are more or less neglected. But still, the shape of a tyre has influence on the aerodynamic characteristics of a passenger car. This influence can be split in two areas. The first one is the design of the tyre, where already small geometric differences can result in effects to aerodynamic drag, the second one is the tyre width, which has a huge impact on aerodynamic drag.

When looking at the geometry of a tyre, there is especially one small part that will influence the aerodynamic characteristics of a tyre: The labelling on the side wall. Investigations have shown that only by modifying the small labelling on the sidewall of a tyre, the aerodynamic drag of a vehicle can be reduced by 1-2% [7]. In this case it is advantageous to have the labelling not raised from the sidewall, because this will typically result in a flow separation, but engraved into the sidewall. One example of a tyre with optimized aerodynamic characteristics is plotted in Figure 8 right. With this tyre, the aerodynamic drag of a wide variety of vehicles could be reduced compared to the standard production tyre in the left picture.

Figure 8: Standard production tyre (left) and tyre with optimized aerodynamic characteristics (right) [7]

The width of the tyre is the second important parameter influencing the aerodynamic characteristics of a vehicle. With a wider tyre, not only the frontal area is increased, but also the aerodynamic drag rises. This could be shown when comparing three different tyres on the same vehicle with sizes of 195/60 R16, 205/55 R16 and 225/50 R16. The results show an increase of 1% in aerodynamic drag between the 195 and the 205-tyre and an increase of 2% between the 205 and the 225-tyre.

Figure 9: Tyre shape for two tyres of the same type (205/55 R16) [7]

The same effect can occur even within the same tyre size, when the absolute dimensions of the tyres vary due to legal tolerances. In **Figure 9** two tyres are plotted, both with the size 205/55 R16. The measured dimensions of both tyres differ by 10 mm, resulting in an increased aerodynamic drag of around 2% with the wider tyre.

The effects of rims and tyre cannot be simply added, because both parts influence each other. If, for example, the shape of the tyre causes a large flow separation, this separation can shield the rim from the flow and reduce the aerodynamic impact of the rim design. On the other hand, the effect of the rim is typically much higher with an aerodynamically optimized tyre. So, in terms of drag reduction, both parts have to be optimized together to achieve the best overall result.

This shows that in combination rims and tyres can have quite some effect on the aerodynamic drag of a vehicle. Although the effects of rim and tyre cannot just be added together, the influence of the wheels can easily be more than 10% of the overall drag of a vehicle. With NEDC, this influence never showed up in the official data but with the new WLTP cycle, this will become an important part in the aerodynamic development, especially if all the available rim and tyre configurations have to be tested and evaluated.

4 Conclusions and Outlook

The aerodynamic influence of tyres and wheels can change the aerodynamic drag of a vehicle by more than 10%. So far, this influence was not considered in the official fuel consumption determination, because only a single type approval was necessary for each vehicle type and optional parts were not considered here.

With the transition from NEDC to WLTP not only the influence of aerodynamics within the cycle gains much more influence, but also optional equipment has to be considered. At this point the aerodynamic influence of the wheels becomes more and more important. Customers often choose to buy their car with larger wheels and wider tyres and both parts result in a higher drag value and therefore in a higher fuel consumption and more CO_2 emissions. This means, that in the vehicle development more work has to be spend not only to improve the drag of the baseline vehicle, but also to improve the aerodynamic characteristics of the optional equipment.

When it comes to rims and tyres, the large variety of options present the aerodynamicists with quite a challenge, because each combination of parts has to be evaluated concerning its aerodynamic properties on the vehicle.

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