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Felix Wittmeier

"A contribution to the aerodynamic development of passenger car tires"

Abstract

Although it is known since the early days of aerodynamic research that a vehicle's wheel has a large influence on aerodynamic drag, the optimization of wheels and tires was neglected for a long time. Only since ground simulation was introduced in automotive wind tunnels, the effects of wheel rotation and their impact on drag came to the fore. But still, the aerodynamic development was merely focused on topics such as optimizing the design of the rims and tire spoilers according to the effects of the rotating wheels. The tire was considered as a given part and in general, aerodynamicists were not interested in the details of its shape. Only newer investigations conducted by vehicle manufacturers show that the shape of the tire can have a major influence on the aerodynamics of a vehicle. Before, investigating the difference between various tires was mostly not intended, but happened inadvertently as a vehicle was measured with two different sets of tires and the results did not match. In the framework of this research, the influence of different geometric parameters of the tire was investigated in detail, focusing on the modes of action of each parameter separately. The results allow judging the effects of each parameter on the aerodynamic drag of a vehicle. This was done with the most common European tire size 205/55 R16. Starting by measuring several tires on different vehicles, it can be shown that the aerodynamic characteristics of a tire are mostly independent of the vehicle. This result sets one of the foundations for this work, because it allows a general investigation of the tire's aerodynamic properties and also reduced the amount of measuring time. The results of the parameter study show that the outside shoulder on the front axle has a huge influence on the aerodynamic characteristics of a tire. When designing a shoulder, the main goal is to guide the flow around it without causing any separation and thus minimizing the losses at the tire. Also, the labeling on the tire can lead to flow separation, as it is often raised from the tire's sidewall. Another important parameter is tire width. Not only is the frontal area of a wider tire larger but also the drag coefficient increases due to a change in the flow field. Based on a fixed frontal area, results show that the drag coefficient increases about $\Delta cD \approx 0.006$ for each 10 mm increase in tire width. The influence due to the change in frontal area is thereby only around 15%. The influence of tire width on aerodynamic drag can also be seen when looking at Reynolds-run measurements. The tire width decreases as the rotational speed increases, which can lead to a difference in tire width of up to 20 mm at a speed of 250 km/h. Therefore, tire width is one factor to consider when measuring a decrease in drag at high velocity with rotating wheels. Based on the results of the parameter study, various suggestions can be given for an aerodynamically optimized tire. Especially a round shoulder shape without any sharply edged design features, a smooth labeling on the sidewall and the use of legal tolerances to achieve a minimal tire width can help to decrease aerodynamic drag. An optimized tire based on these suggestions was designed and built by Michelin to be investigated in the wind tunnel. When compared with the best production tires tested, the aerodynamically optimized tire resulted in a decrease in drag of $\Delta cD \approx 0.005$ without affecting tire performance. This was ensured by keeping the basic shape and material of the production tire, which also means that the potential of tire width is omitted. In the final phase, it was investigated whether the aerodynamic properties of a tire can also be tested in model scale, even though consideration of the tire's deformation is not possible due to technical limitations. Therefore, different full scale tires were digitized and manufactured in quarter scale using rapid prototyping technology. Measurements in the model scale tunnel show that the aerodynamic properties of the scaled tires match the ones of the full scale tires. Furthermore a method for a simple investigation of various shoulder geometries in the model scale wind tunnel was developed. It is based on a tire base body where different tire shoulders can be mounted on the outside. This not only reduces material requirements and therefore model build costs, but also reduces measurement time in the model scale tunnel and enables the aerodynamicist to consider a wide variety of shoulder geometries.