

The New Audi A6/A7 Family - Aerodynamic Development of Different Body Types on One Platform

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ABSTRACT

The paper describes the aerodynamic development and optimization process of the three different new models of the Audi A6/A7 family. The body types of these three models represent the three classic aerodynamic body types squareback, notchback and fastback.

A short introduction of the flow structures of these different body types is given and their effect on the vehicle aerodynamic is described. In order to achieve good aerodynamic performance, the integration into the development process of the knowledge about these flow phenomena and the breakdown of the aerodynamic resistance into its components friction- and pressure drag as well as the induced drag is very important.

The paper illustrates how this is realized within the aerodynamic development process at Audi. It describes how the results of CFD simulations are combined with wind tunnel measurements and how the information about the different flow phenomena were used to achieve an aerodynamic improvement. It also gives some examples of problems that had to be solved during the development. The challenge of an aerodynamic optimization of three different body types on one platform is explained in detail.

INTRODUCTION

In 2010/2011 Audi introduces new models of its upper middle class family "A6". The A6 sedan and the A6 Avant station wagon will be replaced by new models in 2011. The end of 2010 brings an additional model into the family, the A7, a grand four-door coupe.

Nowadays fuel efficiency is becoming more and more important and is one of the major goals in vehicle development. Since the aerodynamic drag has a large contribution to the vehicles total driving resistances, a reduction of the aerodynamic drag is therefore very important to reduce fuel consumption. [Figure 1](#) describes the development of the aerodynamic drag over the last generations of the models A6 sedan and A6 Avant station wagon.

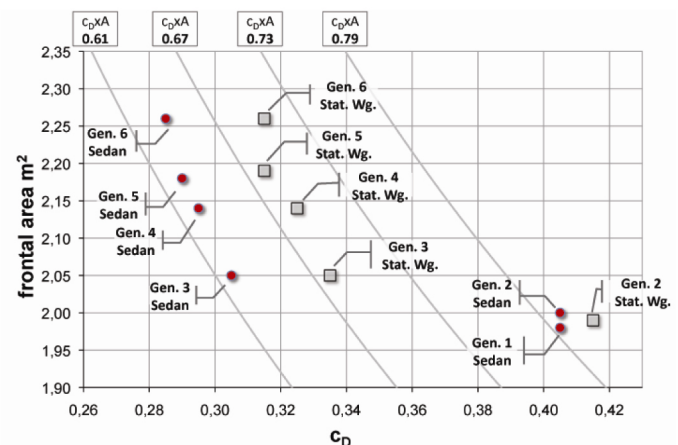


Figure 1. Development of the aerodynamic drag over the different model generations

A measure of the total aerodynamic drag is $C_D \times A$, the product of the drag coefficient C_D and the frontal area A . Referring to [figure 1](#) it becomes apparent that there was a huge aerodynamic improvement from model generation 2 to generation 3. This was the time when vehicle aerodynamics started becoming important. The 3-rd generation A6 sedan

(known as Audi 5000 in the USA) was the first production vehicle reaching the drag value $c_D=0.30$ and was called “ c_D world champion”.

In the ongoing aerodynamic development from generation 3 to generation 6 a further reduction of the drag coefficient was achieved for each generation. However this improvement was almost compensated by an increasing frontal area. This rise in the frontal area was for the benefit of a bigger interior space with improved ergonomics and for other technical issues. The consequence of this is, that there is no noticeable reduction of the total aerodynamic drag since model generation 3. Since a further rise in frontal area must be expected for the next model generation as well, the c_D -improvement must be bigger than the improvement which is necessary to compensate the frontal area growth in order to achieve a noticeable reduction of the total driving resistance.

The aerodynamic properties of a vehicle are affected by the flow around it. For a optimized flow which causes low drag two areas at the vehicle are important, the underbody and the rear end. To reduce costs and production variants, all models of the A6/A7 family share many technical components including the underbody with its various body covers. In contrast to this, every model has a different body type. Comparing the different designs with the three classic aerodynamic body types squareback, notchback, fastback (see [figure 2](#)), it becomes obvious that each model matches one of these types. The A6 sedan is a notchback, the A6 Avant is a squareback type and the A7 is a fastback coupe. It is known, that these three body types have different aerodynamic properties. To reduce the aerodynamic drag of a specific body type, the underbody flow must be optimized together with the flow around the body to achieve the best compromise. The fact that the underbody of the A6/A7 family must be identical makes an appropriate aerodynamic optimization difficult. The shape of each different body types had to be optimized to work best together with one given underbody. The conflicts in the development process that arise from this are presented in this paper.

BASICS

In order to understand some of the problems that had to be solved during the development of the new models, a brief overview of some basics of the flow shall be given first. These basics refer to of the breakdown of the different aerodynamic resistances and some flow phenomena around the vehicle body that have been discussed in the literature, (see for example Hucho [1])

Generally, there are three different types of aerodynamic resistance acting on a vehicle:

- friction resistance
- pressure resistance

- induced drag

FRICITION RESISTANCE

The friction resistance as it is described in the terms of this paper is not the classical surface friction in the sense of wall-shear-stress. The friction resistance discussed here is considered at a more macroscopic scale and refers to friction due to the roughness of the surface e.g. due to obstacles mounted to the vehicle. This type of resistance is not depending on the body type but on the shape of the surface. Modern vehicle have a mostly smooth body with only small obstacles, therefore the friction resistance on the vehicle body is rather small. Looking at the underbody of a vehicle, things are different. The underbody surface is very rough, as there are many obstacles such as axles, the exhaust system or drive train. Due to this, the friction resistance of the underbody is much higher compared to the friction resistance of the vehicle body.

PRESSURE RESISTANCE

In contrast to the friction resistance, the pressure resistance is very much depending on the body type of the vehicle. For passenger cars three different general body types are known: squareback, fastback, notchback. [Figure 2](#) shows these three body types as published in [1]

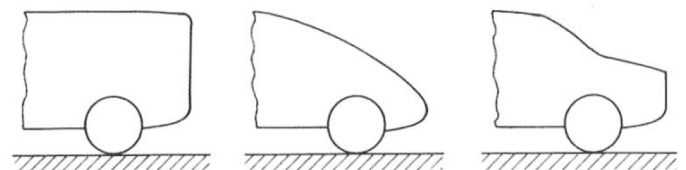


Figure 2. The three classical body types [1]

Squareback

[Figure 3](#) introduces the basic principle of the flow conditions at a squareback vehicle. The flow detaches on the rear edges of the body and forms a ring vortex in the wake of the vehicle. Due to this vortex a very low pressure on the base plane is generated that leads to an increase of the aerodynamic drag.

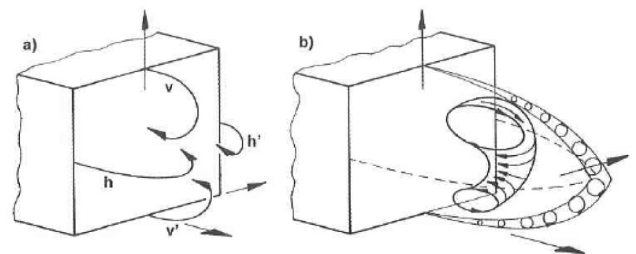


Figure 3. Flow separation and wake of a squareback [1]

Fastback

The flow conditions developed at a typical fastback coupe are shown in [figure 4](#). In comparison to a squareback vehicle, these flow conditions are more complex.

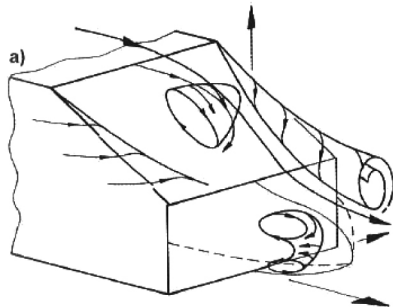


Figure 4. Flow conditions at a typical coupe fastback [1]

A typical coupe fastback is characterized by its very flat back window angle. The dominant flow phenomena of a fastback are the two longitudinal vortices that form along the D-pillar. In addition to these vortices a flow separation zone is generated on the rear window if the radius between roof and rear window is not sufficiently large. Finally, there is a small ring vortex in the wake of the car. All these effects cause areas of very low pressure on the back window and the back plane of the vehicle. On a typical squareback, there is only an increase of drag due to the low pressure conditions. On a fastback car, the low pressures do not act on a vertical plane like on a squareback, but on a slanted one. For this reason there is an increase in drag and in lift. These conditions can become critical at higher speeds when the rear axle lift is too high because this has a negative influence on driving stability.

Notchback

The flow conditions at a notchback vehicle are similar to those at a fastback, but not exactly the same, (see [fig. 5](#))

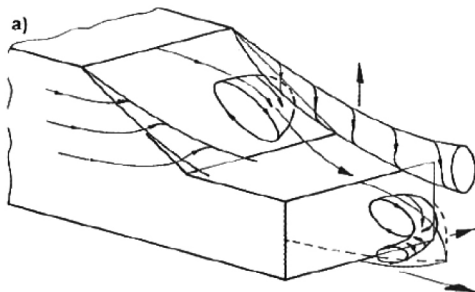


Figure 5. Flow conditions at a notchback [1]

There are also two longitudinal vortices but they are smaller than the ones at a fastback. These vortices form on the D-pillar but re-attach on the deck lid. The flow along the roof forms a separation zone on the rear window that also re-

attaches on the deck lid. Finally there is also a small ring vortex in the wake of the car. Similar to the fastback, these vortices generate a very low pressure. Since the vortices and the slanted back plane are smaller, the negative aerodynamic effects are lower. Thus there is less increase in the aerodynamic drag and lift. Additionally the re-attachment of the flow on the deck lid reduces the negative lift effect due to the low pressure conditions.

INDUCED DRAG

The third resistance part that acts on the vehicle is the induced drag. The concept of induced drag is explained in [2] and its influence on the aerodynamic is shown in detail there. This investigation describes how additional lift or additional downforce have to be paid for by an increase in drag.

As described above, depending on the body type several vortices are formed on the back of vehicle. These vortices cause downwash in the wake and areas of low pressure that lead to an increase of drag or lift. Beyond this, the vortices contain a lot of rotational energy. This energy has to be supplied by the vehicles drive train and is called the induced drag. The bigger and stronger the vortices are, the higher is the induced drag. Since the induced drag is strongly dependant on the vortex structures of the vehicle it is therefore also dependent on the body type.

In the process of an aerodynamic optimization every single component of the resistance has to be minimized. To reduce the friction resistance, a benefit can be achieved in designing a smooth and flat underbody. Optimizing the vortex structures on the back can reduce the pressure resistance and induced drag. Since there is an interaction between the different resistance parts the process is very complex. If the underbody is optimized to reduce friction resistance, the flow split between underbody flow and flow around the upper side of the vehicle is changed. This change affects the flow structure on the back of the vehicle and thus pressure resistance and induced drag.

Regarding the interaction of the different resistance types and flow phenomena it becomes clear, that in order to achieve low drag and lift values, the underbody flow has to be optimized to best fit to the flow around the vehicle body.

Another very important issue for a successful optimization is the wind tunnel. The interaction between underbody flow and the flow around the body was described with its effects on drag and lift. The wind tunnel itself has also an influence on the flow around the vehicle and especially on the underbody flow. For aerodynamic optimization work at the underbody it is important to have a wind tunnel with ground simulation technology [3,4]. The aerodynamic effects of wheel rotation and moving ground on the aerodynamic properties, especially on the induced drag is described in [2].