Aerodynamics of the New BMW X5
A Contribution to BMW Efficient Dynamics

The goal pursued in the development of the aerodynamics of the new BMW X5 was to achieve the lowest drag coefficient in its class. Close cooperation between aerodynamics and design was imperative in order to further reduce the already low value of the predecessor. Besides optimising the exterior shape, also technical measures designed to reduce drag were employed while additionally subjecting classic conflicts of aerodynamics objectives to detailed analysis. Consequently, the aerodynamic development of the new BMW X5 was characterised by meticulous attention paid to all aspects under the premises of achieving the lowest possible drag values.
1 Introduction

Climate change, growing energy demand worldwide, the finite nature of fossil energy sources and political crises are jeopardising our mobility. Mobility, however, is an elementary precondition of our economic system and therefore a key factor in attaining employment, prosperity and quality of life. National and international discussions regarding legislative control of CO₂ emissions additionally provide a compelling case for exercising the greatest possible efficiency when using energy.

Less CO₂ and increased efficiency – the BMW Group remains committed to this goal. In the past, reductions in fuel consumption and CO₂ emissions were largely achieved by pursuing classic routes in terms of further developing engines and transmissions. To realise further significant reductions, it is now necessary to take a function-orientated complete vehicle approach. The first step is to minimise driving resistance to serve as a basis for establishing requirement-orientated energy conversion with maximum efficiency.

In addition to a noticeable reduction in fuel consumption, customers also demand even greater driving pleasure with high degrees of spontaneity and dynamics. Great significance is therefore attached to initially contradictory development objectives for achieving market success. The BMW Group is therefore further advancing the driving pleasure gained with the ultimate driving machine based on „efficient dynamics“. In this respect, sports utility vehicles (SUVs) and sports activity vehicles (SAVs) pose a particular challenge. Especially in this class of vehicle aerodynamics provides enormous scope for implementing the BMW Efficient Dynamics strategy.

2 Strategic Focal Points

The development of aerodynamics is faced with demanding challenges if SAVs are still to be successfully marketed against the backdrop of today’s need to reduce CO₂ emissions particularly in this vehicle class. In comparison with modern saloon design, the task of optimising the shape and function is considerably more involved and difficult for development engineers.

The scope of aerodynamics development is divided into four strategic focal points:
- Form – Proportion
- Internal Flow
- Underbody
- Wheel – Wheel House.

Figure 1: Challenges on SAV aerodynamics

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These strategic focal points represent the main areas of attention for the future in the new BMW aerodynamics test centre.

In addition, the focal points have clearly defined interfaces among each other.

### 3 Driving Resistance – Drag

The factors determining driving resistance of a vehicle are shown in Equation 1.

\[ F = F_k + F_D + F_g + F_a \quad \text{Eq. (1)} \]

Herein \( F_k \) stands for rolling resistance, \( F_D \) for drag resistance, \( F_g \) for gradient resistance when driving on a gradient and \( F_a \) for acceleration resistance. Added up they result in the driving resistance \( F \).

The drag coefficient \( c_D \), which is the best known parameter in aerodynamics, is a dimensionless coefficient for drag resistance. It can therefore be understood as a characteristic value for the form quality, irrespective of the size of the vehicle. The lower the value, the more sleek, i.e. streamlined, the vehicle characteristics in terms of its drag. Multiplied by the frontal area \( A \) of the vehicle, i.e. its projection surface in longitudinal direction, by half the speeds squared \( 0.5 v^2 \) and by the air density \( \rho \) it results in the drag \( F_D \) of the vehicle – Equation 2.

\[ F_D = c_D \cdot A \cdot \frac{1}{2} \cdot v^2 \cdot \rho \quad \text{Eq. (2)} \]

Under the same marginal conditions in terms of air density and driving speed, this means there are two influencing variables governing the drag resistance of a vehicle: the frontal area and the drag coefficient. Since the frontal area is largely defined by the vehicle concept, optimisation of the drag coefficient can be considered as a decisive instrument in the development process.

The uplift at the front and rear axle is derived from Equation 2 by using the lift coefficients \( c_L \) and \( c_U \) for the front and rear axle instead of the drag coefficient \( c_D \).

### 4 Aerodynamic Challenges

The aerodynamic development of an SAV takes into consideration the conflicts between different requirements, Figure 1. The demand for higher speeds goes hand in hand with the need for low fuel consumption and lower emissions. It is also necessary to ensure effective cooling for the engine and assemblies. Among other things, safe vehicle handling assumes manageable and stable uplift characteristics. The demand for agile vehicle handling can be satisfied mainly with a low drag coefficient. A further focal point of aerodynamics development is vehicle soiling which, at low drag coefficient \( c_D \), offers more advantageous characteristics than compared with the predecessor. Compared to a saloon, the off-road performance also represents a demanding challenge in terms of achieving effective aerodynamics [1].

The first BMW X5 was launched in 1999 with a, by comparison, outstandingly low drag coefficient of \( c_D = 0.35 \). The new BMW X5 is to follow suit and assume this top position in terms of aerodynamics. This objective represents an even greater challenge in view of the changed conditions in comparison with the predecessor. For instance, today the frontal area of the vehicle, which greatly influences the drag, counts 2.87 m² compared to 2.5 m² on the predecessor. Likewise, the basic tyre size 255/55 R18 is 20 mm wider than on the predecessor, contributing to the larger frontal area while additionally having an adverse effect on the drag coefficient \( c_D \). The same is true of the wing mirrors that are larger due to a change in legal requirements. This change is also expressed directly in the larger frontal area while additionally aggravating the disrupting effect of the wing mirrors on air flow about the vehicle.

### 5 The Aerodynamic Development Process

As shown in Figure 2, the aerodynamic development process at BMW Group is divided into two phases, i.e. the concept phase and the series development phase [2]. In the concept phase, aerodynamic development focuses completely on the various design competition options. The aerodynamic of initial proportion studies is realised virtually by means of computational fluid dynamics (CFD). Based on 40 % scale models, all competing design proposals are assessed and optimised in the wind tunnel. In this way, each designer taking part in the competition receives feedback concerning the measures implemented for his/her model with the aim of optimising the aerodynamic coefficients for drag and lift. The 40 % models are measured in the model wind tunnel with ground simulation, i.e. with moving ground and rotating wheels. In order to accurately depict realistic interactions between the air flowing about and through the vehicle, the models are fitted with cooling air inlets and a through-flow engine compartment. This is important as the optimum exterior shape of the vehicle greatly depends on these interactions. The pressure loss as the result of air flowing through the en-

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**Cover Story**

**Body**

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**Figure 2:** Aerodynamic process of the new BMW X5
gine compartment is created with a model cooling matrix \([3]\) in the 40 %

scale model. Simultaneously, this matrix

is used to measure the mass air flow

trough the engine compartment for

the purpose of assessing the position and

t size of the air inlet openings. The model

is additionally equipped with a detailed

underbody. In this early phase, work con-

centrates on the whole proportion of the

vehicle, what results in optimised top, side and front view of the vehicle.

Optimisation of the aerodynamics

generally takes place as part of an itera-

tive process with several loops, in which

a design optimisation phase is followed

by an aerodynamic optimisation phase.

Once the design competition has been

whittled down to one or two models the

wind tunnel studies are continued using

100 % scale models, consisting of a body

with production-based axles, steering

units and underbody panelling with an

outer skin made of high-resistance foam

or plasticine. The engine compartment

with engine, radiator and assemblies as

well as all cooling air inlets, brake cool-

ing ducts and additional coolers are rep-

resented in the front end.

Following the design freeze, more de-

tailed wind tunnel studies are performed

based on driveable prototypes. A vehicle

is equipped with a carbon fibre outer

skin specifically for aerodynamics pur-

poses. This facilitates quick and exact

representation of the outer skin, cooling

air ducts and add-on components corre-

sponding to the respective design status.

During the entire process, CFD is used

partly as an accompanying tool and partly

as a substitutive tool to the wind tunnel

studies. The degree of detailing of the

CFD models is also constantly adapted to

the progressive development of aerody-

namic components. Figure 2 also shows

the development of the drag coefficient

for the X5 in the described process. At

the beginning of the aerodynamic optimi-

sation process the design model later

used exhibits a drag coefficient of \(c_D = 0.41\). If the total reduction from \(c_D = 0.41\)

to \(c_D = 0.33\) at SOP equates to 100 %, 70 %

of the realised drag reduction is achieved

in the first two optimisation loops. This

percentage is solely attributed to the aer-

odynamic shaping of the vehicle outer skin – a success ascribed to the close co-

operation between the aerodynamics

and design departments. This intensity

of collaboration is, of course, also the

prerequisite for achieving the ambitious

goals while working within the bounds of

the set conditions. While the vehicle’s

outer skin paneling is the focal point of

aerodynamic optimisation during the

design competition stage, after a design

has been selected, the effect of the under-

body also undergoes fine tuning. 16 %

of the total reduction in the drag coeffi-

cient is attributed to this phase. Follow-

ing the design freeze, optimisation pro-

cedures are concentrated on the under-

body as well as technical measures that

are finely tuned in terms of their func-

tionalility in driveable prototypes. These

measures make up the remaining 14 %

required for achieving the drag coeffi-

cient of \(c_D = 0.33\) in series production.

6 Aerodynamic Measures

Development of aerodynamics takes

place based on the strategic focal points

explained in the introduction. This de-

velopment process entails processing the

special features associated with the con-

cept of an SAV as well as standard aspects

such as brake disc cooling. All relevant

aspects are optimised in line with func-

tional safety and reliability with maxi-

mum benefit in terms of aerodynamics.

6.1 Vehicle Body

The front overhang is a good example

that clearly illustrates the integration of
the focal points shape – proportion and wheel – wheel house. A short front overhang is a distinguishing feature of all BMW vehicles. The BMW X5 is characterised by a particularly short overhang at the front wheels, Figure 3. From an aerodynamic point of view, however, this short overhang also further shortens the flow entry zone ahead of the front wheels, resulting in a high loss rate as the air flows over the front wheels. In order to counteract these losses, particular attention is paid to the design layout of the outer edges on the front apron. The air flowing past the front wheels as parallel as possible to the direction of travel results in lower wheel flow losses. In Figure 4 this is illustrated by the fact that the streamlining is deflected only slightly to the side of the front end. This creates the angular shape of the front apron that is also a characteristic feature of BMW vehicles. The largely cut wheel wells of the X5 are enface with a wide bar, in order to further minimise the aerodynamic losses in this area.

Two further measures for advantageously designing the shape of the vehicle are located at the rear end. With the aid of the roof spoiler the position of the flow stall from the vehicle roof can be configured in such a way as to provide effective drag, Figure 5. For this purpose, the roof line is extended towards the rear, it is drawn in downwards and the edge of the spoiler is made with the smallest possible radius. A rear spoiler integrated in the tailgate would not provide freedom of design to this extent. The sides of the roof spoiler are closed towards the vehicle in order to fully utilise the benefits provided by the extension. The rear edges of these lateral faces are flared to ensure a defined flow stall. A further stall edge is integrated in the tail lights, Figure 6. With its defined flow stall, it also effectively reduces the drag coefficient. The discrete integration in the glass cover of the tail lights combines the advantage of aerodynamics with the advantage of barely influencing the design.

6.2 Underbody
The underbody of the BMW X5 is completely clad through from the front apron up to the rear axle, Figure 7. Compared to the SUVs available on the market, the underbody of the X5 is the most...
panelled off. The development of a closed underbody must take into account the thermal effects from two aspects. The underbody panelling itself must not suffer thermal damage caused by the heat radiated from components such as the exhaust system. Minimum distances from hot components must be maintained for this purpose. From an aerodynamics point of view, however, gaps and non-clad areas should be as small as possible. The required distances are reduced to a minimum by the use of heat shields to protect the panelling components and by making use of more heat resistant materials. It is also necessary to ensure effective cooling of the components that are covered by the underbody panelling. Specifically targeted air inlets in the underbody panelling fulfil this purpose. These two aspects are particularly noticeable at the gearbox cover. This cover is made out of aluminium as it is subjected to high heat radiation from the exhaust system in this area. If a plastic component were used, this heat radiation would necessitate drastic cladding along with an increase in drag. The cover features an air inlet to facilitate targeted cooling of the covered gearbox.

Specific to the type of engine, the so-called 6-cylinder engine panel is installed. It serves the purpose of covering the empty section of the exhaust system on 6-cylinder engine vehicles. This section is filled with the twin flow exhaust system for 8-cylinder engines.

6.3 Technical Measures
The active air flaps represent an active means of reducing drag in terms of air internal flow, Figure 8. The air flowing through the engine compartment is prone to pressure, frictional and pulse losses, resulting in an increase in the overall drag. However, the total cooling capacity and therefore the total mass air flow through the engine compartment is required only under certain operating conditions such as when driving at top speed. The air inlets in the front apron are designed to meet this maximum cooling air requirement. Under driving conditions where a lower mass flow rate of the cooling air is sufficient, the active air flaps throttle the mass air flow rate through the engine compartment by closing off the kidney grille and the central air inlet [4]. In this way, the flow loss and therefore the drag are reduced. Among other parameters, the temperatures for coolant, engine and gearbox are tapped off from the vehicle management system for the purpose of determining the currently required cooling capacity. When the defined limit temperatures are exceeded, the active air flaps open to make available the maximum mass flow of cooling air.

In addition to the aerodynamic advantage and in line with an intelligent operating strategy, these flaps also have positive effects on the internal engine friction ensured by the faster heat-up rate and on the external acoustics. A further aspect of internal flow and wheel-wheel house is ensuring effective brake cooling, Figure 9. The cooling requirement depends on the size of the installed brakes and therefore on the vehicle’s engine. On the one hand, the air is supplied targeted via the brake air ducts that guide the air through the front apron directly onto the brakes while, on the other hand, cooling is also provided by the flow of air from below into the wheel wells. The flow of air to the brakes from the area under the vehicle is influenced by the wheel spoilers ahead of the wheels. They are optimised to the effect that the best possible drag coefficient is achieved while ensuring the necessary degree of cooling. This means two types of wheel spoilers are used corresponding to the cooling air requirement of the installed brakes. The brake air ducts that, in the same way as internal flow in the engine compartment, signify an increase in drag, are also installed specific to the type of engine.

6.4 Results
In terms of aerodynamics, the new BMW X5 with a drag coefficient of $c_D = 0.33$ and lift coefficients of $c_{L_{fs}} 0.06$ at the front axle and $c_{L_{fr}} 0.02$ at the rear axle is firmly positioned at the top of the SUV/SAV segment, Figure 10. Outstanding aerodynamics coefficients have been achieved both at specific points as well as within the challenging conditions laid down by the SAV concept. This success
is attributed to close alliance between the aerodynamics and design departments as well as meticulous attention paid to all aspects of aerodynamic properties.

7 BMW Efficient Dynamics

BMW Efficient Dynamics measures [5], which include highly efficient internal combustion engines and transmission systems, electrification of ancillary devices, kinetic (brake) energy recuperation by intelligent alternator control, tyres with reduced rolling resistance, are further enhanced by the worldwide lowest $c_D$ drag coefficient in this vehicle class. The result is outstanding values in terms of fuel consumption or CO$_2$ emissions and vehicle performance. Figure 11 and Figure 12.

Best aerodynamics – whether passive or active – is an integral part of the BMW Efficient Dynamics strategy. This ensures the new X5 models achieve outstanding values in terms of fuel consumption/CO$_2$ emissions and driving performance.

References


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