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 CO_2 emissions additionally provide a compelling case for exercising the greatest possible efficiency when using energy.

Less CO_2 and increased efficiency – the BMW Group remains committed to this goal. In the past, reductions in fuel consumption and CO_2 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.

The goal pursued in the development of the aerodynamics of the new BMW X5 was therefore to achieve the lowest drag coefficient in its class. The predecessor already assumed this top position for many years with a drag coefficient of c_D = 0.35. Close cooperation between aerodynamics and design was imperative in order to further reduce this already low value. 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.

This article outlines the aerodynamic development of the new BMW X5 and illustrates the measures used to even further reduce the drag coefficient of c_D = 0.35 of the predecessor which, for many years, represented the lowest value, thus retaining the top position worldwide. The article also examines the effects on fuel consumption, CO_2 emission and driving performance within the framework of 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 CO_2 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.

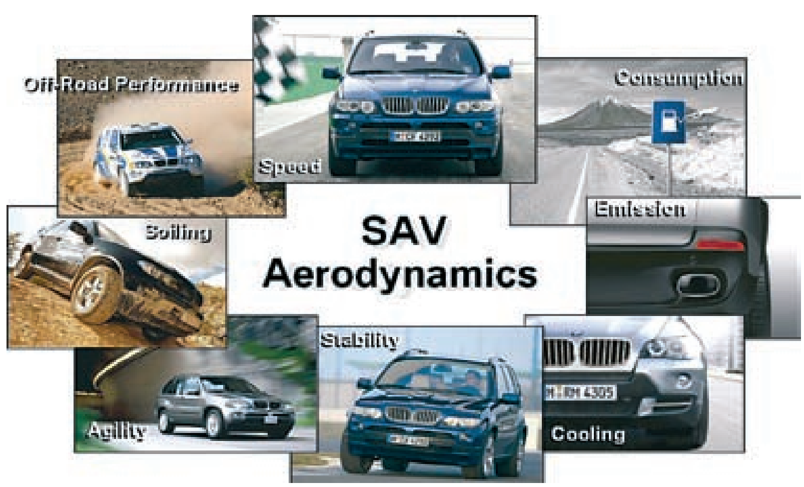

Figure 1: Challenges on SAV aerodynamics

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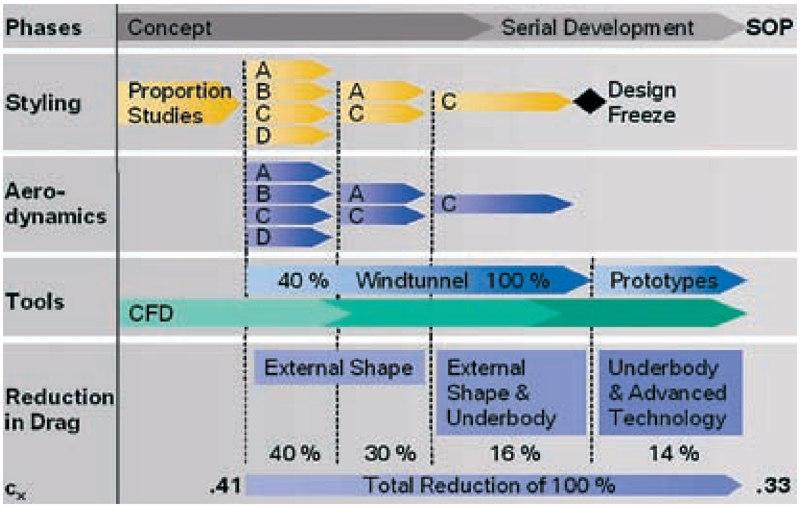

Figure 2: Aerodynamic process of the new BMW X5

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.

$$F = F_R + F_D + F_G + F_a \qquad \text{Eq. (1)}$$

Herein F_R stands for rolling resistance, FD 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 $½\, v^2$ and by the air density ρ it results in the drag F_D of the vehicle – Equation 2.

$$F_D = c_D * A * ½ * v^2 * \rho \qquad \text{Eq. (2)}$$

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_{Lf} and c_{Lr} 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-

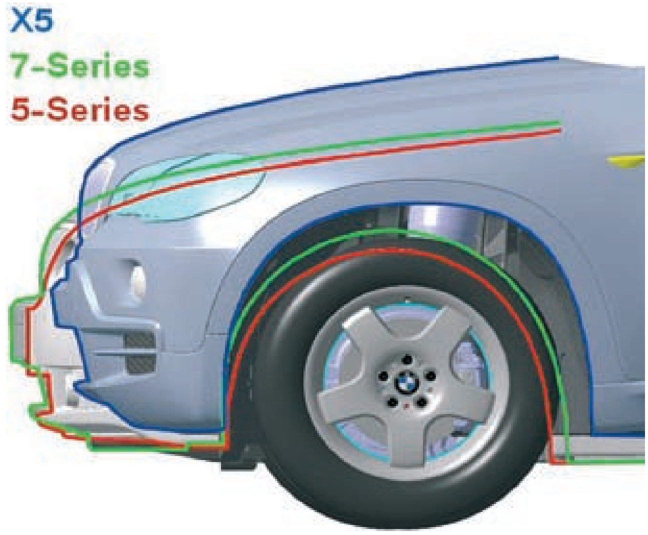

Figure 3: Front proportions of X5 – 7-Series – 5-Series

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 through the engine compartment for the purpose of assessing the position and size of the air inlet openings. The model is additionally equipped with a detailed underbody. In this early phase, work concentrates 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 iterative 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 cooling ducts and additional coolers are represented in the front end.

Following the design freeze, more detailed wind tunnel studies are performed based on driveable prototypes. A vehicle is equipped with a carbon fibre outer skin specifically for aerodynamics purposes. This facilitates quick and exact representation of the outer skin, cooling air ducts and add-on components corresponding 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 aerodynamic components. Figure 2 also shows the development of the drag coefficient for the X5 in the described process. At the beginning of the aerodynamic optimisation 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 aerodynamic shaping of the vehicle outer skin – a success ascribed to the close cooperation 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 panelling is the focal point of aerodynamic optimisation during the design competition stage, after a design has been selected, the effect of the underbody also undergoes fine tuning. 16 % of the total reduction in the drag coefficient is attributed to this phase. Following the design freeze, optimisation procedures are concentrated on the underbody as well as technical measures that are finely tuned in terms of their functionality in driveable prototypes. These measures make up the remaining 14 % required for achieving the drag coefficient 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 development process entails processing the special features associated with the concept of an SAV as well as standard aspects such as brake disc cooling. All relevant aspects are optimised in line with functional safety and reliability with maximum benefit in terms of aerodynamics.

6.1 Vehicle Body

The front overhang is a good example that clearly illustrates the integration of

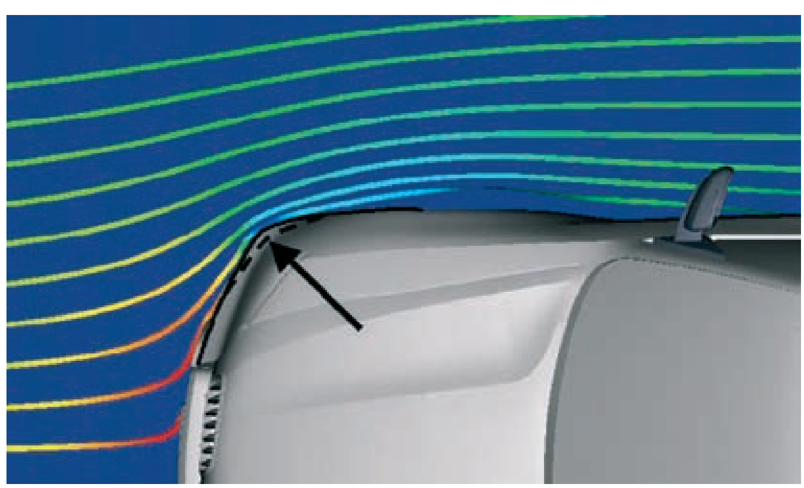

Figure 4: Flow visualisation in the frontend

Figure 5: Roof spoiler with aerodynamic wedge

Figure 6: Tail light with aerodynamic wedge

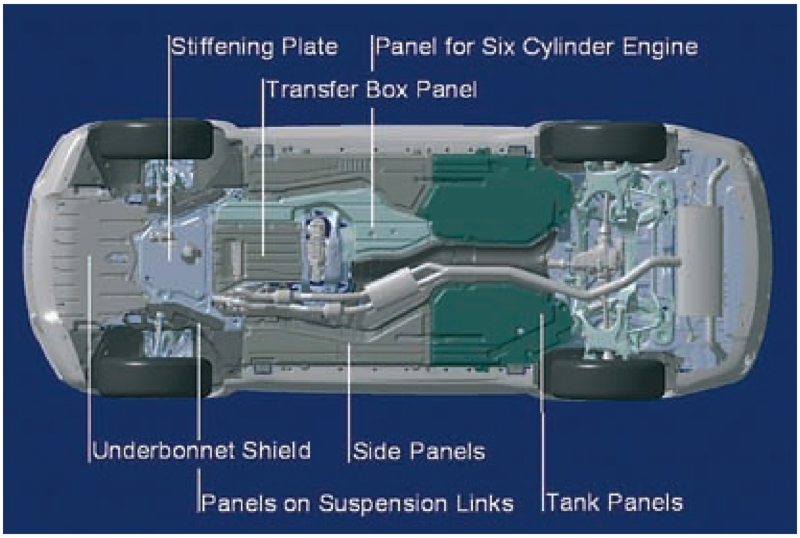

Figure 7: Aerodynamic underbody

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 enfaces 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

Figure 8: Active air flaps: closed – open

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 nonclad 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_{Lf} 0.06 at the front axle and c_{Lr} 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

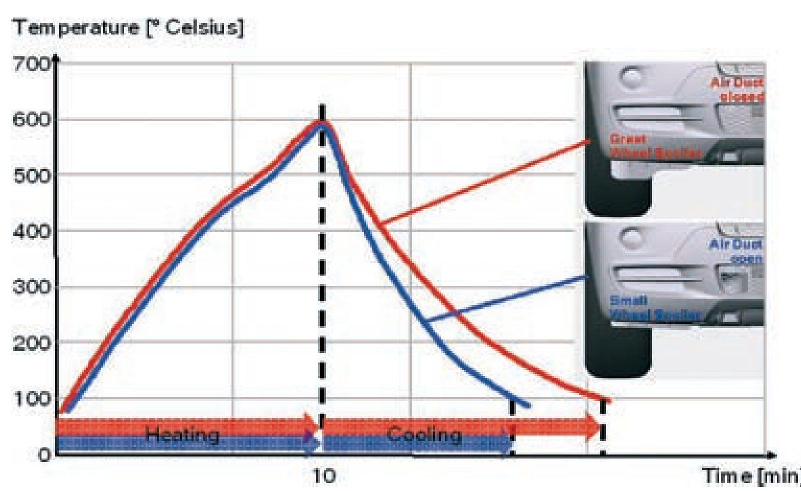

Figure 9: Cooling of the breaks

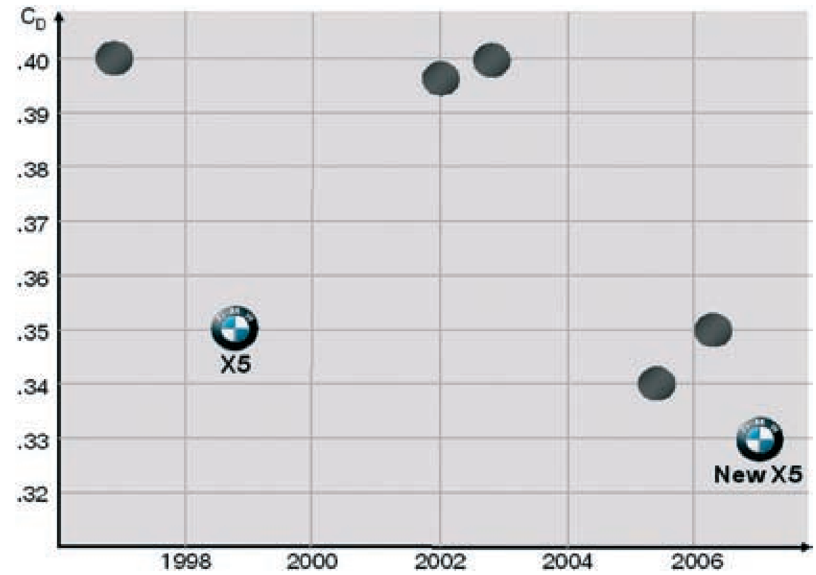

Figure 10: Benchmark of drag coefficient

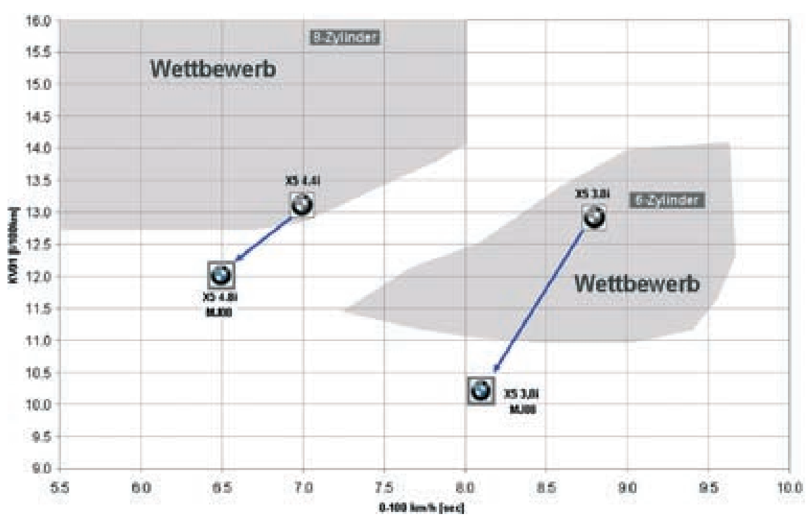

Figure 11: Vehicle performance and fuel consumption – petrol engines

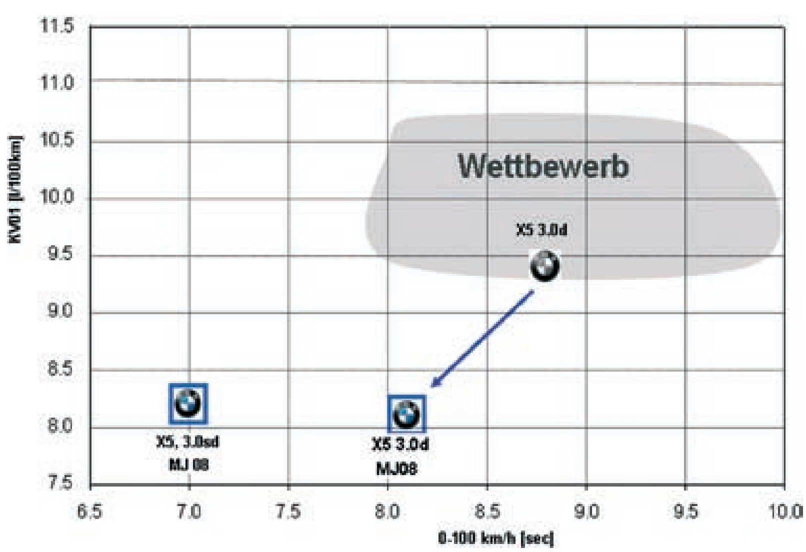

Figure 12: Vehicle performance and fuel consumption – diesel engines

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

[1] E. Pfannkuchen, S. Hillström, A. Stampflmeier, H. Kerschbaum: „Aerodynamics of the New BMW X5", 6th MIRA International Vehicle Aerodynamics Conference, Warwick U.K. 2006

[2] H. Kerschbaum, N. Gruen, P. Hoff, H. Winkelmann: „On Various Aspects of Testing Methods in Vehicle Aerodynamics", JSAE Paper 20045445, Yokohama, 2004

[3] J. Thibaut, J. Wiedemann, H. Winkelmann: „Optimization of vehicle design regarding internal airflow in the aerodynamic development process", FISITA Paper F2006M157, Yokohama 2006

[4] S. Krist, J. Mayer, R. Neuendorf: „Aerodynamik und Wärmehaushalt des neuen BMW 5er". In: ATZ/MTZ-Sonderausgabe „Der neue BMW 5er", Wiesbaden 2003

[5] J. Liebl: „BMW EfficientDynamics™ – CO_2-Reduzierung mit Fahrspaß", 19. Internationale AVL Konferenz „Motor & Umwelt", Graz, Österreich, 2007

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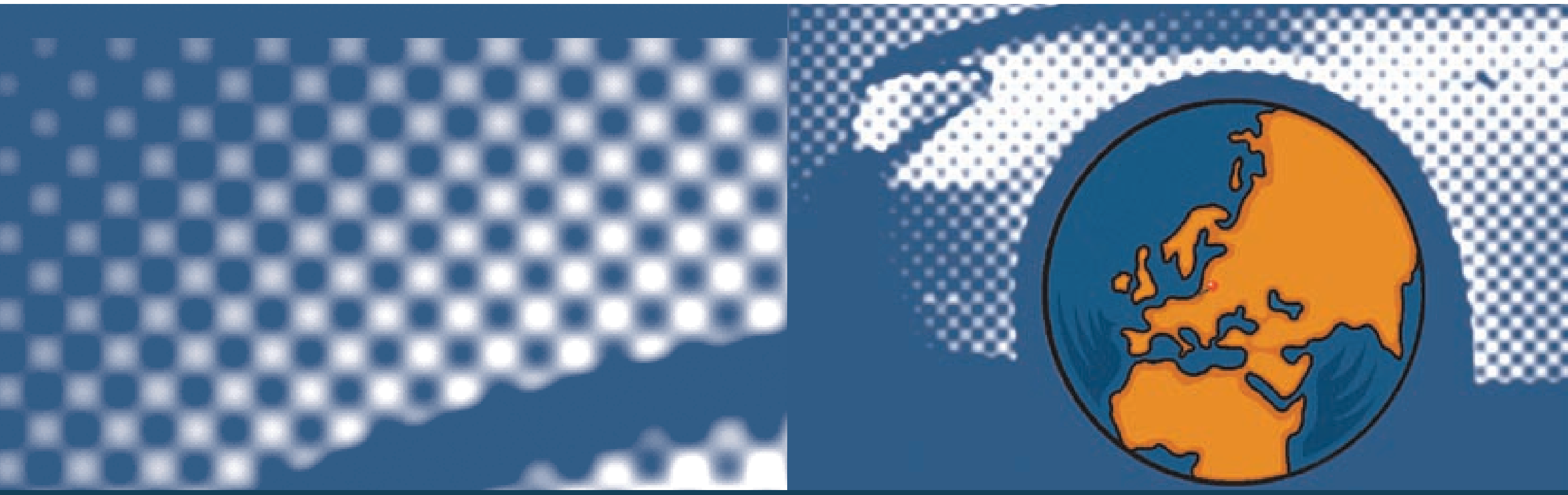

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