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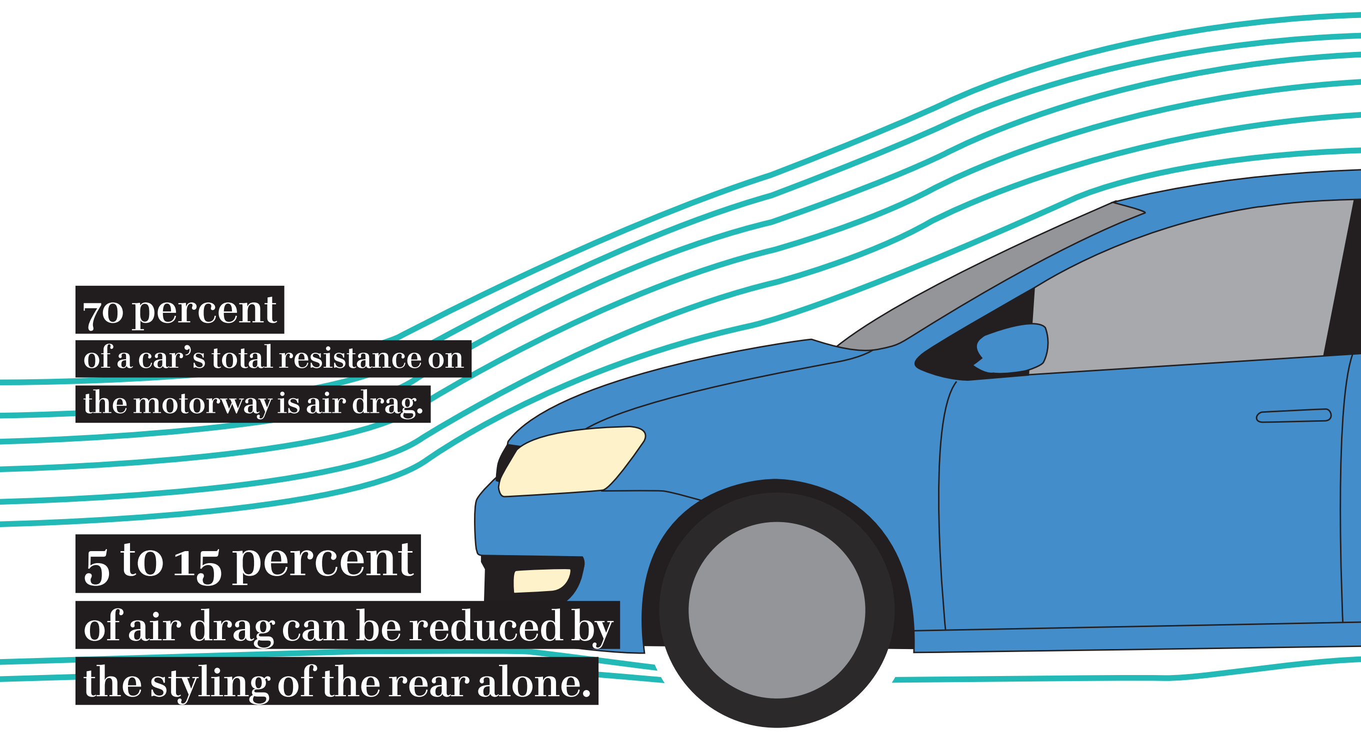
NO 06
July 2012

Aerodynamics

Industrial Espionage in the Realm of Nature



70 percent
of a car's total resistance on the motorway is air drag.

5 to 15 percent
of air drag can be reduced by the styling of the rear alone.

Editorial

Dr. Ulrich Hackenberg, Member of the Board of Management of Volkswagen Brand with responsibility for Research and Development.

There are many ways to make a car more efficient and reduce CO_2 emissions. An aerodynamic design is one of them: the more streamlined a car, the less fuel it needs. On the following pages you will learn what role models exist in nature, how the aerodynamics of the automobile are measured and how they are improved.

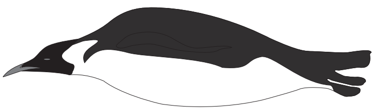
Happy reading.

Streamlined

How Air Influences Movement

Air brakes – this effect is known to anyone who has ridden a bicycle into a headwind and had to pedal harder. The same applies to cars: given increased air resistance the motor has to work harder and fuel consumption increases. Consequently, aerodynamics is more and more at the centre of car design. The designers find role models in nature. In order to improve the aerodynamic properties of prototypes, tests in wind tunnels and calculations are done – always fighting against the braking effect of air resistance.

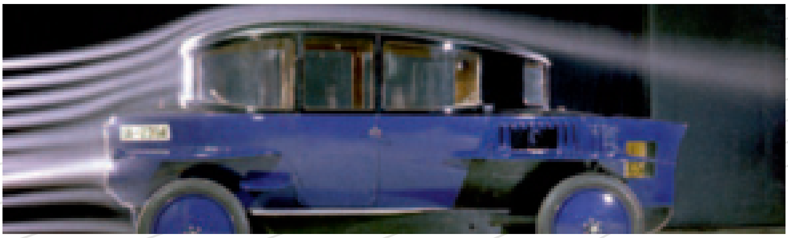
Aerodynamic models from nature:



For a long time a drop of water was considered the most aerodynamic shape, nowadays it is known that the penguin is more streamlined: when water drops the thickest part is at the front, whereas the thick part of a penguin is more drawn out. Seen from an aerodynamic point of view, water and air only differ by their density, which is why the penguin can be used for comparison.

Source: Ilmenau University of Technology (as of 2012)

Historic pioneer:



Picture: Volkswagen Aktiengesellschaft

The Rumpler-Tropfenwagen ("Tear Drop Car"), presented in Berlin by the designer Edmund Rumpler in 1921 at the German Automobile Exhibition, had a c_d value of 0.28, making it significantly more streamlined than many current cars. Viewed from the top it looks like a water drop – considered the ideal aerodynamic shape at that time. The picture was taken in the Volkswagen wind tunnel where, in 1979, the car was tested to find out how aerodynamic it really is.

Source: Deutsches Museum

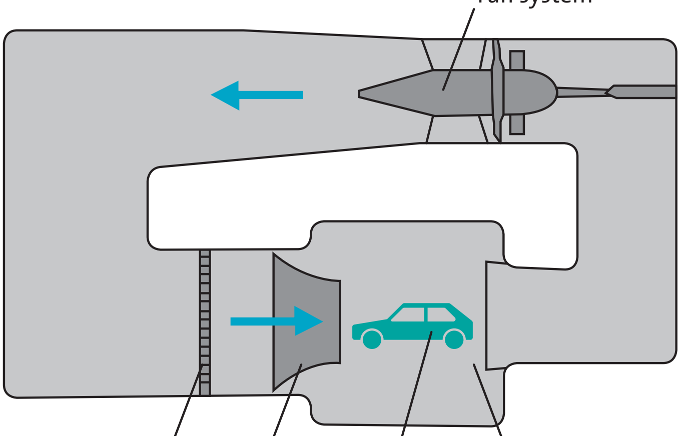
* The c_d value (or air drag coefficient) is measured in a wind tunnel. The lower it is the more aerodynamic the respective object (also see pages 4 and 5).

Measuring Forces

Real Conditions in the Wind Tunnel

Aerodynamic measurements in a wind tunnel are complex because the testing conditions have to be as close to reality as possible. All relevant forces and momentums affecting the vehicles can be measured here. The large automobile manufacturers mostly have their own facilities in which to conduct their tests. The air is mixed with fog to make the exact course of the air flow visible. This way turbulences and air flow can be better observed.

Setup of a wind tunnel:



Most car manufacturers' wind tunnels are constructed as a rectangular hallway in which the air is blown through a flow straightener and a nozzle onto the car from the front and conducted out at the rear wall. This fan can generate wind speeds of up to 300 kilometres per hour.

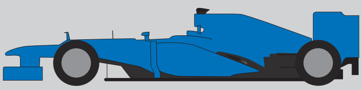
Source: Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (as of 2012)

Measurement

The car stands on a rotating platform, in order to turn the car at a right angle to the nozzle and to simulate side winds.
A treadmill is installed in this rotating platform simulating movement of the wheels and the driving surface. In addition, a scale is installed in the floor of the measuring section.
It measures all forces and momentums on the car by the wind, such as lift induced drag, lateral force and longitudinal force. Using these values the c_d value* is calculated.

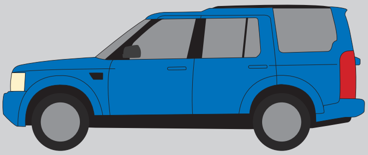
Cars and their c_d values*:

Formula 1 car



c_d value*: **1.2**

Land Rover Discovery



c_d value*: **0.4**

The silhouette of a car does not give any indication as to its c_d value. Formula 1 cars are not designed to be aerodynamic. However, Volkswagen's one litre car, the XL1, and the Technical University Zurich's research vehicle, the PAC-Car II, are especially streamlined.*

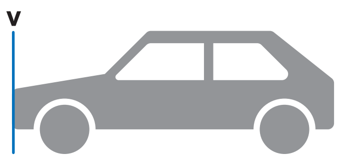
Influencable

Which Measurements Matter

A driving car is constantly pushing aside air – how much depends on its streamline. This is indicated by the so-called c_d value. It can be found in the technical data for new cars, has no unit and usually lies in the area of 0.2 to 0.4. It represents the friction force on a car caused by the air and is composed of different forces, which are usually measured in a wind tunnel.

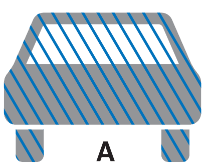
$$c_d = \frac{F_d}{A \times \frac{\rho}{2} \times v^2}$$

F_d is the force of drag, colloquially often called air resistance. It is measured with a force scale in the wind tunnel and its unit of measurement is the Newton.



ρ is the air density. It indicates how much mass is contained in a given volume of air. It is calculated using temperature and air pressure and its unit of measurement is kilograms per square metre.

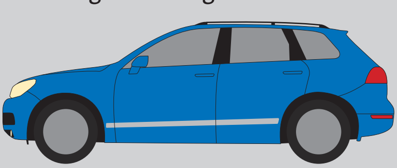
v stands for the velocity of the car and its unit of measurement is metres per second.



A stands for the frontal area of the car, because the air needs to be displaced on this area. It is determined by lighting the car with a lamp from the front and measuring the shadow on a screen behind the car.

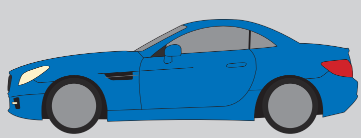
Source: Institut für Luft- und Kältetechnik Stuttgart (as of 2012)

Volkswagen Touareg



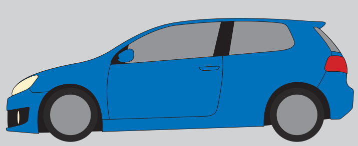
c_d value: **0.35**

Mercedes-Benz SLK



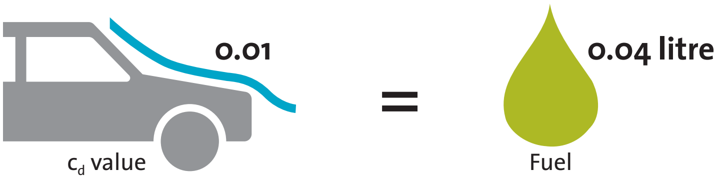
c_d value: **0.3**

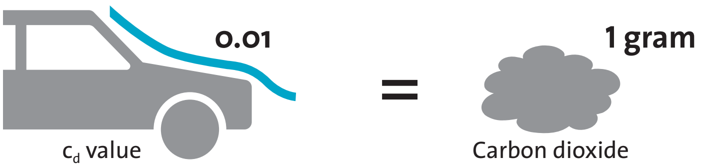
Volkswagen Golf



c_d value: **0.3**

The relation between c_d value and consumption:



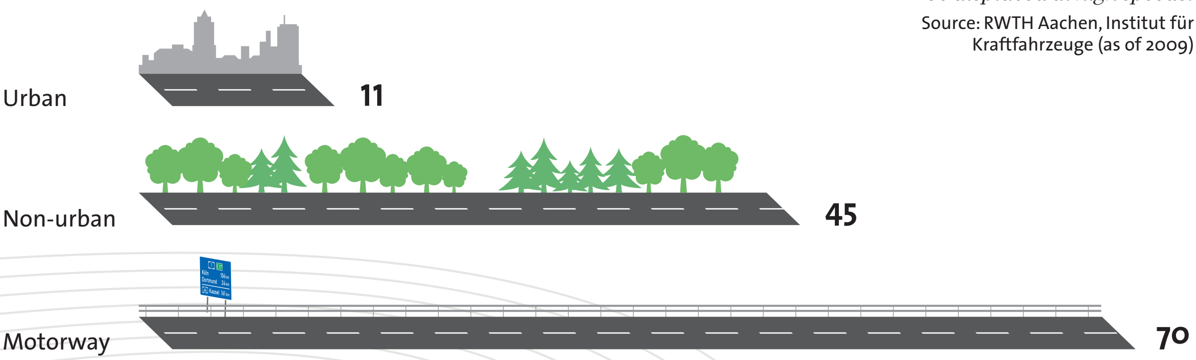


If the c_d value is lowered by 0.01, fuel consumption is decreased by 0.04 litres and, consequently, carbon dioxide emissions by a gram. The values refer to the consumption as determined by the New European Driving Cycle (NEDC). In reality, consumption can be decreased by a tenth of a litre and even by half a litre – during high speeds on motorways.*

Source: auto motor und sport (as of 2011)

* NEDC is a standardised driving cycle with predefined speed and distance, as well as outside temperature and many more parameters.

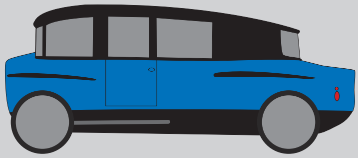
Share of air drag on total resistance:
(in percent)



The lower the average driving speed, the lower the air drag. More air has to be displaced at high speeds.

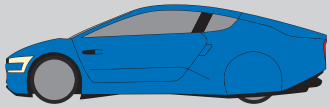
Source: RWTH Aachen, Institut für Kraftfahrzeuge (as of 2009)

Rumpler-Tropfenwagen



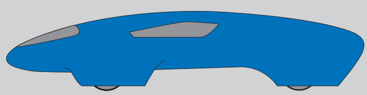
c_d value: **0.28**

Volkswagen XL1



c_d value: **0.186**

PAC-Car II



c_d value: **0.09**

Sources: derstandart.at; company data; Deutsches Museum, Eidgenössische Technische Hochschule Zürich

Little Resistance

Streamlined Components

There are various ways to reduce a car's air drag. Generally it is a question of shape: the design of the bodywork of course can make a vehicle more aerodynamic. But it also means improving individual components where air swirls and air drag are forming, like the engine compartment, underbody and the wheel houses for example. Car designers are trying to harmonise aerodynamics with comfort and looks in this regard.

Windscreen and A-pillars

A windscreen with a convex area is more aerodynamic than a flat windscreen. A front screen that is too arched, however, compromises the driver's view. The A-pillars at the side of the windscreen should ideally be flattened also. This is so that a smaller area of the front is exposed to the wind – the space inside the car, however, must not be limited too much by this.

5 percent less air drag can be achieved using windscreens that are shaped aerodynamically.

Picture: Paco Ayala – Fotolia.com

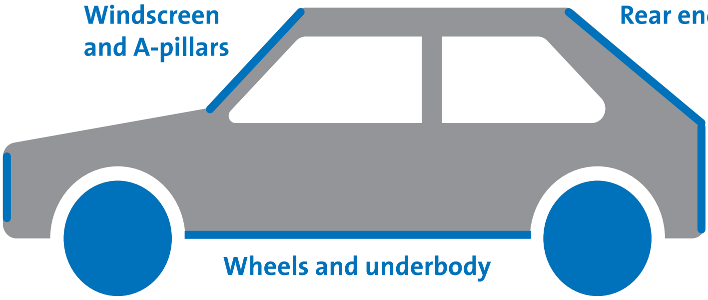
Slightly arched windscreens and flattened A-pillars are a compromise between a vehicle's aerodynamics and its comfort.

If the rear end of a car model is somewhat rounder, as is the case for the Volkswagen Beetle, its aerodynamics can be significantly improved by a spoiler: the air flows directly away and does not swirl.

Rear end

The optimal rear end is either as long as possible and edged, or one that ends abruptly. In both cases, the air flow is able to part horizontally. With a more arched rear end, this effect can be achieved with a little spoiler edge or large spoiler. Shapes that are bad for aerodynamics create air swirls behind the car that cause a suction effect and thus increase the drag.

5–15 percent of air drag can be reduced by rear end design.



The air intakes are vital design elements of the front of a car. If they can be closed, the car will be more aerodynamic.

Ventilation

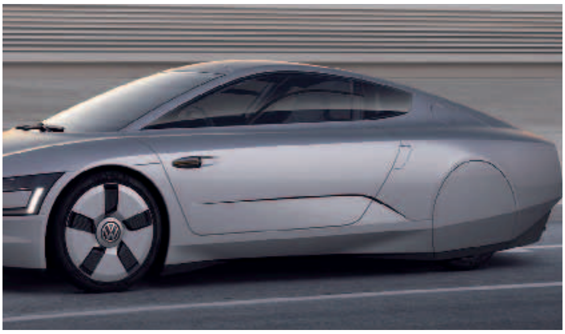
Air flows through the ventilation inlets inside the car in order to cool the engine. The drag that is caused by the radiator can be reduced by making the ventilation inlets smaller. Another method is even more effective: adjustable fins in front of the radiator only supply air on demand. The car has more streamlined properties when the fins are closed.

5-10 percent of air drag can be cut down at the radiator.

Wheels and underbody

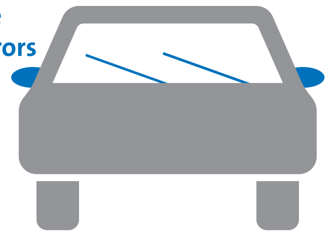
The air that flows past the sides and the underbody of the car can get caught up in the wheel houses and other uneven areas and creates air swirls at these places that slow down the car. The optimal aerodynamic solution would thus be to cover the wheel houses entirely. This is in contrast to the visual demands many drivers have. Underbodies on the other hand are now mostly covered or flattened.

5 percent of air drag can be reduced by wheel house construction.



Streamline properties are optimal when the wheel houses are entirely covered. As of now, this design is only to be found on vehicle studies – like the XL1, the one litre car by Volkswagen.

Sources: *Automobiletechnische Zeitschrift; Autmobil Konstruktion*; aerowolf.de (all as of 2012)



Fine Tuning

Aerodynamics Down to the Smallest Detail

The shape of the bodywork has the biggest effect on the aerodynamics of a car. Many details, however, can be designed in such a way that they provide as little as possible contact area to the wind which gets caught up in little uneven areas, such as windscreen wipers and side mirrors.


Picture: Bosch

These aerodynamically improved windscreen wipers direct the airflow with swept spoiler edges.

Wipers with spoilers

Wipers interrupt the smooth surface of the windscreen and thus increase air drag. By now, there are aerodynamically optimised wipers with something resembling a mini-spoiler that directs the air flow when the wipers are used. Depending on the car, the spoilers are located so close to the A-pillars, next to the windscreen, that they are entirely covered when in their idle position – this reduces the air swirls around the frontal area.

Sources: Bosch; SEAT (both as of 2012)

Cameras replacing side mirrors, as on the above shown XL1, may be seen more frequently on the streets in the future.

Cameras instead of mirrors

Side mirrors in particular interrupt the outline of a vehicle and offer contact area to the wind. If they are replaced by cameras, this exposure will be significantly reduced. The recorded picture is displayed on screens to the left and right of the steering wheel. But in Europe, such cameras will only be legal in four years time.

Sources: *auto motor und sport* (as of 2011); *Automobiltechnische Zeitschrift* (as of 2012)

Imprint

www.viavision.org.uk, www.viavision.org

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Published by
Verlag Rommerskirchen GmbH & Co. KG
Mainzer Straße 16 -18, Rolandshof,
53424 Remagen
Phone: +49 (0)2228/931- 0
www.rommerskirchen.com

Printed by
L.N. Schaffrath GmbH
Marktweg 42-50, 47608 Geldern