Special Project on

vehicle aerodynamics

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Acknowledgment

With great pleasure I wish to express my gratitude to my guide Prof. Ramachandran for his valuable guidance and inspiration through out the project. Without his help during all phases of this work it would have been difficult to complete this project successfully.

My sincere thanks to all my colleagues and faculty members for taking interest in my project and enriching my work with their valuable inputs.

Approval Sheet

The Industrial design Special project entitled “Vehicle Aerodynamics” by Vinish Janardhanan (08613003) is approved, in partial fulfillment of the requirements for Master of Design Degree in Industrial Design.

Guide : Prof. Ramachandran

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Abstract

Aerodynamics is a highly refined science that vies for position with other key vehicle design considerations such as styling and ergonomics. Its importance with respect to the operating efficiencies of a vehicle is undisputed but manufacturers must steer a balanced path between the push and pull of the many other aspects of a car necessary to sell it to the consumer.

A study of various aspects of aerodynamics where studied and how vehicles have been evolved during the years. From the designers point of view of the how the form of the vehicles can be maintained keeping in mind the aerodynamics involved where looked upon.

Introduction to Aerodynamics

The word comes from two Greek words: aerios, concerning the air, and dynamics, which means force. Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object.

Aerodynamics is a subfield of fluid dynamics and gas dynamics, with much theory shared between them. Understanding the motion of air around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties.

The use of aerodynamics through mathematical analysis, empirical approximation and wind tunnel experimentation form the scientific basis for heavier-than-air flight.

Aerodynamics is important in a number of applications other than aerospace engineering. It is a significant factor in any type of vehicle design, including automobiles. It is important in the prediction of forces and moments in sailing. It is used in the design of large components such as hard drive heads. Structural engineers also use aerodynamics, and particularly aero elasticity, to calculate wind loads in the design of large buildings and bridges. Urban aerodynamics seeks to help town planners and designers improve comfort in outdoor spaces, create urban microclimates and reduce the effects of urban pollution. The field of environmental aerodynamics studies the ways atmospheric circulation and flight mechanics affect ecosystems. The aerodynamics of internal passages is important in heating/ventilation, gas piping, and in automotive engines where detailed flow patterns strongly affect the performance of the engine.

Technical

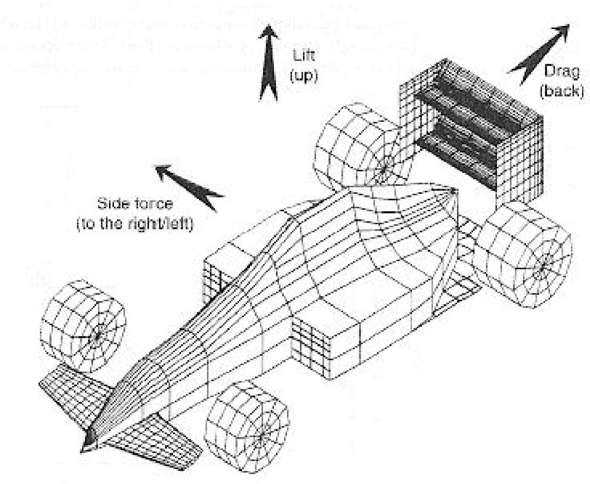


image1: aerodynamic forces on a moving vehicle

Aerodynamic forces

A number of forces act on a moving vehicle, which decides its performance on the road.

- Lift - dangerous at high speeds
- Drag - decreases performance
- Down force - better handling
- Side force - better cornering

Forces and moments applied to bodies moving through the fluid are of two types: pressures and shears. Pressures are created at the surface of a body due to (nearly) elastic collisions between molecules of the fluid and the surface of the body. Shearing forces are produced by fluid viscosity. This quantity is a measure of how well momentum is transferred between adjacent layers of the fluid. Although both types of forces are important in applied aerodynamics, pressures are usually the dominant type of force.

Lift

A fluid flowing past the surface of a body exerts a force on it. Lift is defined to be the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is defined to be the component of the fluid-dynamic force parallel to the flow direction. Aerodynamic lift is commonly associated with the wing of a fixed-wing aircraft, although lift is also generated by propellers; helicopter rotors; wings on auto racing cars; wind turbines and other streamlined objects.

When a wing is propelled through the air, there is a force upward on the wing due to the Bernoulli Effect. Air passes more quickly over the top of the wing than the bottom of the wing produces a lower pressure on the upper surface, hence a lift. There is also an upward force due to the air deflected downward from the bottom of the wing. These two forces taken together tend to lift the wing against gravity and are therefore known as lift.

Downward force

The term down force describes the downward pressure created by the aerodynamic characteristics of a car that allows it to travel faster through a corner by increasing the pressure between the contact area of the tire and the road surface, thus creating more grip.

The same principle that allows an airplane to rise off the ground by creating lift under its wings is used in reverse to apply force that presses the race car against the surface of the track. Because it is a function of the flow of air over and under the car, and because aerodynamic forces increase with the square of velocity, down force increases with the square of the car's speed and requires a certain minimum speed in order to produce a significant effect.

Two primary components of a racing car can be used to create down force when the car is travelling at racing speed:

- the shape of the body, and
- the use of airfoils.

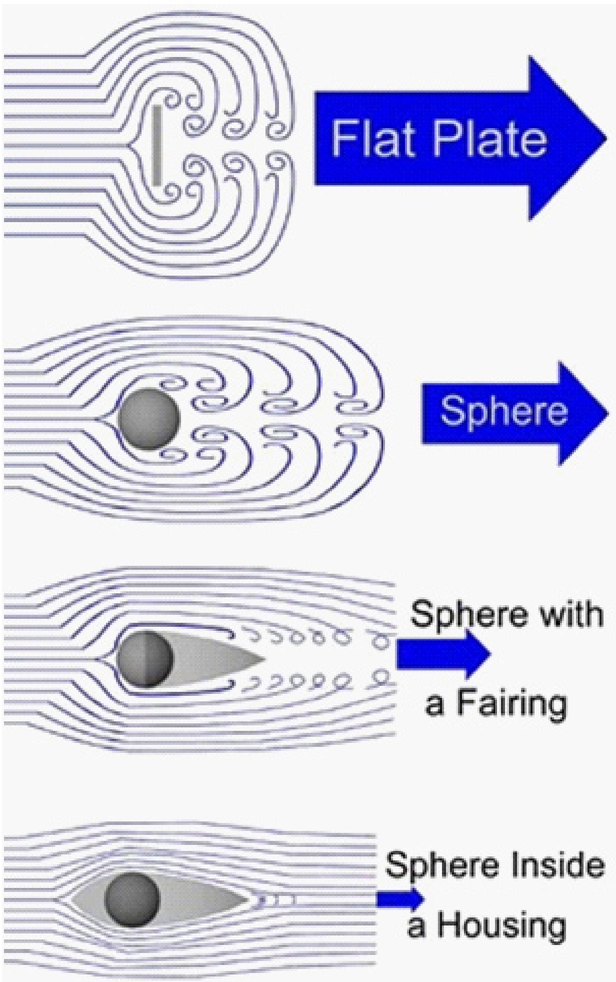


image:air flow around bodies with different shpes

Drag

Any physical body being propelled through the air has drag associated with it. In aerodynamics, drag is defined as the force that opposes forward motion through the atmosphere and is parallel to the direction of the free-stream velocity of the airflow. Drag must be overcome by thrust in order to achieve forward motion.

Drag is generated by nine conditions associated with the motion of air particles over the vehicle. There are several types of drag: form, pressure, skin friction, parasite, induced, and wave.
The term “separation” refers to the smooth flow of air as it closely hugs the surface of the wing then suddenly breaking free of the surface and creating a chaotic tiny vortex flows called vortices. The two objects just above them have a large region of separated flow. The greater the region of separated flow, the greater the drag. By designing a more streamlined body the drag can be reduced.

- Form or pressure drag is caused by the air that is flowing over the body surface. The separation of air creates turbulence and results in pockets of low and high pressure that leave a wake behind the vehicle. This opposes forward motion and is a component of the total drag.
- Streamlining the aircraft will reduce form drag, and parts of an aircraft that do not lend themselves to streamlining are enclosed in covers called fairings,
- Skin friction drag is caused by the actual contact of the air particles against the surface of the aircraft. The magnitude of skin friction drag depends on the properties of both the solid and the gas. Drag can be reduced by keeping the vehicle surface highly polished and cleanThe magnitude of the skin friction depends on the state of this flow.
- Parasite drag is simply the mathematical sum of form drag and skin friction drag.
- Induced drag is the drag created by the vortices at the tip of an aerofoil. The high pressure underneath the wing causes the airflow at the tips of the wings to curl around from bottom to top in a circular motion. This results in a trailing vortex.
- Although prediction of drag and wind tunnel drag measurements of models yield good results, final drag evaluation must be obtained by flight tests.

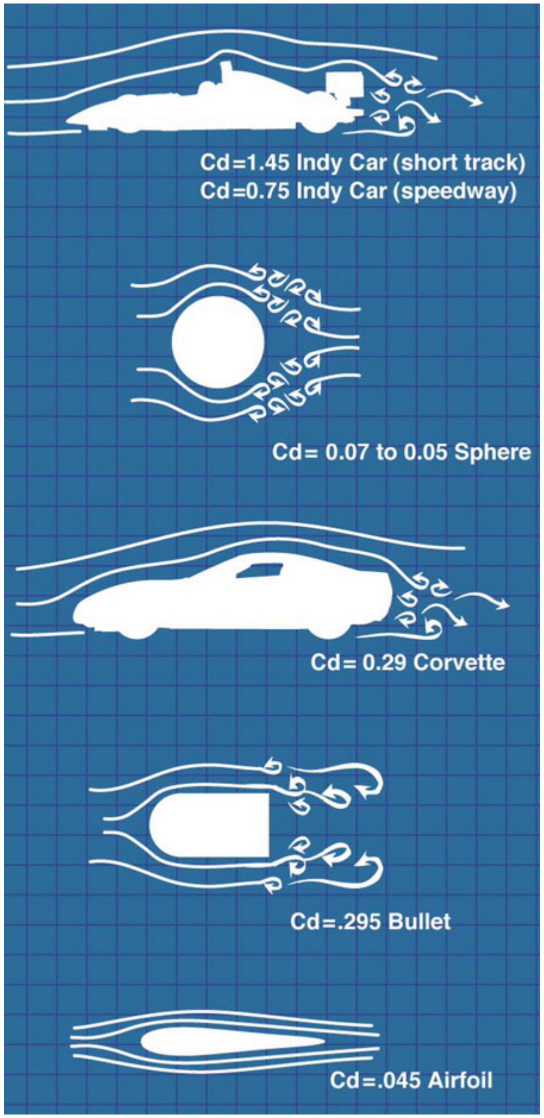


image: coefficeint of drag

Coefficient of drag

The drag coefficient, Cd is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air or water. It is used in the drag equation, where a lower drag coefficient indicates the object will have less aerodynamic or hydrodynamic drag. The drag coefficient is always associated with a particular surface area.

The drag coefficient of any object comprises the effects of the two basic contributors to fluid dynamic drag: skin friction and form drag.
The drag coefficient Cd is defined as:

$$C_d = \frac{F_d}{\frac{1}{2}\rho v^2 A},$$

where
Fd is the drag force, which is by definition the force component in the direction of the flow velocity,
ρ is the mass density of the fluid,
v is the speed of the object relative to the fluid, and
A is the reference area.
Cd-value is for modern passenger cars in the range of 0.30 to 0.35, for Sport Utility Vehicles (SUVs) with their flat fronts in the range of 0.35 to 0.45. It can go down for sport cars to 0.25.

Fluid dynamics

Fluid dynamics is the study of the flow of liquids and gases, usually in and around solid surfaces. The flow patterns depend on the characteristics of the fluid, the speed of flow, and the shape of the solid surface. Scientists try to understand the principles and mechanisms of fluid dynamics by studying flow patterns experimentally in laboratories and also mathematically, with the aid of powerful computers. The two fluids studied most often are air and water.

Aerodynamics is used mostly to look at air flow around planes and automobiles with the aim of reducing drag and increasing the efficiency of motion.

Hydrodynamics deals with the flow of water in various situations such as in pipes, around ships, and underground. Apart from the more familiar cases, the principles of fluid dynamics can be used to understand an almost unimaginable variety of phenomena such as the flow of blood in blood vessels, the flight of geese in V-formation, and the behavior of underwater plants and animals.

Air flow

Air flow is governed by the principles of fluid dynamics that deal with the motion of liquids and gases in and around solid surfaces. The viscosity, density, compressibility, and temperature of the air determine how the air will flow around a building or a plane. The viscosity of a fluid is its resistance to flow.

Even though air is 55 times less viscous than water, viscosity is important near a solid surface since air, like all other fluids, tends to stick to the surface and slow down the flow. A fluid is compressible if its density can be increased by squeezing it into a smaller volume. At low speeds less than 220 MPH, a third the speed of sound, we can assume that air is incompressible for all practical purposes. At speeds closer to that of sound (660 MPH), however, the variation in the density of the air must be taken into account. The effects of temperature change also become important at these speeds.

Laminar and turbulent flow

Flow patterns of the air may be laminar or turbulent. In laminar or streamlined flow, air, at any point in the flow, moves with the same speed in the same direction at all times so that the flow appears to be smooth and regular. The smoke then changes to turbulent flow, which is cloudy and irregular, with the air continually changing speed and direction.

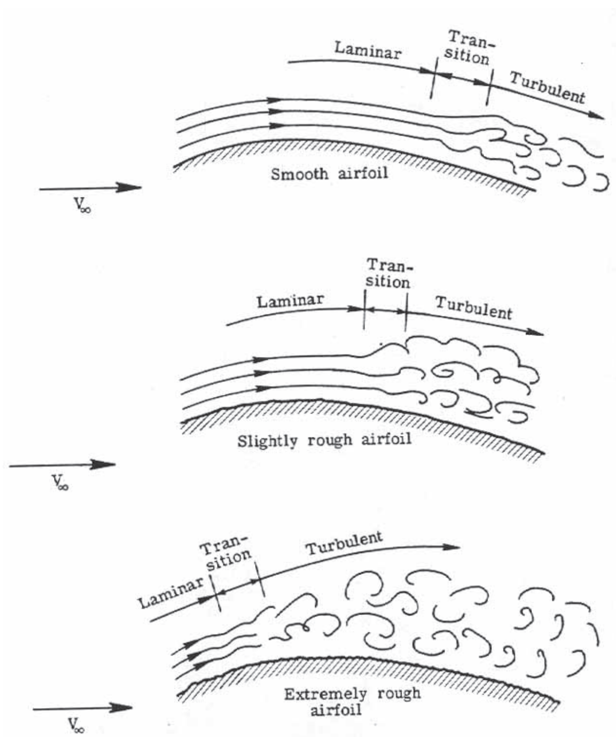


image: air separation on different surfaces

Laminar flow, without viscosity, is governed by Bernoulli's principle: the sum of the static and dynamic pressures in a fluid remains the same. A fluid at rest in a pipe exerts static pressure on the walls. If the fluid now starts moving, some of the static pressure is converted to dynamic pressure, which is proportional to the square of the speed of the fluid. The faster a fluid moves, the greater its dynamic pressure and the smaller the static pressure it exerts on the sides.

Bernoulli's principle works very well far from the surface. Near the surface, however, the effects of viscosity must be considered since the air tends to stick to the surface, slowing down the flow nearby. Thus, a boundary layer of slow-moving air is formed on the surface of an airplane or automobile. This boundary layer is laminar at the beginning of the flow, but it gets thicker as the air moves along the surface and becomes turbulent after a point.

Moving automobiles and airplanes experience a resistance or drag due to the force of air sticking to the surface. Another source of resistance is pressure drag, which is due to a phenomenon known as flow separation. This happens when there is an abrupt change in the shape of the moving object, and the fluid is unable to make a sudden change in flow direction and stays with the boundary. In this case, the boundary layer gets detached from the body, and a region of low pressure turbulence or wake is formed below it. This creates a drag on the vehicle due to the higher pressure in the front. That is why aerodynamically designed cars are shaped so that the boundary layer remains attached to the body longer, creating a smaller wake and, therefore, less drag. There are many examples in nature of shape modification for drag control. The sea anemone, for instance, continuously adjusts its form to the ocean currents in order to avoid being swept away while gathering food.

Numbers used to characterize flow

Air flow is determined by many factors, all of which work together in complicated ways to influence flow. Very often, the effects of factors such as viscosity, speed, and turbulence cannot be separated. Engineers have found smart ways to get around the difficulty of treating such complex situations. They have defined some characteristic numbers, each of which tells us something useful about the nature of the flow by taking several different factors into account. One such number is the Reynolds number, which is greater for faster flows and denser fluids and smaller for more viscous fluids. The Reynolds number is also higher for flow around larger objects. Flows at lower Reynolds numbers tend to be slow, viscous, and laminar. As the Reynolds number increases, there is a transition from laminar to turbulent flow. The Reynolds number is a useful similarity parameter. This means that flows in completely different situations will behave in the same way as long as the Reynolds number and the shape of the solid surface are the same. If the Reynolds number is kept the same, water moving around a small stationary airplane model will create exactly the same flow patterns as a full-scale airplane of the same shape, flying through the air. This principle makes it possible to test airplane and automobile designs using small-scale models in wind tunnels.

Aerodynamics of a golf balls

The flow of air round an object can be described as either laminar or turbulent flow. Laminar flow past a spherical shape will result in the separation of the flow behind the ball - the flow of the air will stream outwards behind the object, like the way that ripples spread apart behind a duck or boat on the water. Flow of air around a rough shape, like a dimpled golf ball, will be turbulent (little air vortexes form in the dimples). Although this can generate more drag, the air flow sort of sticks to the surface and separates much less easily. This means that dimpled balls overall cause the least disruption of the air.

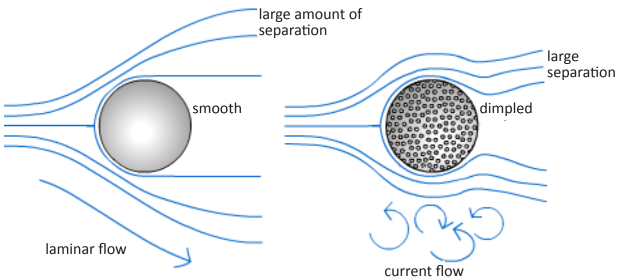


image: aerodynamics of golf ball

In the picture, the smooth ball generates a large wake as it moves through the air. The air pressure in the separated area behind the smooth ball is much lower - air molecules are further apart compared to the air around and in front of the ball. The air will try to equal itself out and air will rush into the area of low pressure, exerting what is known as pressure drag on the ball. You can imagine it like the ball is being sucked backwards into the area of low pressure, slowing it down. The dimpled ball separates the air less and has a smaller wake. The air behind the ball does not differ in air pressure as much as with the smooth ball so the dimpled ball has a smaller pressure drag and can travel further.

So why not make race cars and planes dimpled? Well, race cars are designed to allow the air to flow around them rather than sticking to the surface as drag would slow them down. With a smooth, aerodynamic car, the air flows around the shape and the wake behind is not so big any way. The difference is that a golf ball is not very aerodynamic to start with. Sticking dimples in a car would increase the drag without altering the degree of air separation by much, so it isn't used.

Nature's design

Nature is a true inspiration for designers. Elements in nature is an end product something that has been done effectively for millions of years. There are no design recalls in nature. Understanding and mimicking features from the world of around would be found to be more effective than creating something new.

image: humpback whale

Humpback whales

Humpback whales have bumps on their bodies and fins, which makes them more aerodynamic. Researchers have replicated this design to try to improve the aerodynamics and efficiency of airplanes. Wind tunnels tests have revealed that the bumpy flippers are more aerodynamic than anything the aeronautics industry has created. Bump-ridged flippers do not stall as quickly and produce more lift and less drag than comparably sized sleek flippers.
The sleek flipper performance was similar to a typical airplane wing. But the tubercle flipper exhibited nearly 8 percent better lift properties, and withstood stall at a 40 percent steeper wind angle. Scientists were particularly surprised to discover that the flipper with tubercles produced as much as 32 percent lower drag than the sleek flipper.
Airplanes with similar bumps would have greater maneuverability, smoother lift, and would be more efficient overall. This design could also be applied to helicopters, small airplanes, and ship rudders.


image: shark

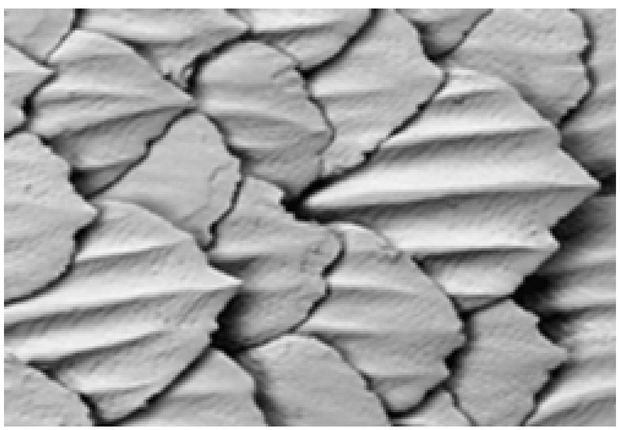


image: shark skin

Shark skin

Most shark species move through water with high-efficiency in order to catch fast-moving prey, obtain sufficient oxygen through largely passive gills, and maintain buoyancy. Through its ingenious design, their skin turns out to be an essential aid in this behavior by reducing friction drag and auto-cleaning ecto-parasites, which are hazardous for the sharks, from their surface. Boat manufacturers have recently taken an interest in how sharks achieve their unimpeded movement through water both because friction drag and the attachment of organisms on a ship's hull are major sources of energy inefficiency.

The secret behind the sharks hydro dynamism is its skin. The very small individual scales of shark skin, called dermal denticles, are ribbed with longitudinal grooves which result in water moving more efficiently over their surface than it would were shark scales completely featureless. Over smooth surfaces, fast-moving water begins to break up into turbulent vortices, or eddies, in part because the water flowing at the surface of an object moves slower than water flowing further away from the object. This difference in water speed causes the faster water to get "tripped up" by the adjacent layer of slower water flowing around an object, just as upstream swirls form along riverbanks. The grooves in a shark's scales simultaneously reduce eddy formation in a surprising number of ways:

- the grooves reinforce the direction of flow by channeling it,
- they speed up the slower water at the shark's surface (as the same volume of water going through a narrower channel increases in speed), reducing the difference in speed of this surface flow and the water just beyond the shark's surface,
- conversely, they pull faster water towards the shark's surface so that it mixes with the slower water, reducing this speed differential, and finally,
- they divide up the sheet of water flowing over the shark's surface so that any turbulence created results in smaller, rather than larger, vortices.

Shark skin applications

New engineered surfaces for medical devices and healthcare environments modeled on shark skin can reduce the incidence of microorganisms and, ultimately, hospital-acquired infections, which otherwise negatively impact tens of thousands of people each year. Moreover, these anti-biotic surfaces do not encourage resistance (because they work without killing microbes) and do not require the use of harsh chemical treatments.

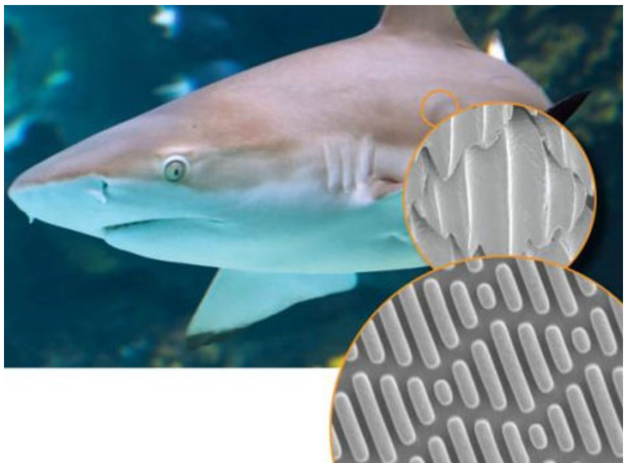


image: shark skin

New surface coatings for boats which emulate shark skin texture and fine-scale movement have been shown to reduce fouling by 67% over conventional surfaces, and at 4-5 knots be completely self-cleaning. Due to their clean surfaces, boat hulls treated with these new shark-inspired surfaces are subsequently much more energy efficient. In addition, such boats do not require the toxic, biocidal chemicals used previously to clean their hulls of adhering organisms. The transportation of invasive aquatic species from one geographical location to another is also greatly reduced.

Shark-inspired coatings for automobiles are also demonstrating potential energy savings.
The swimsuit company Speedo has incorporated shark-inspired textures into their swimsuits.
Beyond their skin, sharks are inspiring other technological innovations as well. A company called BioPower Systems, for example, has developed a device akin to a shark's tail which converts wave energy to electrical energy, which is both more likely to withstand extreme weather conditions and less likely to injure marine species than blade-style wave-energy generators

History

People have been experimenting with aerodynamics for thousands of years-though the term is less than 100 years old-as the yearning to harness the wind and to utilize the surrounding atmosphere for the purposes of mobility is well engrained in the history of man.

Appearing in Norse legends, a Finnish blacksmith named Ilmienen is said to have produced metal wings with which to fly. Shun, the emperor of China in 2000 B.C., was taught to fly by two princesses of his court, and 500 years later, Chinese writing depicts a flying cart with wheels that resemble propellers. Early tales in India tell the story of a flying wooden horse with a mechanized engine that could carry a rider. A winged human figure is illustrated on the grave of Ramses II of Egypt, and the folklore of Uganda in Africa includes flying men. Let's not leave out the myths of the flying carpet in the Far East and the brooms of witches throughout history and fiction.

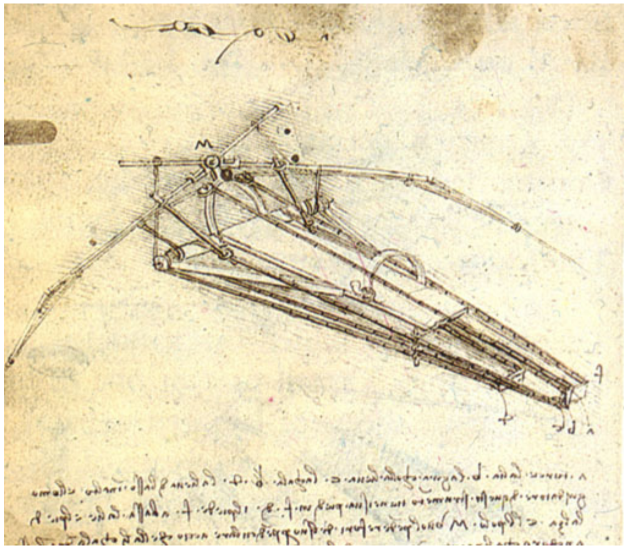


image: Leonardo da Vinci's codex on Flight of Birds

Kites were the forerunners of airplanes that used lift and drag to obtain flight. They made their first appearance in China and other countries in the Far East, but they are believed to have been invented in China around 400 B.C. by Mo To Tzu. As history progressed, the speed at which we were able to understand flight and eventually the concepts of aerodynamics as they apply to airplanes, balloons, and cars would increase.

Images and stories of flight have appeared throughout recorded history, such as the legendary story of Icarus and Daedalus. Although observations of some aerodynamic effects like wind resistance were recorded by the likes of Aristotle, Avicenna, Leonardo da Vinci and Galileo Galilei, very little effort was made to develop governing laws for understanding the nature of flight prior to the 17th century.

In 1505, Leonardo da Vinci wrote the Codex on the Flight of Birds, one of the earliest treatises on aerodynamics. He notes for the first time that the center of gravity of a flying bird does not coincide with its center of pressure, and he describes the construction of an ornithopter, with flapping wings similar to a bird's.

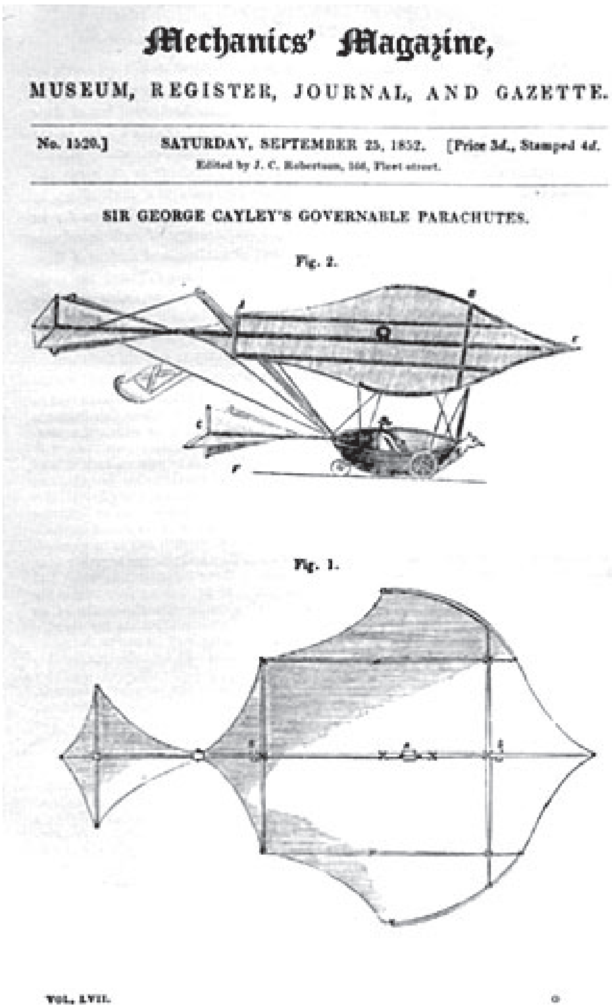


image: A drawing of a glider by Sir George Cayley, one of the early attempts at creating an aerodynamic shape

Sir Isaac Newton was the first person to develop a theory of air resistance, making him one of the first aerodynamicists. As part of that theory, Newton believed that drag was due to the dimensions of a body, the density of the fluid, and the velocity raised to the second power. These beliefs all turned out to be correct for low flow speeds. Newton also developed a law for the drag force on a flat plate inclined towards the direction of the fluid flow. Using F for the drag force, ρ for the density, S for the area of the flat plate, V for the flow velocity, and θ for the inclination angle, his law is expressed below.

$$F = \rho SV2\sin2(\theta)$$

Unfortunately, this equation is completely incorrect for the calculation of drag (unless the flow speed is hypersonic). Drag on a flat plate is closer to being linear with the angle of inclination as opposed to acting quadratically. This formula can lead one to believe that flight is more difficult than it actually is, and it may have contributed to a delay in human flight.

Sir George Cayley is credited as the first person to identify the four aerodynamic forces of flight - weight, lift, drag, and thrust, and the relationship between them. Cayley believed that the drag on a flying machine must be counteracted by a means of propulsion in order for level flight to occur. Cayley also looked to nature for aerodynamic shapes with low drag. One of the shapes he investigated were the cross-sections of trout. This may appear counterintuitive, however, the bodies of fish are shaped to produce very low resistance as they travel through water. Their cross-sections are sometimes very close to that of modern low drag airfoils.

These empirical findings led to a variety of air resistance experiments on various shapes throughout the 18th and 19th centuries. Drag theories were developed by Jean le Rond d'Alembert, Gustav Kirchhoff, and Lord Rayleigh. Equations for fluid flow with friction were developed by Claude-Louis Navier and George Gabriel Stokes. To simulate fluid flow, many experiments involved immersing objects in streams of water or simply dropping them off the top of a tall building. Towards the end of this time period Gustave Eiffel used his Eiffel Tower to assist in the drop testing of flat plates.

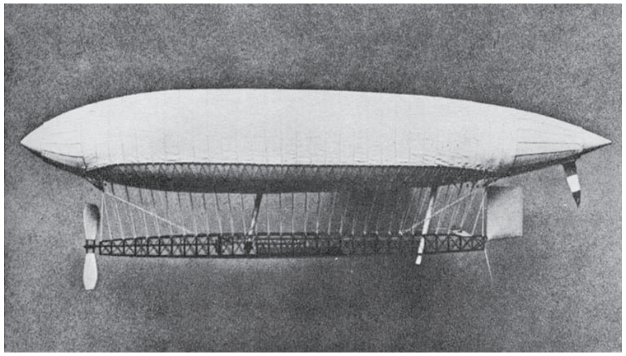


image: Model of the electric powered airship “La France” by Charles Renard

Of course, a more precise way to measure resistance is to place an object within an artificial, uniform stream of air where the velocity is known. The first person to experiment in this fashion was Francis Herbert Wenham, who in doing so constructed the first wind tunnel in 1871. Objects placed in wind tunnel models are almost always smaller than in practice, so a method was needed to relate small scale models to their real-life counterparts. This was achieved with the invention of the dimensionless Reynolds number by Osbourne Reynolds.

During this time, the groundwork was laid down for modern day fluid dynamics and aerodynamics, with other less scientifically inclined enthusiasts testing various flying machines with little success.

In 1889, Charles Renard, a French aeronautical engineer, became the first person to reasonably predict the power needed for sustained flight. Renard and German physicist Hermann von Helmholtz explored the wing loading of birds, eventually concluding that humans could not fly under their own power by attaching wings onto their arms. Otto Lilienthal, following the work of Sir George Cayley, was the first person to become highly successful with glider flights. Lilienthal believed that thin, curved airfoils would produce high lift and low drag.

Octave Chanute provided a great service to those interested in aerodynamics and flying machines by publishing a book outlining all of the research conducted around the world up to 1893.

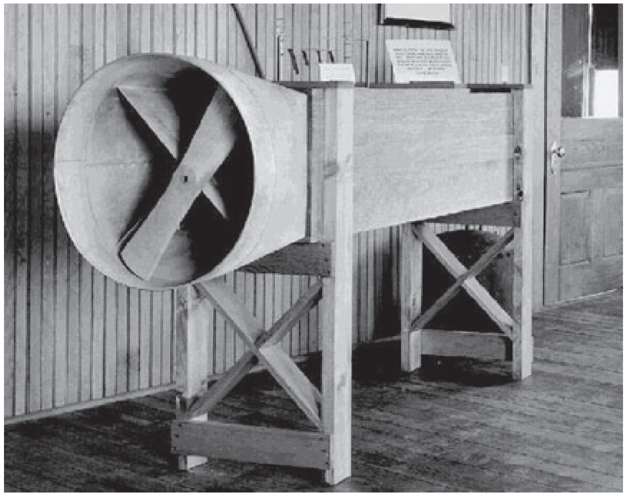


image: Wright Brother's wind tunnel

With the information contained in that book and the personal assistance of Chanute himself, the Wright brothers had just enough knowledge of aerodynamics to fly the first powered aircraft on December 17, 1903, just in time to beat the efforts of Samuel Pierpont Langley. The Wright brothers' flight confirmed or disproved a number of aerodynamics theories. Newton's drag force theory was finally proved incorrect. The first flight led to a more organized effort between aviators and scientists, leading the way to modern aerodynamics.

During the time of the first flights, Frederick W. Lanchester, Martin Wilhelm Kutta, and Nikolai Zhukovsky independently created theories that connected circulation of a fluid flow to lift. Kutta and Zhukovsky went on to develop a two-dimensional wing theory. Expanding upon the work of Lanchester, Ludwig Prandtl is credited with developing the mathematics behind thin-airfoil and lifting-line theories as well as work with boundary layers. Prandtl, a professor at Gottingen University, instructed many students who would play important roles in the development of aerodynamics like Theodore von Kármán and Max Munk.

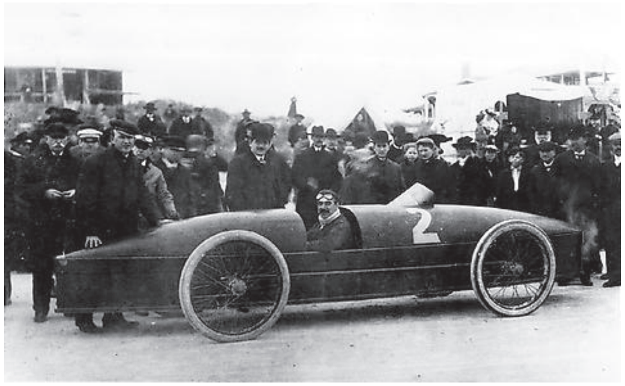
History of Aerodynamic Car Design

While scientists have more or less been aware of what it takes to create aerodynamic shapes for a long time, it took a while for those principles to be applied to automobile design.

In the beginning, automakers were mainly concerned with improving the mechanical aspects of their cars. Styling of the body evolved around a given chassis, drive train, and passenger area structure. Most of the popular early cars followed standard box-type design elements. Even external items and accessories, such as lights and fenders, were simply attached to the box body wherever it was needed or convenient.

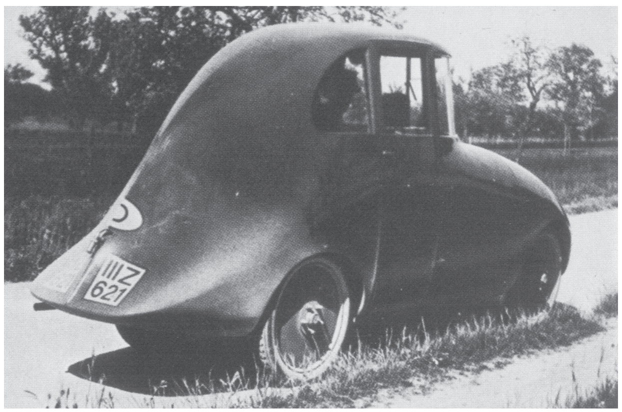
There was nothing aerodynamic about the earliest cars. Many of these early cars didn't need to worry about aerodynamics because they were relatively slow. However, some racing cars of the early 1900s incorporated tapering and aerodynamic features to one degree or another.To a racecar designer, having the car slip easily through the air was of a vital importance, and at the time, less drag equals more speed (at least until you had to turn a corner), and there are many examples of this throughout early auto racing history.

However, early production car designs focused their attention not on how well the shape slipped through the air, but how well the engine and transmission could punch a hole through the same air.



1906, Stanley Rocket

Stanley Rocket is the earliest streamlined automobile. Its body was made from an upside down canoe, since this was the lowest drag shape the Stanley brothers could think of. It was built to break the land speed record, which it did at 127mph. The Stanley brothers fine tuned its shape by towing it behind another car while measuring its drag with a spring scale on the tow rope.



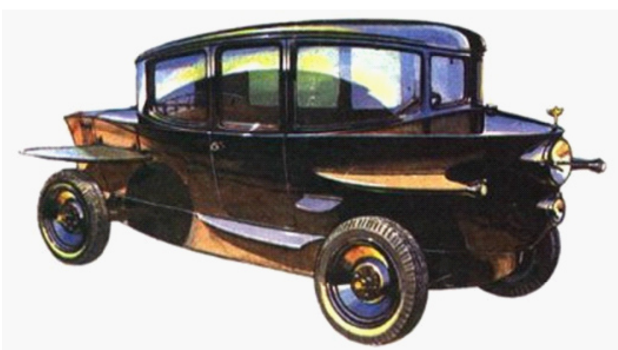
1912, Aerodynamic Shape

Hungarian engineer, Paul Jaray, was the first to establishished the form and function design concepts that established the modern automobile. Jaray studied the air-resistance of vehicles. His 1922 patent provided the basic aerodynamically efficient shape of a round nosed and taper tailed automobile.

1921, Ley T6

The world's first aerodynamic car appeared: the Ley T6. Following Jaray's streamline principles, the car could reach speeds in excess of 100 km/h (62 mph) using a four-cylinder 1.5 liter engine with only 20 hp.

The lower part of the body body has the form of a half streamline body and covers the chassis with the wheels, the engine compartment and the passenger compartment. The lower surface is even and runs parallel to the floor space. On this main part a substantially narrower streamline body is set, which is carried by a framework-like construction, which is developed on the chassis for its part.



1921,Rumpler-Tropfenauto

In 1921, German inventor Edmund Rumpler created the Rumpler-Tropfenauto, which translates into "tear-drop car." Based on the most aerodynamic shape in nature, the teardrop, it had a Cd of just .27, but its unique looks never caught on with the public. Only about 100 were made.

image: Stanley Rocket, Ley T6, Rumpler- Tropfenauto

Beginning in the 1930s, specifically 1932, production car designers were shying away from the square-shaped cars that were built on simple, high-stepped carriage-influenced chassis with foot boards, sunshades on the exterior of the windshields, detached headlights, and rear lights set off of the fenders. They were bulky, awkward, and heavy. From 1932 on American cars changed as well. American cars appeared with rounded edges, headlights built within the chassis of the car, but the driving comfort improved, too. The radiator grille and shell were raked back slightly, which made the cars look speedier. And speed sold just as well then as it does today.

The aerodynamic vision also became an important part in designing cars throughout the '30s. Aerodynamics and the streamlined design increased as well as the volume of the automobile's engine. Streamlining a car also meant that more fuel, which already was cheap in the U.S., could be saved because of this streamlining.

In Europe, Auto Union had made considerable progress in the development in the mechanics of its cars, but its engineers were now seeking new methods of styling and material selection for their body development work to increase efficiency and speed.

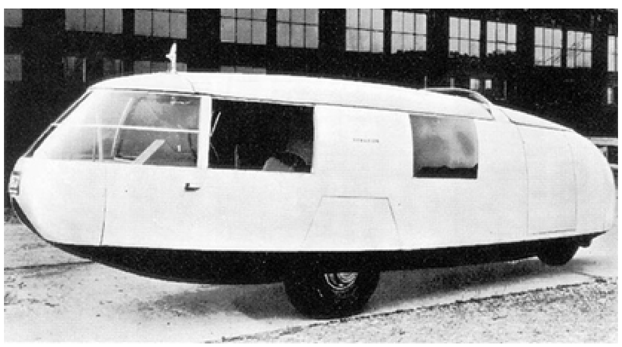


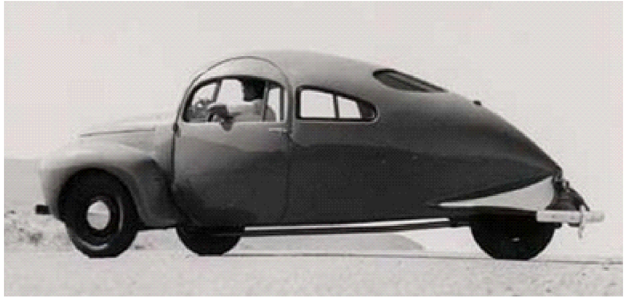
image: Model T Mod, Dymaxion

1933, Model T Mod

Harry Stevinson's modification of Model T Ford to a streamlined one-off car that was both faster and more efficient. He understood the role and importance of aerodynamics, which led him to the obvious conclusion: cars should be streamlined too - both for higher speed, and better fuel efficiency.

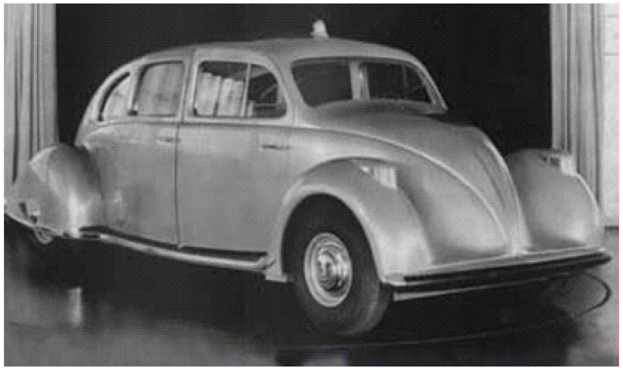
1933, Dymaxion

Dymaxion Car was a teardrop-shaped, 3-wheeled, aluminum bodied auto, designed by Buckminster Fuller in 1933. It was a big van: it seated the driver and 10 passengers, but weighed less than 1000 lbs., went 120 miles/hr on a 90 horsepower engine, and got between 30-50 miles to the gallon of gas.



1934, Airomobile

The Airomobile was a prototype designed by Paul M. Lewis in 1934. It used e 3-wheeled configuration which provided better streamlining and economy.



1934, Volkswagen

Around the same time Volkswagen came out with a similar aerodynamic car.

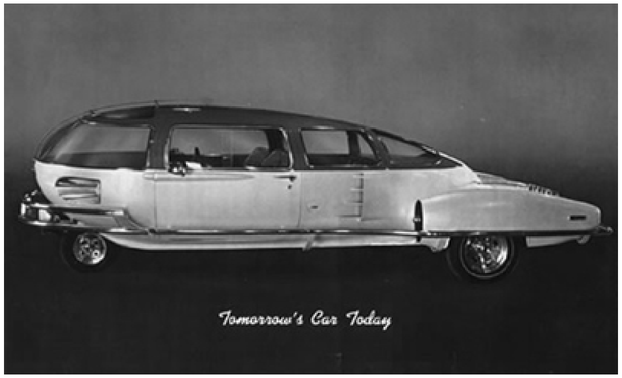
1934,McQuay-Norris

The six McQuay-Norris Streamliners produced in 1934 were built to be driven by McQuay-Norris engine component sales representatives. The McQuay-Norris Streamliner's chassis and running gear were based on a Ford V8, and the aerodynamic bodywork was made from steel and aluminium attached to a wooden frame. The curved windows were made from Plexiglas.

image: Airomobile, Volkswagen, McQuay-Norris

1934, Chrysler Airflow

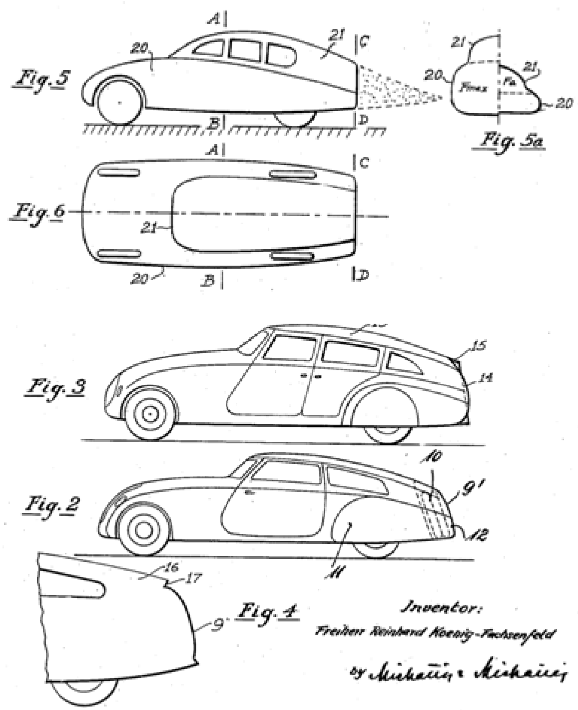
On the American side, one of the biggest leaps ahead in aerodynamic design came in the 1930s with the Chrysler Airflow. Though it used some unique construction techniques and had a nearly 50-50-weight distribution (equal weight distribution between the front and rear axles for improved handling), because of its unconventional looks, and the car was considered a flop.



1934, Fascination

Paul M. Lewis's second car creation the Fascination nearly revolutionized car design at the time. This sleek, jet-tube-fendered three-wheeler even today looks very futuristic.

image: Chrysler Airflow, Fascination



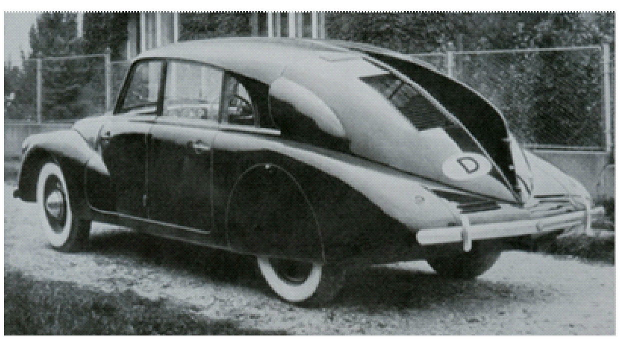


image: Kammback cut-off tail, Tatra T-87

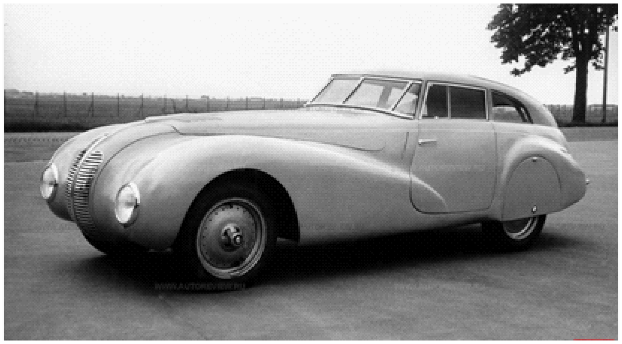
1936, Kammback cut off tail

Research was undertaken by Baron Reinhard von Koenig-Fachsenfeld, an outstanding aerodynamics engineer, on reduction of turbulence, or drag, caused by the shape of the automobile. He worked on experimental cars in a Stuttgart (Germany) wind tunnel. As a result of his research, he developed a chopped off tail and patented this design in 1936. Dr. Koenig-Fachsenfeld proved that having a shorter tapered rear end makes for worse airflow at the rear of the car, compared to a sharply sheared tail where drag coefficients as low as 0.20 were achieved in experiments. His design incorporates a smooth roofline with a taper in the automobile's body that is then whacked off at the rear end. Thus, at higher speeds, the air flow acts as if the full tapered "tail" patented by Jaray was still there. Koenig-Fachsenfeld's aerodynamic solution proved to be very effective, as the design managed to keep the air flow from becoming turbulent.

Koenig-Fachsenfeld continued his work with a German Professor, Wunibald Kamm, who developed a prototype in 1938. After World War II, Professor Kamm continued to espouse the truncated design. As a result, his name became attached to the chopped off rear end design -- the Kammback.

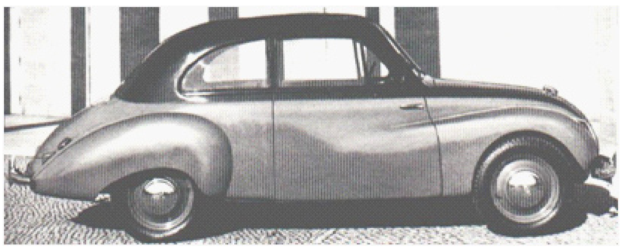
1937, Tatra T-87

The Tatra T-87 emerged in 1937 as the first true streamlined production motor car. Its pioneering design was developed by Austrian-born Hans Ledwinka and engineers at the Czech Tatra company. Around 1930, Tatra engineers conceived a radical redesign of what had become the standard box-shaped automobile, mounting an air-cooled engine at the rear of a backbone chassis. . Its distinctive features were a central seat for the driver and a dorsal rear fin similar to those used in contemporary racing cars. Despite its advanced design, the car's road holding was criticised and relatively few were produced before the T-87 appeared two years later.



1938, Kamm-Coupe

In 1938, BMW tested a prototype of the so-called ‘Kamm’-Coupe based their “328 chassis”. It had a drag coefficient of only 0.25



1939, DKW F9

The Central Body, Development, and Design Office pursued the idea of streamlining from the very outset, using the patents of Paul Jaray as its basis. The optimum aerodynamic properties were first calculated by theoretical methods, then tested out in the wind tunnel.
DKW F8 with a drag coefficient of 0.58

DKW F9 with a drag coefficient of 0.42 using Following Jaray’s streamline principles.

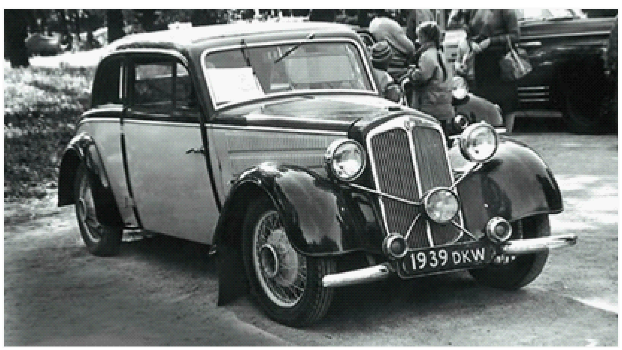
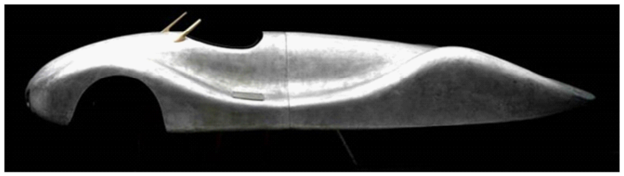


image: Kamm-Coupe, DKW F8, DKW F9

1948, Norman E. Timbs Buick Streamliner



Mechanical engineer Norman E. Timbs created this dramatic streamliner in the 1940s. He designed the project himself which included a custom aluminum body and steel chassis. It took him over two years to finish the streamliner which in many ways was the ultimate American hot rod. The body is nod to the German GP cars which at the time mimicked aeronautical practice. The smooth shape is long and low with a complete underbelly panel. With the engine occupying the rear of the chassis, the cockpit is pushed forward. In keeping with the aerofoil shape, no doors were are cut out of the body. A large one-piece rear panel opens hydraulically to reveal the entire rear end of the chassis.

1968 Colani C-Form, Colani

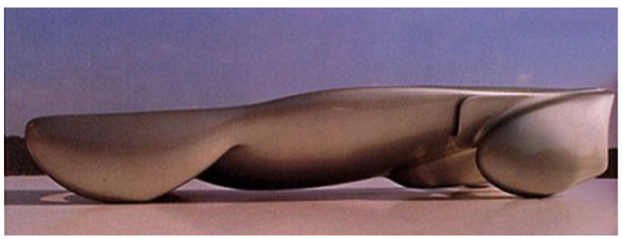


image: Bick Streamliner, Colani C-Form

Colani presented an ideal vehicle aerodynamic form with his “C-Form” concept in 1968, a vehicle where the whole body forms an inverted wing.

As the 1950s and ‘60s came about, some of the biggest advancements in automobile aerodynamics came from racing. Originally, engineers experimented with different designs, knowing that streamlined shapes could help their cars go faster and handle better at high speeds. That eventually evolved into a very precise science of crafting the most aerodynamic race car possible. Front and rear spoilers, shovel-shaped noses, and aero kits became more and more common to keep air flowing over the top of the car and to create necessary downforce on the front and rear wheels.

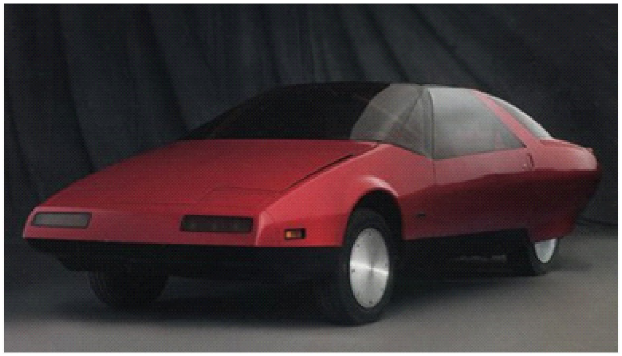


image: Probe I, Probe II, Probe III

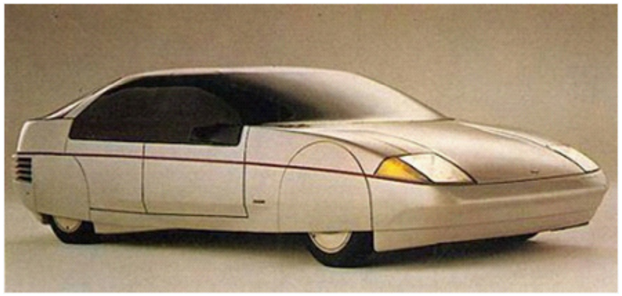
1970’s, Probe Seris

Starting in the late 1970s, Ford and Ghia started exploring a series of futuristic designs under the “probe” series of concept vehicles.

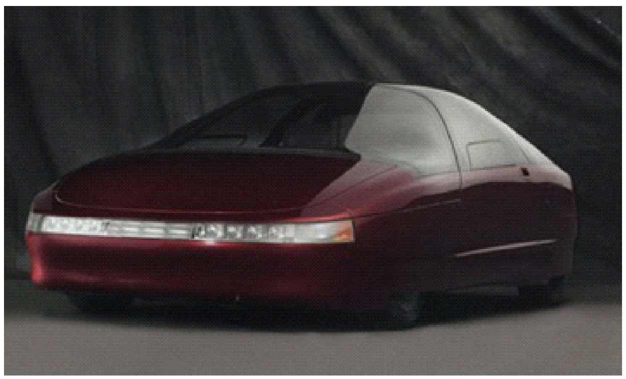
1979, Probe I
Probe I was created at the Ford Dearborn Design Center where Kopka was the executive director of the Advanced and International Design Studio. Its sleek and pointy aerodynamic shape, flat wheel covers, popup headlights and skirted rear wheels achieved a drag coefficient in the wind tunnel of 0.25

1980, Probe II
Probe II, whose hatchback styling was also reminiscent of the pony cars

1981, Probe III
The 1981 Probe III was an advanced demonstrator with covered wheels, but its bodywork evolved into the more conventional Ford Sierra (or Merkur XR4Ti) and styling notes that were used on the Ford Taurus



1983, Probe IV
The 1983 Probe IV was an amazingly aerodynamic yet practical hatchback. Its Cd figure of 0.15 was spectacular, achieved by wheels covered by urethane “membranes”, meticulous airflow management and a spoiler at the base of the windscreen



1985, Probe V
It achieved a 10% reduction in drag coefficient, achieving 0.137

image: Probe IV, Probe V

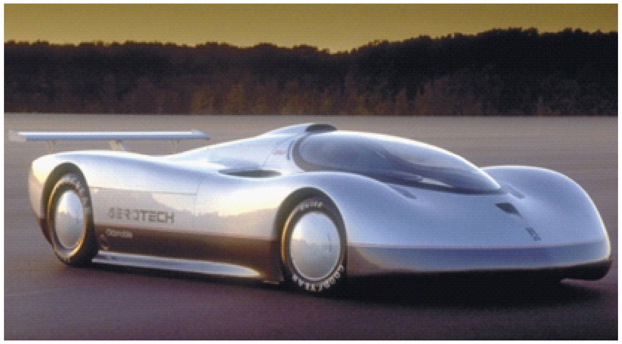



image: Oldsmobile Aerotech I, Oldsmobile Aerotech II, Oldsmobile Aerotech I

1987-1992, Oldsmobile Aerotech

The Oldsmobile Aerotechs were a series of experimental high-speed vehicles created between 1987 and 1992 incorporating the latest in performance technology with the intention of breaking multiple automobile speed records.

Oldsmobile Aerotech I
The car consisted of a March Indycar single seat chassis enclosed in an extremely efficient aerodynamic body shell. It was powered by a highly turbo-charged version of the 2-litre Oldsmobile Quad 4 engine. The Aerotech body was designed by GM Design staff and was one of the sleekest vehicles ever developed for use on a high speed track. The design of the Aerotech included the capability of adjusting underbody sections to control the distribution of downforce, front to rear.

Oldsmobile Aerotech II

Oldsmobile Aerotech III
A functional front air dam and a lumpy aerofoil on the stubby rear deck helped cut down on aerodynamic lift and drag forces. Up front were experimental “mini cube” headlamps and hugging the ground were low profile tires on 17-inch aluminum wheels.

Present day Vehicles

Aptera

Using computer-assisted design, Aptera’s engineers went on to design a car that weighs just 1,700 pounds with a body made from an impact-resistant material that is lighter than steel but three times as strong. The car will run 100 miles on a single charge and it’s got some nifty features, including butterfly-styled doors that pop open and a solar-assisted climate control system. Its top speed is 90 mph and it goes from zero to 60 in less than 10 seconds.
 The most important one is the Aptera’s optimized aerodynamic form. It claims that the drag coefficient of the vehicle will be approximately than 0.06, which is dramatically less than any current production vehicle on the road. The Aptera was designed to minimize this resistance without regard for aesthetics, resulting in a car that doesn’t needlessly burn gasoline just to push air out of its way.

image: Aptera, Mercedes Bionic Car

Mercedes-Benz Bionic Car

 DaimlerChrysler is using a new concept vehicle to examine the great potential of bionics for automobile development, taking from a fish called “boxfish” not only the idea of an aerodynamic, safe, comfortable and environmentally compatible car, but the formal and structural whole. Computer simulation is used to configure body and suspension components in such a way that the material in areas subject to lower loads can be made less resistant, and can perhaps even be eliminated completely, while highly stressed areas are specifically reinforced


image: Saab 9-X Biohybrid

Saab 9-X BioHybrid

A bio-hybrid Concept car developed by Saab which runs on 85% bioethanol and delivers a very ample 200 hp and promises 48 mpg. This sleek vehicle will appeal to those with style. Notice there are no rear view mirrors on the side. This is to maintain aerodynamics and thus fuel efficiency. Instead cameras are used with screens on the dashboard to show what is behind.

The rear design features active aerodynamics to reduce drag and fuel consumption at highway cruising speeds. Upper and lower bodywork reshapes as the roof spoiler extends automatically to lengthen the roof line, while an underbody diffuser deploys from the rear bumper's bottom. The rear spoiler rises during heavy braking (from over 62 mph), which creates additional downforce over the rear axle.

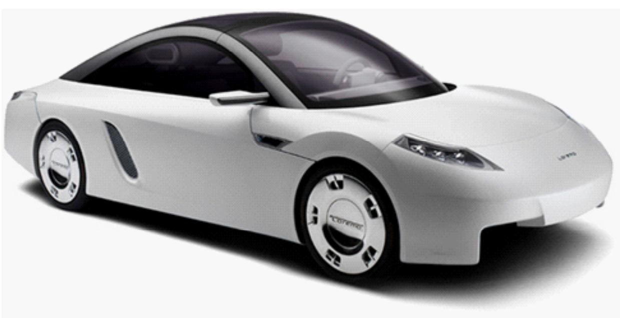


image: Lomero

2000, Lomero

Loremo AG is a German automaker corporation, based in Marl. It was founded in 2000. Loremo is focused on designing and manufacturing cars with very low weight and air resistance, the term "Loremo" is an abbreviation for Low Resistance Mobile.
The non-load-bearing, self-supporting, thermoplastic body panels mould to the linear cell structure and help the Loremo to achieve its aerodynamic shape. It gives a Cd of 0.2. This material has a number of advantages: it is light weight, weatherproof, scratch-resistant and it is economical. It substitutes the classical paint by a thin film, in the color of the car, during the manufacturing process. In this way the Loremo receives a high-quality, paint-like surface without environmental damaging paints.

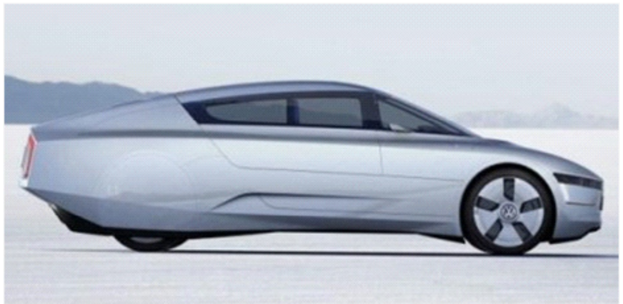


image: VW 1 Litre

2009, VW 1 Litre

VW 1 Litre is a two-person diesel hybrid concept car produced by Volkswagen. The 1-litre car was designed travel 100 km on 1 litre of diesel fuel. To achieve such economy, it is produced with lightweight materials, a streamlined body and an engine and transmission designed and tuned for economy.
For aerodynamics, the car seats two in tandem, rather than side-by-side. There are no rear view mirrors and it instead uses cameras and electronic displays. The rear wheels are close together to allow a streamlined body. The total aerodynamic drag is very small because both the drag coefficient and the frontal area are small. The drag coefficient is 0.159.
For light weight, the car uses an unpainted carbon fibre skin over a magnesium-alloy subframe. Individual components have been designed for low weight, including engine, transmission, suspension, wheels (carbon fibre), etc.

image: Hoda Insight

1999, Honda Insight

A great deal of effort has gone into designing the Insight around the goal of achieving excellent aerodynamics, the end result being a drag coefficient of only 0.25. The Insight's body is tapered so that it narrows towards the back, creating a shape that approaches the optimal tear-drop shape. To allow the body to narrow, the rear wheel track places the rear wheels 4.3 inches closer together than the front wheels. The cargo area above the wheel wells is still narrower. The floor under the rear portion of the car actually slopes upwards, while the downward slope of the rear hatch window also contributes to an overall narrowing of the car at the rear. At the very back of the Insight, the teardrop shape is abruptly cut off Kamm back.

Another important aerodynamic detail that greatly contributes to the Insight body's low coefficient of drag is the careful management of underbody airflow. The Insight body features a flat underbody design that smoothes airflow under the car, including three plastic resin underbody covers. Areas of the underside that must remain open to the air, such as the exhaust system and the area around the fuel tank, have separate fairings to smooth the airflow around them.

image: Ondelios

2008, Ondelios

It's an outlandish vision of what a six-seater tourer might look like in the future. The bizarre shape, says Renault, is all about aerodynamics - the Ondelios has a drag coefficient of just 0.29. That bizarre rear end is the result of minimising drag without compromising headroom in the rearmost row of seats.

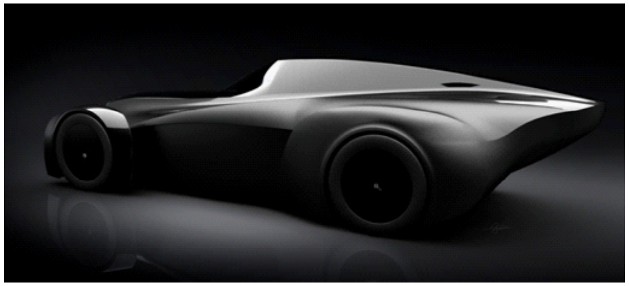


image: Bentley Aero Ace

Bentley Aero Ace - Speed VI

Aerodynamic lead design direction for a new Bentley coupe using state of the art Exa digital aerodynamic evaluation software, the design should speaks to lean mid 21st century tastes, and that truly embraces aerodynamics to both reduce energy consumption and form part of a future Bentley design aesthetic

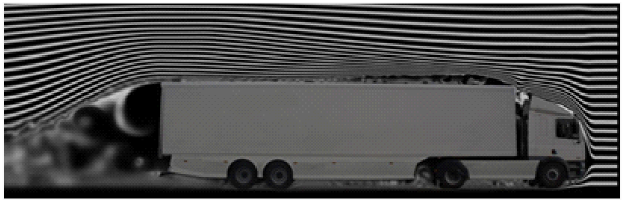
- Semi enclosed wheel for maximized aerodynamic efficiency
- Double wishbone suspension integrated within the adjustable front spoiler
- Battery cells located evenly to achieve weight distribution
- Twin heat exhaust ducts and sculptured integrated diffuser

Conclusion of history

Through the years, countless factors have shaped the way cars are designed, from increased safety regulations to the price of oil. In most of the passenger vehicles on the road today, aerodynamics plays a comparatively minor role in the overall design of the vehicle. John H. Lienhard, a professor of mechanical engineering and history at the University of Houston and author of The Engines of Our Ingenuity adds, “It took time for engineers to see that they had to smooth the bottom of an automobile as much as the top. It took time to see that sharp corners on the front of a car were terrible drag-inducers. Only in the last generation did 18-wheelers sprout those strange-but-effective, drag-reducing cowls over their cabs.” We have come to associate an appealing car design if it emulates the lines of a race car. Aside from making a car as aerodynamically safe as possible within specific design parameters, other considerations arguably play more prominently into the final production line of most vehicles, and its success doesn’t hinge on how quickly it slips through the atmosphere; if it did, we would have never witnessed the boon in SUV sales in the last decade or the minivan rush the decade before. All cars today would be shaped like a drop of rain.

Of course, the downside to better technology and higher demand for drag reduction is that, according to Lienhard, modern cars are “looking more and more alike. As designers work with increasing knowledge of design limitations, they close in on optimal designs that cannot vary much from one car to the next.”

Trucks



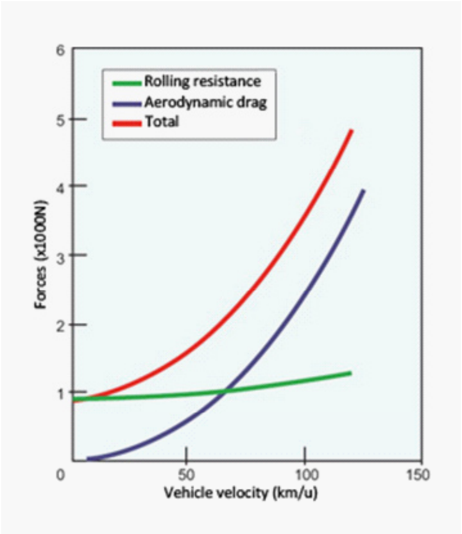


image: Relation between Vehicle velocity and Forces

Bicyclists, motorcyclists, and even pedestrians feel a push and pull of air as large trucks pass. The larger a vehicle is and the faster it moves, the more air it pushes ahead. For a large truck, this can mean a particularly large surface moving a large quantity of air at a high velocity—its blunt face acting like a fast-moving bulldozer, creating a zone of high pressure. The displaced air must go somewhere, spilling around the cab into swirling vortices. The air traveling along the side moves unevenly, adhering and breaking away, and sometimes dissipating into the surrounding air. At the end of the cab or trailer, the opposite effect of the high-pressure zone at the front develops; the airflow is confronted with an abrupt turn that it cannot negotiate, and a low-pressure zone develops.

The high pressure up front, the turbid air alongside and under the vehicle, and the low pressure at the back all combine to generate considerable aerodynamic drag.
A study published in Automotive Engineering in August 1975 found that a tractor trailer unit moving at 55 miles per hour displaced as much as 18 tons of air for every mile traveled. In such cases, roughly half of the truck's horsepower is needed just to overcome aerodynamic drag.

Aerodynamic design is an important issue to be understood while considering trucks as it helps to reduce the truck fuel consumption. It is important to distinguish between different types of truck. The chart shows the components that use energy in an articulated vehicle expressed as losses. As the chart shows, 15% of the fuel is used to overcome mechanical friction in the engine, gearbox and drive shaft. 45% of the fuel is used to overcome the rolling resistance. Drag is responsible for 40% of fuel consumption.

The correlation between fuel consumption and travelling speed is similar to the curve of overall drag. At a constant speed of 50 kmph less than 40% of the engine power is used to overcome drag, as against 60% at a speed of 80 kmph.

A moving truck encounters resistance from the air. This drag is made up of pressure drag and skin friction drag. The oncoming airflow pushes against the front of the tractor, creating a high-pressure region. It also creates a low-pressure region behind the tractor and the semi-trailer: these areas ‘suck’ the vehicle backwards, as it were. Interestingly, the high-pressure region at the front contributes just as much to drag as the low-pressure region at the rear, each accounts for about 1/3 of the overall drag. The remaining 1/3 of the overall drag is created by the vehicle’s under-body.

The source of the skin friction drag is the contact between the airflow and the bodywork. Because of the viscosity of air, a layer of air around the vehicle, known as the boundary layer, is dragged along with it, creating shearing forces. The sum of the shearing forces over the entire surface produces the skin friction drag, with the sides and top making the largest contributions. It should be noted that skin friction drag increases with vehicle length. To keep the skin friction drag low the surfaces need to be smooth.

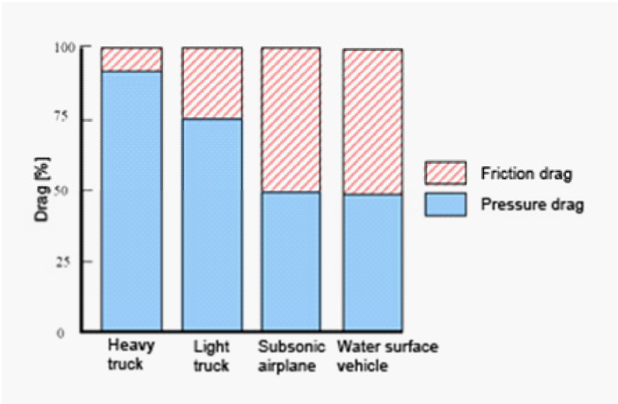
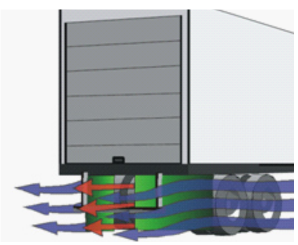


image: Drag on Various Vehicles

This shows that pressure drag is by far the main drag component in the case of heavy goods vehicles.

Fuel consumption can be reduced by lowering the coefficient of drag of the overall vehicle. Certain areas can be considered to reduce the overall drag of the trucks.

- The sharp edges of the cab create a separated turbulent airflow that adversely affects the drag. On the other hand a cleaner flow pattern owing to the rounded corners.
- The cab should be at the same height as the semi-trailer.
- The gap between the cab and the semi-trailer should be minimised. Tractor side panels or collars can be used to guide the airflow across the gap in the case of an articulated vehicle. The correlation between the gap and the height of the semi-trailer: the bigger the gap, the greater the drag.
- The wind rarely comes constantly from the front, so it is important to consider this situation. In a crosswind situation the airflow will be nicely attached on one side, but on the other side of the cab or semi-trailer it will become detached, resulting in a higher drag coefficient, hence more drag. On top of this, the gap between the wheels and the under-body of the vehicle disrupts the airflow in crosswind conditions.



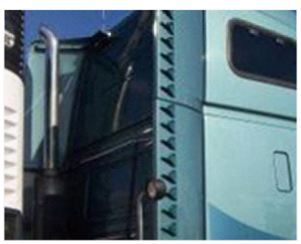


image: Deflector, Hub caps, Boat tail, High momentum mud flaps, Vortex Generators

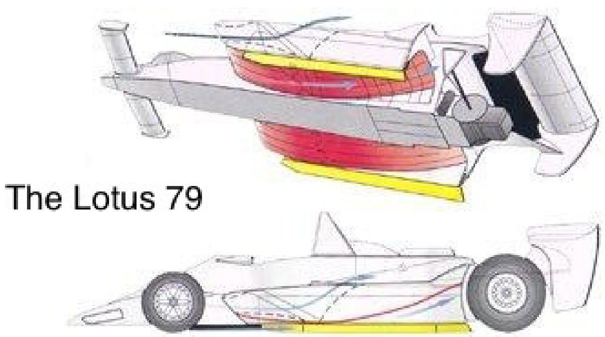
Many aerodynamic aids are available to reduce drag on a on trucks with an aim to reduce the fuel consumption. Aerodynamic aids available to reduce drag on a tractor (i.e. the motive power unit in an articulated vehicle, or the cab of a rigid vehicle or a draw bar vehicle):

- Cab side-edge turning vanes
- Aerodynamic side mirrors
- Additional lights and horns
- Air dam
- Eco-flaps
- Side panels
- Hub caps
- Chassis filler panel
- Sun visor
- Roof fairing or deflector
- Collar with roof fairing
- Tractor side panels
- Base bleed

Aerodynamic aids available to reduce drag on the container portion of the vehicle:

- Fairing
- Vortex stabilisers
- Eco Liner
- Teardrop roof
- Sloping roof
- Rotating cylinders
- Flatbed container
- Side panels
- Wedge
- High-momentum mud flaps
- Air wedge
- Aerodynamic under-body
- Rear mud flap
- Underride guard
- Boat tail
- Inset boat tail
- SDR
- Vanes
- Vortex generators
- Vortex strakes
- Blowing slots

Aerodynamics in Formula1



Due to the little development areas left for engine improvements, aerodynamics are now the most important area for improving the performance of a Formula One car. A modern Formula One car has almost as much in common with a jet fighter as it does with an ordinary road car. Aerodynamics have become key to success in the sport and teams invest up to 20% of their total budget in the science of the winds, making their cars even faster with innovative aerodynamic designs each year. Meticulous precision work is undertaken down to the last millimeter.

The aerodynamic designer has two primary concerns: the creation of down force, to help push the car's tyres onto the track and improve cornering forces; and minimising the drag that gets caused by turbulence and acts to slow the car down.

Several teams started to experiment with the now familiar wings in the late 1960s. Race car wings operate on exactly the same principle as aircraft wings, only in reverse. Air flowing on the two sides of the wing creates a pressure difference resulting in the wing to move in the direction of low pressure side. Planes use their wings to create lift, race cars use theirs to create downforce. A modern Formula One car is capable of developing 3.5 g lateral cornering force (three and a half times its own weight) thanks to aerodynamic downforce. That means that, theoretically, at high speeds they could drive upside down.

Early experiments with movable wings and high mountings led to some spectacular accidents, and for the 1970 season regulations were introduced to limit the size and location of wings. Evolved over time, those rules still hold largely true today.

image: Brabham BT46B, Ferrari with its narrow waist

By the mid 1970s 'ground effect' downforce had been discovered. Lotus engineers found out that the entire car could be made to act like a wing by the creation of a giant wing on its underside which would help to suck it to the road. The ultimate example of this thinking was the Brabham BT46B, designed by Gordon Murray, which actually used a cooling fan to extract air from the skirted area under the car, creating enormous downforce. After technical challenges from other teams it was withdrawn after a single race. And rule changes followed to limit the benefits of 'ground effects' - firstly a ban on the skirts used to contain the low pressure area, later a requirement for a 'stepped floor'.

Despite the full-sized wind tunnels and vast computing power used by the aerodynamic departments of most teams, the fundamental principles of Formula One aerodynamics still apply: to create the maximum amount of downforce for the minimal amount of drag. The primary wings mounted front and rear are fitted with different profiles depending on the downforce requirements of a particular track. Tight, slow circuits like Monaco require very aggressive wing profiles - you will see that cars run two separate 'blades' of 'elements' on the rear wings (two is the maximum permitted). In contrast, high-speed circuits like Monza see the cars stripped of as much wing as possible, to reduce drag and increase speed on the long straights.

Every single surface of a modern Formula One car, from the shape of the suspension links to that of the driver's helmet - has its aerodynamic effects considered. Disrupted air, where the flow 'separates' from the body, creates turbulence which creates drag - which slows the car down. Look at a recent car and you will see that almost as much effort has been spent reducing drag as increasing downforce - from the vertical end-plates fitted to wings to prevent vortices forming to the diffuser plates mounted low at the back, which help to re-equalise pressure of the faster-flowing air that has passed under the car and would otherwise create a low-pressure 'balloon' dragging at the back. Despite this, designers can't make their cars too 'slippery', as a good supply of airflow has to be ensured to help dissipate the vast amounts of heat produced by a modern Formula One engine.

image: Modifications on McLaren 2009 under the regulations of FIA 2009

In recent years most Formula One teams have tried to emulate Ferrari's 'narrow waist' design, where the rear of the car is made as narrow and low as possible. This reduces drag and maximises the amount of air available to the rear wing. The 'barge boards' fitted to the sides of cars also helped to shape the flow of the air and minimise the amount of turbulence.

Revised regulations introduced in 2005 forced the aerodynamicists to be even more ingenious. In a bid to cut speeds, the FIA robbed the cars of a chunk of downforce by raising the front wing, bringing the rear wing forward and modifying the rear diffuser profile. The designers quickly clawed back much of the loss, with a variety of intricate and novel solutions such as the 'horn' winglets first seen on the McLaren MP4-20.

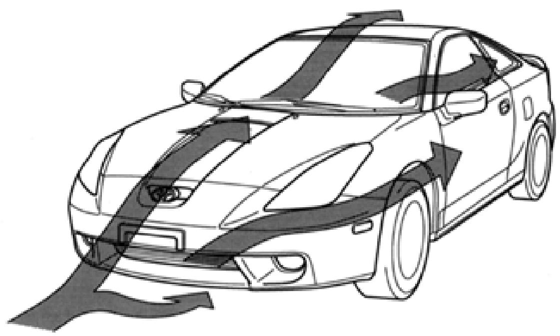
Most of those innovations have been effectively outlawed under the even more stringent aerodynamic regulations imposed by the FIA for 2009. The changes are designed to promote overtaking by making it easier for a car to closely follow another. The new rules take the cars into another new era, with lower and wider front wings, taller and narrower rear wings, and generally much 'cleaner' bodywork. Perhaps the most interesting change, however, is the introduction of 'moveable aerodynamics', with the driver now able to make limited adjustments to the front wing from the cockpit during a race.

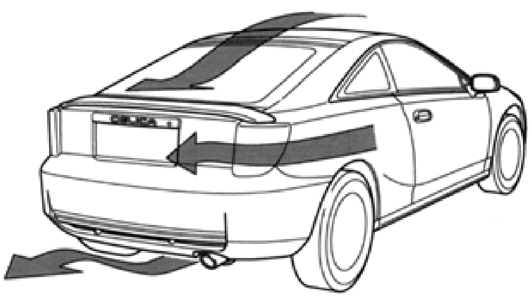
All this will make the cars slower initially, but as ever Formula One's best brains will be working flat out to make up the performance shortfall as quickly as possible.

Passenger Car Aerodynamics

Most of the information about car aerodynamics are centered around generating down force. While this may be needed for race cars, the average 3000+ pound car driving at speeds below 90 MPH does not need to be concerned with down force. To improve the efficiency of the vehicle, reducing the coefficient of drag (Cd) should be the main concern.

In this day and age of expensive fuel and inefficient vehicles, it makes sense both economically and ecologically to conserve as much fuel as possible.





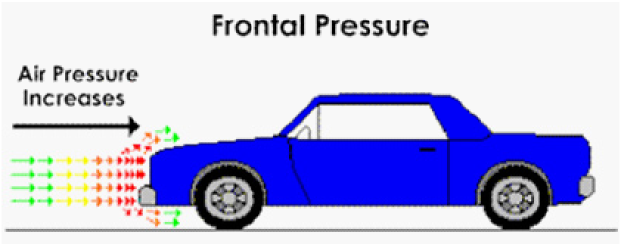
Car Aerodynamics

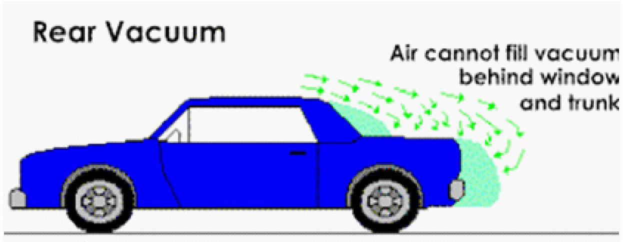
Most cars on the road are aerodynamically sound enough on their own to not really need any help from fancy aerodynamic accessories-that is, at legal speeds, of course. Any modern car, for example, fits this category, and under normal driving conditions it maintains its integrity throughout the trip. However, for those on the track, the benefits and effects of the forces created by the air are severe and evident.

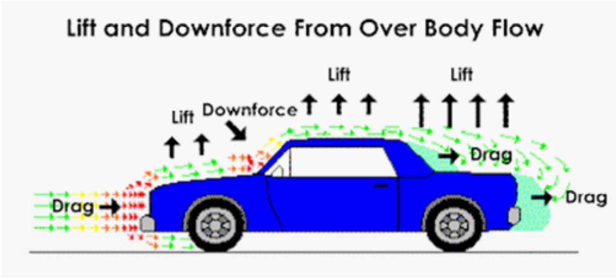
A modern car inside a wind tunnel, air would flow up the hood, over the windshield and across the roof. The majority of the airflow leaves the car straightly at the end of roof line. The dramatic drop of the rear window and deck lid creates a low pressure area around the back of the car. This low pressure acts as a vacuum that sucks some air back toward the car, thus creating turbulence. In addition, the rear window's roughly 45-degree angle causes the airflow to be particularly unstable on a high-speed Mercedes. Turbulence always deteriorates drag coefficient, in effect adding weight to the car.

The forces which act can be clearly understood by analyzing the effects of wind on a blocky shaped Bus, for example the old Volkswagen bus. As the blocky shape of the Bus drives down the road, it literally punches a hole in the air, which is forced out of the way via the four sides of the box. This force is called Frontal Pressure, which creates high pressure as the air rams into the front of the Bus and packs in together.

The usual measure of aerodynamic efficiency is the drag coefficient, Cd. It compares the drag force, at any speed, with the force it'd take to stop all the air in front of the car. Drag coefficients for the first boxy autos with large frontal surface areas were up over 0.70. Instead of letting the air slip past, they brought most of it to a halt right in front of the car.





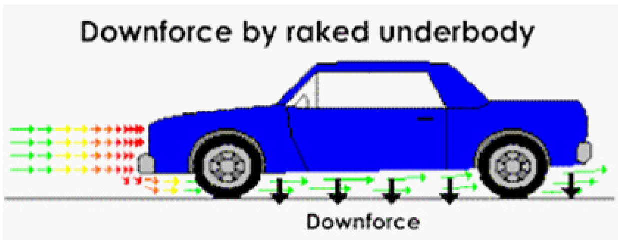


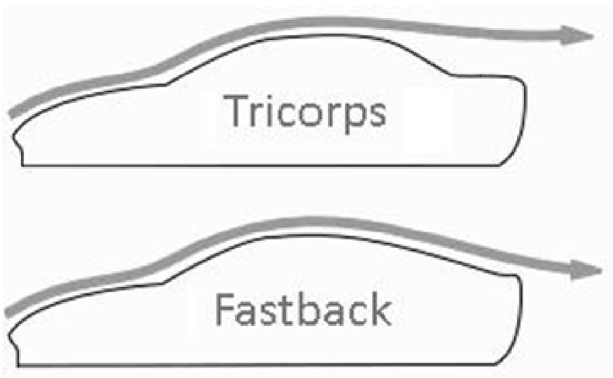
What is really happening is that the air slows down as it approaches the front of the Bus, and as a result, more molecules are packed into a smaller space. Once the air stagnates at the point in front of the Bus, it seeks a lower pressure area, such as the sides, top, and bottom of the vehicle. To give a few examples, the worst possible streamlining would be expected from a parachute, which is designed to maximize wind resistance. The Cd of a parachute is about 1.35. The lowest possible resistance is desirable in the airplane wing, which has a Cd of about 0.05.

Automobile Cd figures lie between these two extremes. In the past 60 years, automakers have managed to cut Cd figures for production models nearly in half, from about 0.70 to about 0.40. In a practical sense, gas mileage is increased by 5 percent for every 10 percent improvement in aerodynamics.

At speed, the space directly behind the Bus is empty, devoid of air like a vacuum, a concept used for drafting in stock car racing. This empty space is there because the air molecules are not able to fill the hole as quickly as the Bus can make it. The air molecules attempt to fill in this area, but the Bus is always one step ahead. As a result, a continuous vacuum sucks in the opposite direction of the Bus, and this inability to fill the hole left by the vehicle is technically called Flow Detachment, where the air is yanked away from the car.

In the case of a passenger vehicle, as the air flows over the hood of the car, it loses pressure, but when it reaches the windshield, it again comes up against a barrier and briefly reaches a higher pressure. The lower pressure area above the hood of the car creates a small lifting force that acts upon the area of the hood. The higher pressure area in front of the windscreen creates a small (or not so small) downforce and drag. This is like pressing down on the windshield and slowing the car, while the front end is lifted upward.





Where most road cars get into trouble is the fact that there is a large surface area on top of the car's roof and underneath the car, like with our example. As the higher pressure air in front of the windshield travels over the glass, it accelerates, causing the pressure to drop. This lower pressure literally lifts on the car's roof as the air passes over it, while the air passing underneath the car adds additional lift; all of this is a tight-wire act, balancing between too much lift and too much drag. The end result is aerodynamic efficiency.

Ground effect is not too suitable for road cars. It requires the bottom to be very close to the ground to form the closed channel. McLaren F1 followed Brabham's lead by using two electric fans to create ground effect, but it is difficult to determine its effectiveness.

It wasn't until the 1960s that automakers noticed that if they reduce the slope of the back of the car to 20 degrees or less, the airflow will follow the roofline and drop off the back of the car, greatly reducing drag. The term for this design was called Fastback, and an excellent example is the Porsche 935/78, better known as the "Moby Dick." The Fastback design isn't without its flaws, especially in the area of lift. Because it has a very large surface area (the roof, in effect, has been extended to the bumper) in contact with airflow, it suffers from a low pressure on top of the car all the time. Usually, wings are used to combat this problem. It seems that good drag and good lift are mutually exclusive-you can't have both of them in equal amounts at the same time.

On the Mercedes, once the air makes its way to the rear window, the drop created by the window and the flat trunk of the car leaves a sizable vacuum, a low pressure space that the air is not able to fill properly and quickly. The flow is said to detach, and the resulting lower pressure creates turbulence, which always deteriorates drag coefficient.

However, the three-box design is still better than a design combining a three-box like the Mercedes with a fastback like the Porsche. If the rear window angle is around 30 to 35 degrees, the airflow will be very unstable. In the past, automakers had little knowledge of this and created many cars in this fashion; thankfully most weren't equipped for speed.

Aerodynamic effects on cars

Aerodynamics influences or controls a wide range of key vehicle characteristics in a vehicle, including:

- Aerodynamic shaping of the vehicle also influences occupant comfort; heating, ventilation and air-conditioning performances by proper directing the air flow internally.
- Occupant comfort in open top vehicles
- The maximum speed and acceleration of a vehicle depends on how swiftly it can cut through the air with a minimum drag resistance. By controlling the air flow along and through the vehicle the performance of the vehicle is highly influenced.
- Vehicle stability issues can influence subtle handling characteristics of a racecar through to major safety considerations for a fully-loaded 38-tonne truck. Both very different issues, but equally crucial for their respective operators
- Aero-acoustics is a key issue when it comes to perceived levels of refinement and comfort in a vehicle. Several techniques – both computer based and wind tunnel testing– to reduce the acoustic effects caused by wind noise around the vehicle. This ultimately creates enhanced occupant comfort and customer satisfaction.
- The influence of styling over such aspects of a vehicle's design as guttering and guides to manage rain water has passed much of the responsibility for water management to the aerodynamicist. Aerodynamicists employ subtle changes to windscreen and A-pillar design along with aerodynamically and visually unobtrusive gutters to improve visibility and eliminate potential sources of customer annoyance.
- In inclement weather visibility is affected by the vehicle shape and the flow of air around the vehicle. Aerodynamicists endeavor to maintain forward and rearward visibility and also to allow clear views of the exterior mirrors.
- Soiling is prone to occur in regions of separation and poor airflow. For this reason we pay particular attention to areas around doors and boot openings as dirt accumulation in these areas can lead to customer annoyance.
- Aerodynamics also take under consideration of vehicle design and packaging to optimize airflows for power train and brake cooling performance through selective combinations of CFD modeling and physical testing.
- Drag foreces increases exponentially with increase in velocity of the vehicle. More fuel is consumed to counter the aerodynamic forces. By providing a better air flow management fuel consumption and pollution can be greatly reduced.

Aerodynamically efficient body surfaces may interfere with the styling intent. There is a clash between the autostylist and performance of the machine. Therefore vehicles have to be designed keeping the aerodynamic basics in mind.

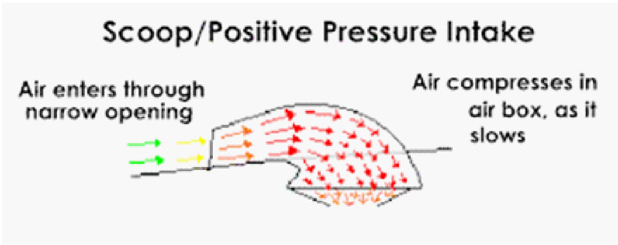
Affects of Aerodynamics on Fuel Economy

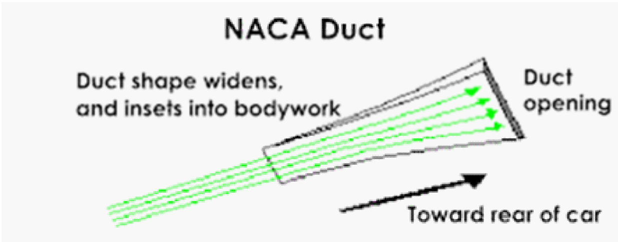
Automakers have been interested in aerodynamics at least since the introduction of the Chrysler Airflow in 1934. But the need to improve fuel economy in recent years has pushed aerodynamics toward the top of automakers' priority lists.

The easiest way to improve a vehicle's fuel economy is to make it smaller and lighter and giving it a smaller engine. But to improve efficiency of sports cars, SUVs and tow vehicles, these vehicles should be made to slip more smoothly through the air. The main driver for lower aerodynamic drag is fuel economy, as long as federal standards for fuel economy increase and fuel costs go up, aerodynamic drag will have to be improved.

Measuring a vehicle's aerodynamics starts early in the design process. From the earliest conceptual stages on through the working-prototype stage, automakers rely on computer software and wind tunnels to ensure vehicles meet their aerodynamic targets.

Fuel economy is directly related to the coefficient of drag of a vehicle, i.e. how easily a vehicle moves through the air. The other factors that affect the fuel efficiency of a vehicle down force, lift, yawing moment (which is basically when you're in a crosswind, how much does the vehicle get steered by the wind that is pushing on it), noise, etc.





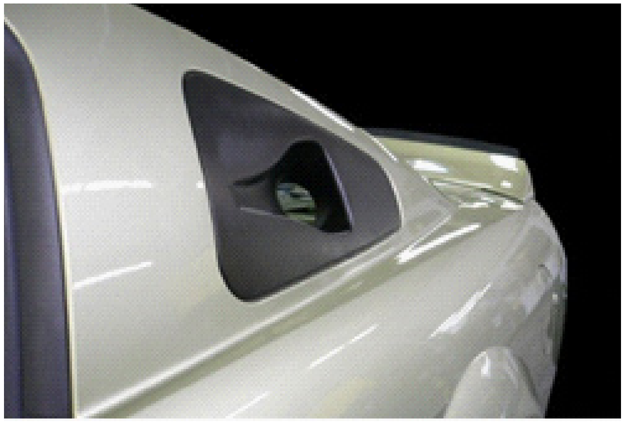


image: Scoop, NACA Ducts

Aerodynamic Devices for cars

Scoops

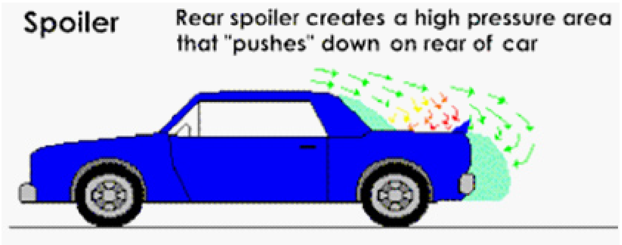
Scoops, or positive pressure intakes, are useful when high volume air flow is desirable and almost every type of race car makes use of these devices. They work on the principle that the air flow compresses inside an “air box”, when subjected to a constant flow of air. The air box has an opening that permits an adequate volume of air to enter, and the expanding air box itself slows the air flow to increase the pressure inside the box.

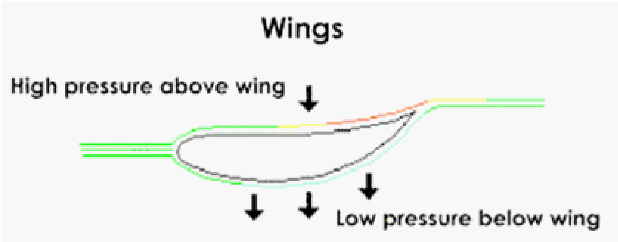
NACA Ducts

The purpose of a NACA duct is to increase the flowrate of air through it while not disturbing the boundary layer. When the cross-sectional flow area of the duct is increased, you decrease the static pressure and make the duct into a vacuum cleaner, but without the drag effects of a plain scoop. The reason why the duct is narrow, then suddenly widens in a graceful arc is to increase the cross-sectional area slowly so that airflow does separate and cause turbulence (and drag).

NACA ducts are useful when air needs to be drawn into an area which isn’t exposed to the direct air flow the scoop has access to. Quite often you will see NACA ducts along the sides of a car. The NACA duct takes advantage of the Boundary layer, a layer of slow moving air that “clings” to the bodywork of the car, especially where the bodywork flattens, or does not accelerate or decelerate the air flow. Areas like the roof and side body panels are good examples. The longer the roof or body panels, the thicker the layer becomes (a source of drag that grows as the layer thickens too).

Anyway, the NACA duct scavenges this slower moving area by means of a specially shaped intake. The intake shape, shown below, drops in toward the inside of the bodywork, and this draws the slow moving air into the opening at the end of the NACA duct. Vortices are also generated by the “walls” of the duct shape, aiding in the scavenging. The shape and depth change of the duct are critical for proper operation.
Typical uses for NACA ducts include engine air intakes and cooling.





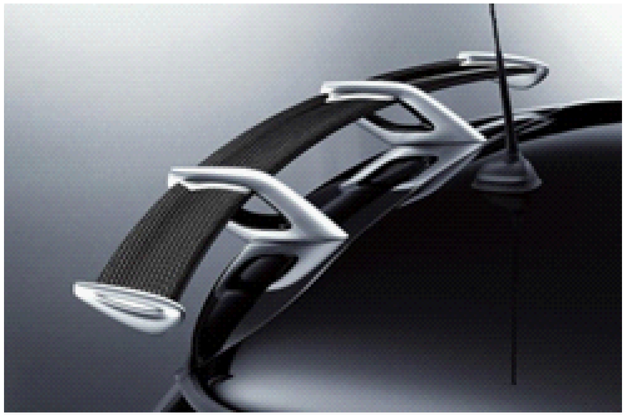


image: Spoiler, Wings

Spoilers

Spoilers are used primarily on sedan-type race cars. They act like barriers to air flow, in order to build up higher air pressure in front of the spoiler. This is useful, because as mentioned previously, a sedan car tends to become "Light" in the rear end as the low pressure area above the trunk lifts the rear end of the car. Front air dams are also a form of spoiler, only their purpose is to restrict the air flow from going under the car.

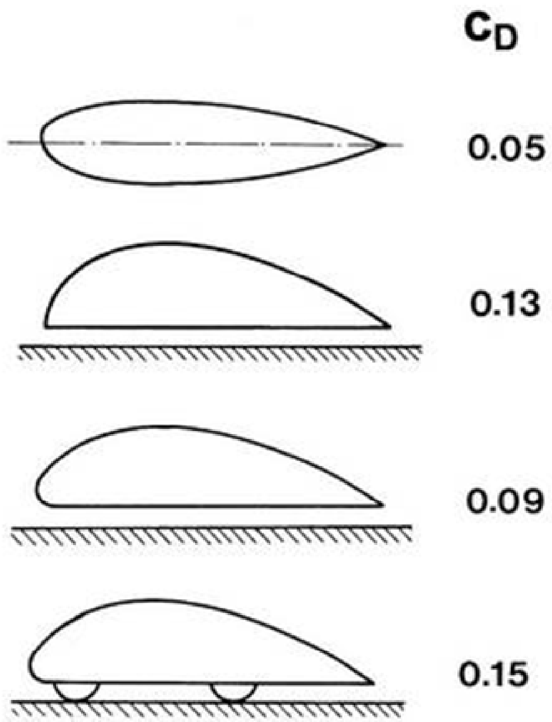
Wings

Probably the most popular form of aerodynamic aid is the wing. Wings perform very efficiently, generating lots of down force for a small penalty in drag. Spoiler are not nearly as efficient, but because of their practicality and simplicity, spoilers are used a lot on sedans.

The wing works by differentiating pressure on the top and bottom surface of the wing. As mentioned previously, the higher the speed of a given volume of air, the lower the pressure of that air, and vice-versa. What a wing does is make the air passing under it travel a larger distance than the air passing over it (in race car applications). Because air molecules approaching the leading edge of the wing are forced to separate, some going over the top of the wing, and some going under the bottom, they are forced to travel differing distances in order to "Meet up" again at the trailing edge of the wing. This is part of Bernoulli's theory.

What happens is that the lower pressure area under the wing allows the higher pressure area above the wing to "push" down on the wing, and hence the car it's mounted to.
Wings, by their design require that there be no obstruction between the bottom of the wing and the road surface, for them to be most effective. So mounting a wing above a trunk lid limits the effectiveness.

Spoilers for automobiles are often incorrectly confused with, or the term used interchangeably with, wings. Automotive wings are devices whose intended design is to generate downforce as air passes around them, not simply disrupt existing airflow patterns.



Aerodynamic Shape

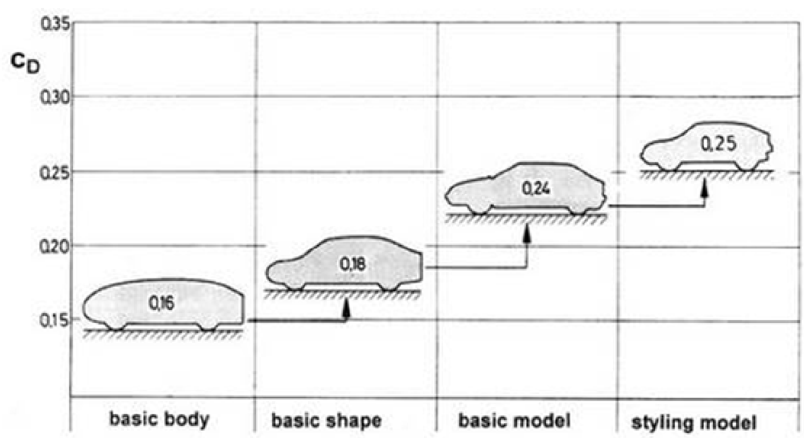
When a vehicle pushes thru the air, it has to move the air out of the way. The air wants to 'rejoin' and continue on it's original track after the vehicle passes. The more air is disrupted the higher the drag.

The most aerodynamic shape considered a body shaped like an elongated tear-drop shape that is five times longer than it is in diameter. Engineers call this a 'body of revolution with a slenderness or fineness ratio of 5'. This is the 'mythical' shape used by designers. The tear drop shape works well in the air and water, but approaching the ground changes the best aerodynamic shape.

But the shape and the properties change when the technical component features are added.

Various techniques are used by designers to achieve aerodynamics in cars. Traditional car design starts with the desired shape then tries to 'force' some aerodynamic cleanup after the fact. Like the GM Volt had to be developed more aerodynamically to reduce the drag.

Some designs start with the basic aerodynamic body in air and then lessens the affect of the ground on airflow around the car. E.g. Aptera, Sunraycer, etc.



Aerodynamic Tips while Designing a Passenger Car

The following significant areas for thought when attempting to design a typical car (not a sports car or commercial vehicle):

- Smooth unbroken contours with favorable pressure gradients as far back as practical should be used.
- Strongly unfavorable pressure gradients at the rear should be avoided; some taper and rear end rounding should be used.
- The form should produce negligible lift.
- A If a hatchback configuration is required, the backlight angle should not be in the region of 30º, and if a notchback (saloon) is to be used, the effective slope angle (ie. the angle of a direct line between the roof and the highest, most rearward point) should also not be in the region of 30º.
- The underbody should be as smooth and continuous as possible, and should sweep up slightly at the rear,
- There should be no sharp angles (except where it is necessary to avoid cross-wind instability).
- The front end should start at a low stagnation line, and curve up in a continuous line.
- The front screen should be raked as much as is practical.
- All body panels should have a minimal gap.
- Glazing should be flush with the surface as much as possible.
- All details such as door handles should be smoothly integrated within the contours.
- Excrescences should be avoided as far as possible; windscreen wipers should park out of the airflow.
- Minor items such as wheel trims and wing mirrors should be optimised using wind-tunnel testing.
- wheels create a great deal of drag and air flow turbulence, full covering bodywork is probably the best solution,
- use of aerodynamic devices such as wings, air damps, spoilers,etc.

- The cooling system needs to be designed for low drag.
- Another useful technique is to use the natural high and low pressure areas created by the bodywork to perform functions. For instance, Mercedes, back in the 1950s placed radiator outlets in the low pressure zone behind the driver. The air inlet pressure which fed the radiator became less critical, as the low pressure outlet area literally sucked air through the radiator.
- A useful high pressure area is in front of the car, and to make full use of this area, the nose of the car is often slanted downward. This allows the higher air pressure to push down on the nose of the car, increasing grip. It also has the advantage of permitting greater driver visibility.
- Exposed wishbones (on open wheel cars) are usually made from circular steel tube, to save cost. However, these circular tubes generate turbulence. It would be much better to use oval tubing, or a tube fairing that creates an oval shape over top of the round tubing.

Although aerodynamic concerns are not as strong in this vehicle as they may be in a sports car, for example, the basic principles outlined here should be observed throughout the design process. Energy efficiency can be improved with low drag and low levels of wind noise improve passenger comfort.

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