The Formation of Dynamic Lift

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Overview

If an aircraft is set in motion (engine or loss of potential energy), its wings cause air to accelerate downwards due to their angle of attack. This creates a pressure cushion under the wing (positive pressure) and a pressure deficit above (negative pressure). The pressure difference creates an upward force (lift). If there is sufficient speed and a suitable angle of attack, the resulting force is large enough to carry an airplane. It is only due to the properties of the air that locally limited pressure zones can be created.

This explanation is written in simple terms. Physics does not have to be presented in a complicated way. It can also be explained correctly in simple words. **Read all the following pages to follow the argumentation.**

You don't need math to understand physics. Mathematics can calculate physical correlations but not explain them. That is why we have deliberately dispensed with it. Momentum / impulse / impact is immediately understood when it comes to solid objects such as Newton's cradle. It's different when it comes to fluids (liquids and gases), which you can't see straight away - but it's the same principle.

Picture: NASA Endeavour landing at KSC

Air has an enormous internal energy potential. This means that if it is possible for local differences in air pressure to be generated which are separated from each other by a barrier (wing), then enormous forces can act on the barrier (wing). If bodies/wings positioned in relation to the direction of movement accelerate air downwards (impulse), then areas of different air pressure are formed. Overpressure at the bottom ("pressure cushion"), underpressure at the top ("pressure deficit"). Air pressure forces are only transmitted from the side of the higher pressure (air cannot "suck" - only push). The higher pressure acting on the underside of the wing is offset by the lower pressure on the upper side of the wing (pressure difference), resulting in an upward force, the lift force.

The "pressure deficit" is not formed by a flow that would be caused by the longer running distance of the airfoil spine. The "pressure deficit" is essentially created by the geometric opening of the wing (angle of attack). In the short time of the passing (airspeed and inertia/viscosity of the air), the space opening cannot fill up completely (deficit). A wing or a wing cross-section (airfoil) is optimized to create the required pressure ranges most effectively and to achieve controllable flight characteristics.

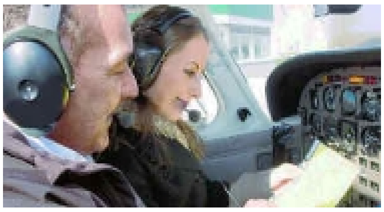
An aircraft is moving, the air is essentially stationary. When air is accelerated (angle of attack), it is mainly deflected downwards and upwards (vertically) and flows back again immediately after the wing passed. Flow suggests a movement of the air along the surface of the body (horizontal), which does not exist in this form when flying. When considering streamlines, the inertial system of the object is used, not that of the air which leads to the well-known incorrect conclusions.

It is misleading to refer to terms such as Bernoulli, circulation or other phenomena as causes when explaining dynamic lift - they are only effects and not causes in the sense of classical mechanics. It is better not to mention these terms at all when attempting to explain the phenomenon in order to avoid confusion.

Above all, however, it is advisable not to use the general term "flow" or airflow, which originates from fluid dynamics, when talking about dynamic lift. The term "unsteady flow" is applied to the movement of the displaced air particles at the beginning of the movement, but not to the actual state of flight.

Since pressure can be defined by the momentum / impulse of the air molecules, the physical cause of the lift can be summarised by the law of reaction (actio-reactio), which Newton had already defined.

Introduction



Working through the checklist before the start is obligatory. Of course, you should understand what effects the individual points can have too.

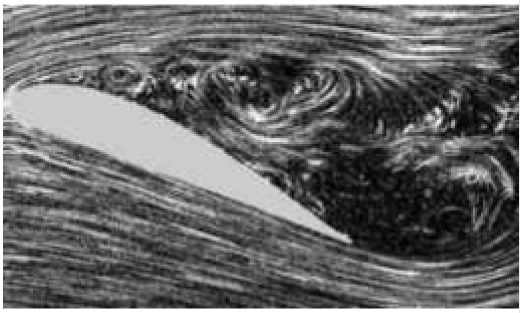
A pilot does not necessarily need to grasp the scientific causes of flight in detail. Only a few aerodynamic correlations are important for a pilot. He must interpret wind and weather correctly and be in a controlled flying position at all times. The most difficult part is and remains take-off and landing. The most important thing here is to maintain a minimum speed in order to avoid a dangerous lift collapse (stall).

This is precisely why pilots should want to understand the basics of physics. There are countless attempts to explain why an aeroplane flies. But most explanations end up being a mixture of aerodynamic effects and theories. Are all effects causal, or only some? Which theory comes closest to reality? Conventional explanations (based on fluid mechanics) sound logical, but they are not. When it comes to the "supreme discipline" of aerodynamics - the stall - there are no well-founded, physically correct explanations.

It is true that fluid mechanics has its justification, is complex and can be applied to "real" flows. However, using it as a basis for explaining dynamic lift leads to a dead end. There is no horizontal flow on an aeroplane wing; therefore there is no reasonable explanation for dynamic lift and for stall in particular.

Mathematics can be used to calculate physical relationships, but mathematics cannot be used to discover relationships. First comes the realisation, then a theory, then the practical proof and finally a mathematical formula. A wind tunnel is an experimental set-up, not reality. What is observed and measured is real, but because the inertial system is reversed, the result does not quite correspond to reality.

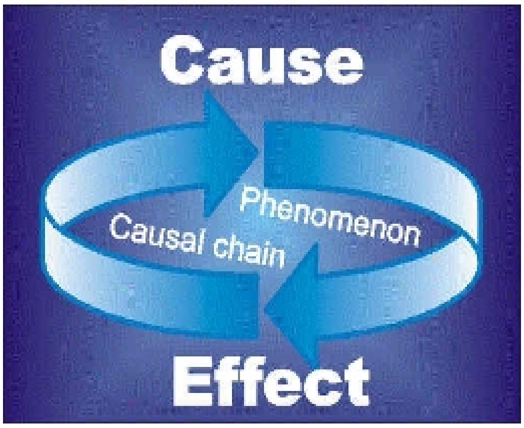
As flying is a dynamic air pressure system, e.g. the airfoil, and the small displacement paths of air particles are in no way proportional to the movement of the wing itself, the term "flow" is misleading. Until further consideration, "pressure distribution" (the flow => the pressure spread or, more precisely, the dynamic pressure spread) and "lift collapse" (the stall => the lift collapse) are proposed.



Lift collapse (stall) in the flow tunnel,a real image leads to false conclusions because the inertial system has been swapped.

You will find the physical evidence on the following pages, which go into more detail. One chapter builds on the next.

Cause and Effect



Cause and effect are inextricably linked

In the meantime, you can find correct partial explanations regarding the dynamic lift (e.g. Wikipedia). At other side explanations regarding this topic are obscured by mixing them with effects such as Bernoulli's equation, Coandă effect, circulation theory, Venturi effect, flow deflection.... The more mathematical equations are presented, the stronger the obfuscation becomes. It is then no longer recognisable what is the physically true cause and what is just for illustration.

The aforementioned effects are connected with flying, but they are not not causal. Effects are impacts, only natural laws can establish ultimate causes. There is no need for maths to understand nature, which is why we do without it.

As with all seemingly complex topics, you should get an overview first. Interrelationships should be presented simply but not in such a way that they become false through simplification. Later on, less common terms are chosen in order to break away from old thought patterns.

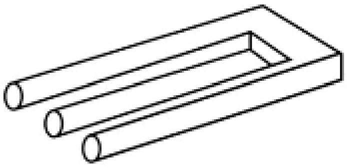
Physical effects occur during flight, but they are not causal. Effects are consequences, only the laws of nature can ultimately explain causes. A new look at known physics enables new thinking.

Although the exact choice of words is crucial in physics in particular, we don't want to get lost in this, so the terms momentum, impact, energy, force etc. are sometimes used in an extended sense for the sake of general comprehensibility. There are no new findings, but known knowledge may be seen in a different light. The aim should be to find out the ultimate cause of dynamic lift. The effects as a consequence of causes must not be ignored thereby because they can be part of a causal chain. Cause and effect are inextricably linked. Incidentally: Regardless of which theories one subscribes to, a pilot can, if the specified operating limits adhered, control his aircraft safely.

Obviously, it doesn't matter much whether the cause of flight and the formation of lift are physically correct.

Most of us are pilots and not designers / physicists / structural engineers who still have to consider strength, stability, controllability ... in mind. However can develop further, however, if you reflect on the basics about the air and some basic physical forces.

Note to prospective pilots and students: Learn what is in the books, tick the "correct" answers, do the math as given, repeat what is expected. After all, you want to pass the exams.



Impossible perspective. Escape is futile.The more you get involved with the airstream, the more impossible it becomes to break away from it.

Aerodynamics / Aerokinetics

Picture: Rüdiger Bachmeier

Aerodynamics / aerokinetics describes the behavior of bodies in compressible fluids (for example air). Kinetics because it is about movement. Our airplanes moves in the air, so the air is forced to swerve.

Applied aerodynamics in vehicle construction is just as exciting and is subject to the same laws. In carracing, lift is an issue too. However, the opposite is sought, downforce - to improve traction. Good aerodynamicists have a feeling for flowing shapes and think their way into the elastic medium of air - more an intuitive process than a technical one. Luigi Colani, for example, also studied aerodynamics, but in essence he was a gifted designer.

Everything that moves dynamically in the air is subject to the same physical laws.

It does not matter whether it is an aircraft, car, bird, hummingbird, bumblebee, insect, model airplane, helicopter, gyrocopter, parachutist, stone, ball or anything else. When bodies move in the air, they displace air. The speed of the bodies (e.g. fuselage, wings, propeller) causes air to be displaced relatively quickly, i.e. accelerated.

In contrast to a vehicle, which has to struggle with air resistance, among other things, gravity is constantly trying to force the aircraft to the ground. The strategy for fighting gravity is to generate lift.

Picture: NASA Dominic Hart

Lift Against Gravity

Picture: Indoor Skydiving Bottrop - A vertical Windtunnel - What would happen if a parachute was activated now? The abrupt realisation: swapping an inertial system has consequences (see also "Wind Tunnel Flow")

Here we reduce the term gravity to the earth's gravity. Counteracting gravity means applying an opposing force. It does not matter whether the cause of gravity has already been determined. As an ether theory, according to Einstein's ART, in quantum physics as a graviton or otherwise. What can we observe and measure? Let's just look at it from the point of view of the effect, classical mechanics. The acceleration due to gravity is 9.8m/s². The gravitational constant can be ignored at the heights at which we fly.

Example skydiver: In the first second 4.9m were covered, in the second second already 19.6m and in the third second 44.1m (neglecting the air resistance). This increase in speed (no uniform movement) would only continue in a vacuum, but fortunately the air resistance increases so that the final speed is reached after approx. 7 seconds. Obviously, the air resistance (acceleration of air downwards by the falling jumper) generates a force which turns the acceleration due to gravity (m/s²) for the jumper into a constant sinking speed (m/s) for the jumper. Aircraft also have a vertical speed - not a vertical acceleration. Also measured in m/s, although this is only 0 m/s in horizontal flight.

Lift is the counterforce to gravity. Vertically acceleration becomes vertically speed. Since flying takes place in the air, an airplane can only act on the air to generate a counterforce.

Flying With Wings

Flying is the controlled movement of a body through the air. Wings are special surfaces that are suitable for generating lift. For this purpose, they are set at a relatively flat angle to their direction of movement. Rotor blades, propellers, insect wings etc. are also wings that can generate lift or, depending on their orientation, propulsion.

Picture: EXTRA Flugzeugproduktion- u. Vertriebs- GmbH

Everything that is heavier than air, such as our aircrafts, can only fly dynamically. Even if almost all aircraft are equipped with wings, the correct statement "an airplane flies because it has wings that act on the air" does not reveal the true physical reason for flying.

When movement (dynamics - aerodynamics) comes into play, a wing is very helpful. In special cases such as knife-edge flight, however, you can also fly without one.

For example, in knife-edge flight the fuselage essentially takes over the function of the wing (lift generation), and the propeller also plays its part. If the presence of a wing cannot fully explain the cause of flight, then the wing profile cannot provide the answer either. Especially not because a wing profile is not necessarily required.

You can also fly with a flat plate, the wing profile of an F-104 is almost a flat plate without extending the lift aids, there is a slight thickening mainly for strength reasons. A special form of the flat plate is the curved plate. The upper and lower sides have the same running length, the curved plate is significantly more effective than the flat one. Lilienthal discovered this more than 130 years ago. Of course, we are aware that lift and flight characteristics can be significantly optimized with sophisticated wings and wing profiles.

In order to understand the basic principle of flight, the elementary laws of nature/basic forces that interact with lift-producing surfaces must be taken into account. These basic forces were investigated and defined almost 340 years ago.

If we still talk about the wing, wing surface and airfoil, it is only because the wing represents an optimized lift-producing surface. Such optimized airfoils (e.g. Clark-Y) are illustrated hereinafter. The pressure ratios are slightly different for non-optimized profiles such as a flat plate or a curved plate, but in principle not essential. The elementary laws of nature are universally applicable to all bodies and therefore also to fuselage and wings with every kind of airfoil or no profiling.

We have already touched on gravity, now it is time to look at the medium of air.

The Air Pressure

Magdeburg hemisphere Picture: Ulrich Arendt

Air is a mixture of gases and static pressure (air pressure) is generated by the air column. Air has an internal (kinetic) energy because air molecules (mass) are in motion. Gas particles in motion collide with each other, but can also act on body surfaces, such as a hollow sphere or a wing.

Air pressure is the resulting force per unit area generated by the movement (momentum / impact) of the gas molecules.

1 m³ of air near the ground has a weight of approx. 1.3 kg. Even more impressive is the pressure generated by the column of air above us at 1000 hPa: ~10 tons/m² weigh on the earth's surface and every m² of our body. At this high pressure, which we do not perceive (because it also acts against us from the inside), even the slightest fluctuations in air pressure can cause enormous forces.

Unimaginable forces are released in the weather, even the smallest differences in pressure can be indicated by instruments, small suction cups hold amazing loads, enormous weights float on air cushions, etc. The high energy potential of air pressure demystifies the phenomenon of flight because even the smallest differences in pressure can cause high forces on corresponding surfaces.

Pressure in itself can only transmit forces if there are pressure differences. If there is a barrier between the areas of different air pressure, forces act on this barrier (piston, wall, wing...). Air pressure acts in all directions but always at right angles to the surface of a body/wall.

When you say "something is being sucked in", you mean that the vacuum (suction) is pulling. However, air pressure can only push - not pull. The higher pressure on the opposite side works against the lower pressure, the resultant determines the direction and force. Many illustrations that show the suction above the wing profile with force arrows starting from the back of the profile are therefore not physically correct. There is also air pressure in a low-pressure environment, just less. Negative pressure is by no means a vacuum. So the word vacuum has no place in our subject area, even if it is used colloquially all too often.

The word "suction" suggests the idea that air pressure can actively pull. Even if everyone thinks they know what is meant, there is no reason to hold on at a such fundamentally misleading idea.

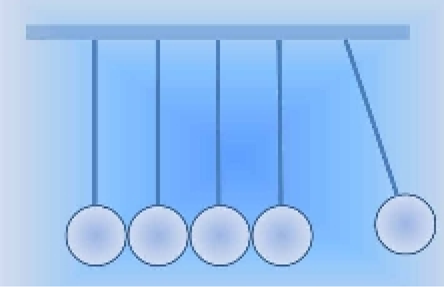
This is well known in pneumatics and also in carburetor technology, which is why turbos or compressors are used to help achieve high piston filling in 4-stroke engines - "suction" alone, i.e. the low-inertia ambient air pressure does not achieve 100% piston filling. In this sense, the dirt is not drawn into the hoover, but the hoover creates a negative pressure and the incoming ambient air " pushes" the dirt along with it.

The speed when pressure differences equalize (pressure equalization = flow) must not be confused with the speed of sound (wave propagation). While the speed of sound measures the spread of sound waves, the speed of pressure equalization is incomparably lower. Pressure equalization is mass displacement of air (kinematic movement).

The speed of mass displacement (pressure equalize) depends on the energy applied to the air, which is slowed down by inertia, viscosity and resistance. While the speed of sound is approx. 343 m/s, a pressure equalization can be a few m/s to a maximum of a few 10 m/s (depending on the triggering and ambient conditions). This is relevant when it comes to pressure equalization caused by the action of a moving wing.

Pressure equalisation = flow that is slowed down by inertia, viscosity and resistance. It ranges from a few m/s to a maximum of a few 10 m/s. Among other things, this limits the maximum angle of attack until lift collapse (stall).

Impulse / Momentum Flow



Graphic: Newton's Cradl

Into the "general" static air pressure, a moving wing accelerates air downwards - now it becomes dynamic. This momentum / impulse is passed on to the air and within it, called impulse flow. Due to the compressibility and viscosity of the air, thereby areas of different air pressure form around the source (wing/airfoil/glider...).

A wing with an angle of attack in motion accelerates air downwards (dynamic, momentum, impulse, momentum flow) which leads to pressure differences between the bottom and top of the wing. The higher pressure works in the direction of the lower pressure. The pressure difference in relation to the wing surface determines the strength of the force.

This applies not only to the wing, but in principle to all bodies such as the fuselage, provided there is a certain angle of attack in relation to the flight path. Without an angle of attack there are no pressure differences, without pressure differences there is no resulting force. Newton's laws, known as axioms, formulate the relationships between inertia, impulse and reaction. Every action causes an equally large reaction. Therefore it can be said:

The reaction effect, also known as the interaction principle, described by Newton's third axiom (actio and reactio), can be used to explain dynamic lift in terms of classical mechanics.

Even if interactions occur simultaneously, one can still speak of a causal chain because there must always be a triggering moment and and a impulse in the mechanical sense is transmitted with a certain deceleration).

Explanation:

An aircraft is set in motion (reactio) by an external force (actio). The resulting downward acceleration of air (actio) causes different pressure ranges (reactio). Air pressure is generated by the impulse of the air molecules (actio) which causes an opposing force on the wing (reactio). The difference in pressure results in a force opposing the force of gravity (lift).

By lift, however, we don't just mean any upward force, but at least one that is strong enough to achieve an acceptable descent rate. Better still, a horizontal flight or climb (with the support of muscle power, motor, thermals). This requires conditions such as the discussed angle of attack, the necessary speed and air with its characteristics. An equilibrium must be established for each stable flight condition. We could interweave the conditions into the causal chain mentioned above or extend it, but this would not change the core statement.

Pressure Cushions, Pressure Deficit, Circulation, Vortices

The acceleration of air causes pressure zones (higher and lower pressure) to form around the aerofoil. The formation and dissipation is a continuous process. The pressure zones are created and localised with the speed of the aircraft. Pressure zones have a practically finite size due to the viscosity of the air. Take the underside of the wing as an example: Air particles bounce off the wing, passing on their impulse to neighbouring air particles until at some point the impulse transmission in the edge area of the "pressure cushion" has become negligibly small.

With regard to the nature of air pressure (momentum of the air molecules - momentum flow - pressure gradient), the areas of different air pressure can be divided into "pressure cushion" ("overpressure"), "pressure deficit" ("underpressure") and static air pressure. "Pressure cushion" and "pressure deficit" are merely auxiliary linguistic constructions to provide a striking image. In particular, it simplifies the visualisation of the pressure distribution as described in "lift at the airfoil".

Picture: DLR Vortex wake

A word about circulation and vortices: these occur in all sizes and different forms when flying. The tip vortices of an airliner, for example, are very impressive. Circulation and vortices are equalising movements of the air. Turbulent boundary layers and wave movements/vibrations can also be categorised as such. They are an effect and not a cause. They form at various points. The aim is to reduce them as much as possible by design (preventing them completely is only possible if you don't fly) - an exciting further topic.

Due to the practically finite nature of pressure ranges (flattening of impulse transmission), one might think that energy would be lost, which of course cannot be the case. A small proportion is converted into thermal energy, so energy is supplied to the air in various forms (ineffective impact). The pressure gradient within the pressure ranges is ignored under "Plausibility check pressure difference" because in particular the pressure conditions on the body surface are relevant. The boundary layer is also ignored. Both, pressure gradient and boundary layer, are not insignificant for the formation of the pressure areas. For a general understanding, however, they can be ignored for the time being.

Pictorial representations of pressure spreading, as we all know them, are only idealised. It depends on the profile, surface, angle of attack, speed ... ... For us as pilots, the ground effect can be a practical indicator of how extensive the "pressure cushion" can be in its effectiveness. It is, of course, somewhat more extensive, but beyond that it is hardly relevant for the pilot.

Bernoulli and The Energy Conservation Principle

Foto: Julian Moos

The law of conservation of energy states that energy cannot be lost, but neither can it be gained from nothing. The Bernoulli formula shows that the sum of the pressure energy, potential energy and kinetic energy along the current tube is constant, i.e. no energy is added.

But without energy supply there is no flying. Where does the energy come from? From the positional energy of the aircraft, and/or hopefully usually also from the propulsion system (fuel). Example: Take-off with a full tank, landing at the take-off site with an empty tank, the aircraft now has the same positional energy again, where has the energy from the fuel gone? In the air in the form of heat, air movement (downdraft) and, a special form of air movement, in vortices.

Firstly, flying in an open air system is not directly comparable with a tube that is open at the front and back, and secondly, flying involves a form of energy transfer (acceleration of air mass downwards) to the air, which is not included in Bernoulli's formula.

Pulsed smoke spots in the wind tunnel show that the air particles that initially split at the leading edge at the same time do not arrive at the end at the same time. However, the simultaneous arrival of the air particles is often used to apply the "longer path" and the Bernoulli formula.

Thus, the experiment of a constricted tube, in which a lower pressure prevails in the constriction (Venturi tube), but the same energy state prevails again at the outlet, is unsuitable to explain the true cause of the lift. Bernoulli effects occur partially around the airfoil (airfoil nose) when considering the pressure equalisation movements in detail. However, the overall energy state is the same in front of and behind the flow tube.

Plausibility Check for Pressure Differences

Picture: A321 MFS X

Can the movement/acceleration of air and thus the creation of pressure ranges be sufficient to keep an aeroplane in the air or must there not be unknown forces at play that need to be uncovered?

We assume a pressure difference of ~ 1/300 bar between the top and bottom of the wing and an air pressure of 1000 mbar (hPa). With the frequently assumed pressure spreading of 1/3 positive pressure from below and 2/3 negative pressure above, the ratio would be 1001.1 mbar below (~1.1 mbar positive pressure) and 997.8 mbar above (~2.2 mbar negative pressure). 10200 kp/m² / 300 *12m² = 408 kp - yes, that could be enough - very ambitious - perhaps an microlight glider.

An A320 does not require 3.3 mbar (hPa), but a pressure difference of around 60 hPa, depending on the configuration. Not even that impressive as the weather-related air pressure fluctuations already measured can be up to 90 hPa. Low-pressure weather above the wing, high-pressure weather below the wing.

The pressure gradient within the pressure ranges (and thus the pressure conditions that act directly on the wing surface) is neglected here for the sake of simplicity, so these calculations are gross simplifications, but are permissible as a plausibility check.

When flying, stronger overpressure and underpressure areas only occur in very small areas, but on average they are moderate to low. The air pressure can cause enormous forces, so that even relatively small pressure differences can generate large forces on corresponding surfaces.

Flow and The Windtunnel

Ludwig Prandtl 1904 - 1,5m water test chanel Picture:Estate administration University of Göttingen (Germany)

The word "airflow" or "airstream" (in german "Strömung") has become ingrained in us through repetition. "Airflow" is a legitimate term when it comes to sailing ships, water, pipelines or wind power, for example. Lilienthal did not yet use the term "Airflow", he spoke of "wind". Ludwig Prandtl is said to have introduced it to aviation for the first time. As an engineer he developed suction systems, as a professor a water channel and later a wind tunnel. This may be where the dilemma of terms began.

The wind tunnel is an experimental set-up. The object stands in it, fixed by brackets with sensors. The air mass is moved.

The results of measurements are similar to reality if you put a lot of effort into them. For example, it is about the Reynolds number (Re number). The aim is to achieve a Re number in the wind tunnel using a wide variety of measures, as it occurs in reality. The Re number describes the ratio of the inertia forces to the viscosity forces. The closer you get to the desired Re number, the more realistic the measurement results will be. Smoke threads are rarely blown in for optical reasons, in which case you can see the path of the air particles lined up next to each other and the image of a stationary flow (streamlines) becomes recognisable.

The image of permanent smoke trails (Streamlines) is not the reality of flying. Such smoke trails are not the trajectory of a single air particle (which is deflected vertically) but are a series of successive air particles.

In fluid mechanics, streamlines (trajectories of lined-up particles) are referred to as steady flow. If there is no flow (i.e. the air mass has not been set in motion) but a wing / propeller / rotor blades are set in motion, the equalising movements of the displaced air particles are referred to as unsteady flow. The word flow for the sake of flow.

If you feel a headwind on the ground, then you might believe in a flow, but as soon as the aircraft is flying, the TAS is relevant for safe operation - regardless of how strong the wind is. In the event that entire air masses shift, the entire observation system / inertial system is in motion and in this system the air has no speed but the aircraft does.

Every pilot knows that they are moving with their aircraft and that the air is almost stationary - not the other way around. In real flying in the open air, the kind of airflow suggested by smoke trails in a wind tunnel does not occur, so it is astonishing that this rational insight is immediately lost in the next breath.

It is therefore a question of choosing the right inertial system. Smoke trails in the wind tunnel or drawn streamlines are seen from the inertial system of the measurement object (stationary flow).

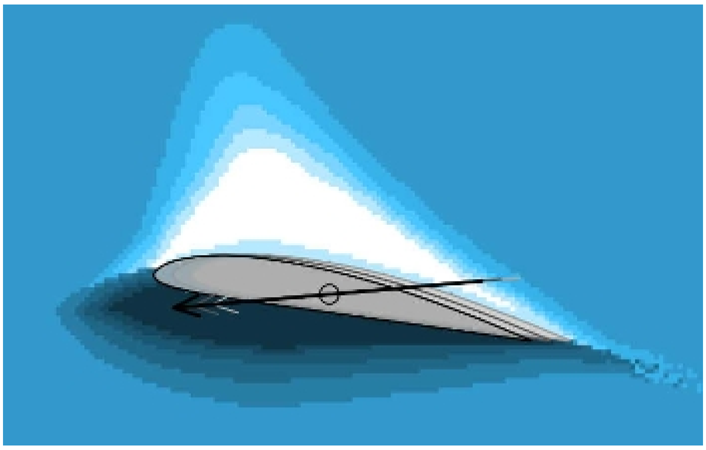
In order to understand how the impulses (air pressure) make themselves felt on the wing, it is necessary to choose the air mass as the observation system. Streamlines do not reflect the direction of momentum / impulse. Air pressure acts on surfaces at right angles.

Picture: NASA Langley Research Center Windtunnel

Lift is primarily an air pressure system around the wing cross-section. The movements of the pushed out and reunited air particles are essentially vertical. The aircraft essentially moves horizontally. The term "flow", which for everyone suggests a direction that follows the body surface, is misleading for the real movement of the air particles (unsteady flow - just because you write "flow" on it doesn't mean it's flow).

Lift At The Airfoil

In flight, a non-symmetrical "pressure cushion" builds up under the wing due to the angle of attack. The air particles are first caught in the front bottom airfoil area and accelerated downwards. They therefore already have a downward velocity vector as the underside of the profile is swept.



Idealised, exaggerated representation of the pressure spread in normal flight.

As a result, a stronger "pressure cushion" builds up at the front (also due to the overlap with the dynamic pressure). This "pressure cushion wedge" already influences the air in front of the airfoil. The "pressure cushion" decreases along the underside of the profile and "sands" behind the aerofoil with a downward component.

Due to the leading "pressure cushion", air particles are deflected upwards in front of the profile and accelerated slightly above the wingnoses due the "pressure deficit" at the top. The sloping upper wing profile (profile back) creates a free space. The air lifted in front of the wing, but above all the static pressure, fills this up. This temporary incomplete filling caused by the inertia therefore leads to the aforementioned "pressure deficit" (negative pressure) over the back of the profile. The pressure gradient is relatively large due to the space opening (also depending on the shape of the upper profile camber) so that the air particles pushing (shooting) from above have a downward component at the end of the profile (viscosity and mass inertia) also. The airfoil moves almost horizontally, forcing the air to deflect essentially vertically.

The wing profile moves almost horizontally, forcing the air to move essentially vertically. "Essentially" because the surface friction "entrains" air particles in the direction of flight, but this is negligible for general understanding. The known directions of the boundary layer vectors (laminar, turbulent) apply to real flow, e.g. in pipes/tubes, but they look different and lead to an opposit direction on a moving wing, which also shows that it is not possible to simply swap inertial systems.

If the wing profile, angle of attack and speed are optimised, both the upper and lower air particles at the end of the profile have a downward vector. I.e. the upper particles are so energetic (high kinetic energy + weak pressure energy) that the "pressure cushion" cannot yet fill the "pressure deficit" around the trailing edge of the airfoil.

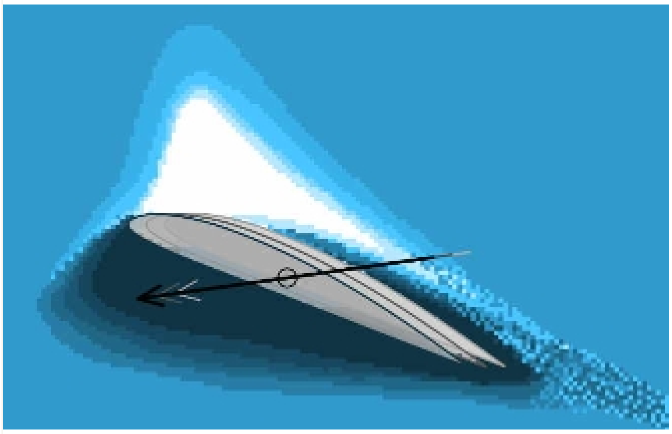
What prevents the lower air cushion from equalising the pressure deficit of the upper side around the trailing edge of the wing? The sum of the kinetic energy and pressure energy of the upper wing surface (in the area of the trailing edge) is almost identical to the sum of the kinetic and pressure energy of the lower surface. This means that while there is less pressure on the upper side (lower pressure energy), the kinetic energy (kinetic energy with downward vector) is higher. The opposite is true at the bottom.

The two air masses moving downwards do not mix homogeneously at the end of the wing (the differences in kinetic and pressure energy are equalised) but in the form of small waves and vortices. This relatively small turbulence wake primarily affects the pressure equalisation of the airfoil.

What remains is a downward-directed air mass that subsequently mixes with the surrounding air in the form of upward-directed vortices. Mixed with the tip vortices of the wings, a larger wake vortex remains. This wake vortex behind heavy aircraft is well known and very dangerous for following aircrafts (even from the first wake turbulence category Light (L)). The aircraft flies on, the air mass behind it comes to rest after a while. What remains: Energy input into the air in the form of a thermal energy (kinetic energy is converted into heat).

The lift therefore results from the acceleration of the air mass downwards. The effect is increased because this creates a "pressure cushion" at the bottom and a "pressure deficit" at the top. The force on the wing arises from the pressure difference. Regardless of how the pressure areas expand, air forces (lift, drag) only act directly on the physical surface of the body / wing / fuselage - see also "Pressure cushions....".

Stall Without Flow



Idealised, exaggregated representation of a beginnpng lift collapse (stall)

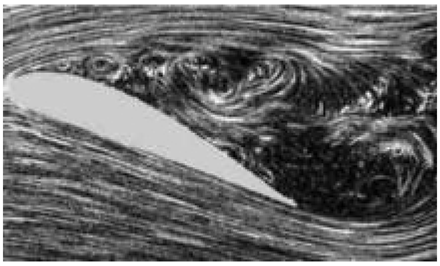
What we call a "stall" can be described in German as a "lift collapse". Such a "collapse" does not happen purely by chance but is essentially dependent on the angle of attack in addition to the profile surface of the airfoil. This is very similar for most airfoils (with rounded nose approx. 18°, at flat plate 12-15°). In practice, it is then said that it was flown too slowly. From a physical point of view, however, it is primarily a question of the angle of attack.

A higher angle of attack (e.g. pulling on the control stick) leads to more lift and drag, but also to lower speed. The pilot can read the speed from his instrument (also audible from the wind noise), which is the reference for him. The decisive factor, however, is the angle in relation to the flight path. To reduce the risk of a "collapse", it is therefore advisable to approach a little faster (+ half the gust speed) when landing in gusty conditions.

Increasing the angle of attack causes a forward shift and intensification of these pressure areas. By continuing to pull, the "pressure cushion" becomes stronger and spreads further. The "pressure deficit" increases due to the even greater drop in the backshape of the profile. But what happens if you "overpull"?

Now, at the latest, we have to look at the pressure conditions at the end of the profile. The sums of pressure energy and kinetic energy (total pressure) of the trailing edge upper side and the trailing edge lower side are out of balance. While the pressure energy increases on the underside, the kinetic energy remains almost the same and on the upper side the kinetic energy (downward direction vector) increases but the pressure energy decreases significantly. the total pressure on the underside of the profile now predominates, e.g. at the end of the profile.

Air now flows from behind around the trailing edge of the profile in the direction of flight, the pressure difference decreases - lift collapse (stall) occurs. This is not a sudden event, nor is it a complete collapse of lift. Depending on the profile, the event can happen abruptly, but it can also happen more gradually, so that the pilot notices the collapse of lift and can restore the glider to a flyable condition by immediately applying pressure (see lift diagram of corresponding profiles). Glued-on woollen threads in the stall flight test show this filling / flowing back.



Lift collapse (stall) in the flow tunnel - not in real flight

Both images show the same situation. The first from the point of view of the pressure distribution (usually invisible). The second with smoke trails in the flow tunnel (artificially visible). Both illustrations are unrealistic.

The real movement of the pushed air particles could be shown in a sequence of images of the individual air particles. Alternatively, you can show a colored pressure distribution in which the direction vectors of the air particles (intensity by length of the arrows) are drawn. The total pressure (pressure energy + and kinetic energy) is shown on each directional arrow with a more or less large circle.

Controlled stalls (starvation - slow pull on the control stick with sufficient altitude) are generally not really dangerous if there is no spin tendency. In uncontrolled stalls, the "collapse" usually occurs on one side, triggered by an increase in the angle of attack. Caused, for example, by turbulence (with an upward component) in speed ranges close to the lower limit or in slow turns, e.g. when turning downwind. Uncontrolled stalls must always be avoided, as they are potentially life-threatening for us normal pilots with our airplaines, except we are aerobatic pilots.

In general, pressure zones form and equalize again, regardless of the flight condition, but equalization must not take place on the back of the profile. Air pressure acts directly on the airfoil surface; if the pressure zones above the airfoil equalize partially or completely, the pressure difference is reduced. Low pressure difference = little lift.