A description of lift of a wing

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Abstract

Physicists and aeronautical engineers still debate the fundamental principles of lift.

The explanations they use to teach the principles of flight is mainly based on two theories that are only partly explained i.e. The Newtonian and the Bernoulli theories. Other theories are often supported in long mathematical equations not easily understood by airplane passengers.

What some may need is a clear tangible theory based on the laws of physics and logical deductions.

A new approach to the description of lift is presented here and meant to give food for thought and fuel the discussion of the fundamental issues underlying the mystery of flight.

I. Introduction

Initially I will briefly describe what I feel is missing in the Newtonian and the Bernoulli theories.

Newtonian.

The Newtonian theory explains lift as a result of Newton's third law of motion i.e. as there is a force lifting the wing there must exist an equal and opposite force exerted by the wing. The alleged opposite force is supposed to be a result of air being diverted downward by the wing. The problem with that theory is that the amount of air required diverted down parallel to gravity is enormous and the force acting on the air is explained possible because of the Coanda effect in combination with air viscosity. No explanation of the low pressure over- and forward of the leading edge is offered. Accelerating 60 tons by a force equal to gravity is way beyond the available engine power of a Boeing 737. It needs to be explained where all that power comes from.

A rough example on the magnitude of force needed is given in the appendix indicating that a Boeing 737 at cruising level needs to continuously accelerate vertically down 1.050 m^3 of air from above the wing with a force resulting in 1.298 m/s^2 (more than 130 times gravity) or accelerate 140.000 m^3 by a force equal to gravity or any combination of mass and acceleration in between. Anyway there will be a lot of air coming down. As a former military pilot (F-100 and F-16) I have flown miles of close trail including behind aircraft of significant size e.g. B52 and never experienced any significant downdraft. Come to think of it, throwing down 60 tons of air to elevate 60 tons of aircraft is rocket science not fluid dynamics.

Intuitively the idea does not add up.

Bernoulli.

Of every explanation I have read based on Bernoulli theorem they all failed to explain how the high speed over the wing is achieved or it is explained in a nonsensical way with no support in the laws of physics e.g. “the equal time transit” or “because the pressure is low the speed is high” and “because the speed is high the pressure is low” as understood it goes hand in hand.

Furthermore the Bernoulli theory has been rejected in other articles' description of lift.

There's a separate tap on my homepage where Bernoulli's theorem is questioned.

This is not saying that Bernoulli equations cannot be used for estimating pressures by measuring speeds around an airfoil. More on that later.

A submarine submerged in water glide in level cruise by displacing a mass of water equal to its own weight. The fluid is displaced in *all* directions.

And the oldest successful human-carrying flight technology, the hot air balloon also displace fluid in all directions with very little fluid turning downward.

In both cases it is the difference in pressure acting downward and pressure acting upward on the vehicle, that balance the weight of the thing.

An airplane immersed in air, say it displaces a mass of fluid or it diverts a mass of fluid around the aircraft in any direction and thereby creating a difference in pressure acting downward and pressure acting upward on the aircraft, big enough to balance its own weight should it then not fly?

I believe it will.

II. The new approach

An aircraft maintain altitude because pressure below the wings is higher than pressure above the wings, it flies.

It is important to understand that lift can be created in other ways than just by pulling down on air above the wing (Newton's third law). If you empty the area above the wing by throwing all the air out to the *side* you have a vacuum over the wing and pressure under the wing will make the aircraft climb.

Assuming a Boeing 737 at 60 tons and 120 sq. meters of wing area. Disregarding any lift from the fuselage, the mean pressure force difference between upper and lower surfaces of the wing is 60.000 kg divided by $120m^2$ = $500kg/m^2$. = $500kg/m^2$ times $9.8m/s^2$ (gravity) = $4.900N/m^2$ = 49 hPa.

Pressure at 31.000 feet is app. 287 hPa which means there is some room left for a 49 hPa average pressure drop and from the 49 hPa deduct any positive pressure resulting from under the wing. Obviously one cannot drop the pressure just right above the wing surface so in fact it takes somewhat more molecules than just a few missing right above the wing surface.

Around an aircraft pressure differentials accelerate the air. The high speed of the air on the upper side of the airfoil is not the sole reason for low pressure (Bernoulli explanation) as may be read in textbooks explaining lift. As you will see in the following the high air velocity over the wing in combination with Newton's first law lower the pressure on top of the wing and create lift. This is sometimes referred to as the Coanda effect. (Coanda effect is discussed in the appendix.) Since air pressure differentials are the only force driving the system of air movement, the speed of the air around a wing can be used to estimate the pressure by the use of Bernoulli's equation, assuming that the total pressure is constant, an increase in the dynamic pressure must result from a decrease in the static pressure ($p_1 - p_2 = ½ \rho v_2^2 - ½ \rho v_1^2$).

Atmospheric air can be regarded as an ideal gas and the ideal gas law $pV = nRT$ is governing for some part of the gas behavior. p is pressure, V is volume, n is number of *mol*, R is the gas constant and T is the temperature in Kelvin.

What is the pressure of an ideal gas e.g. air? Pressure is the number of molecules per volume at a certain temperature. Double the number of molecules inside a rigid container while maintaining the temperature constant will double the pressure inside that container and vice versa. For lowering the pressure of the volume above the wing surface the number of molecules or the air temperature or both has to be lowered. As simple as that, almost!

Cooling the air does not seem feasible whereas reducing the number of molecules above the wing should be possible by diverting the flow away from that area.

Using the above example with a B737 at 31.000 feet a 17% reduction in the number of air molecules (the density) right above the wing surface is required to create the necessary lift assuming the temperature is constant and taking no account of the higher pressure on the underside of the wing. Since the density decrease is caused by air expansion which causes a drop in temperature the 17% reduction must be corrected downward and as mentioned earlier it is not possible to lower the pressure just right above the wing surface so that require a correction upward. The meat and potatoes in this is that there is a factor to be applied to the 17% reduction.

Following here is a theory on how the air molecules' access to the area above the wing is hampered:

The word “parcel” is used here in the meaning of a very small amount of air but with a big number of molecules within it and with a mass remaining constant.

Crossflows in areas forward of and above the wing leading edge cause pressure fields in these areas, and in conjunction with Newton's first law, this will give lift as explained below.

What *crossflows*?

The lower frontal part of the wing creates a pressure wave which propagates downward and forward. Parcels in front of the pressure wave will be accelerated in the direction of the flightpath and will diverge upward (known as upwash) away from the higher pressure. This is the crossflow from a level lower than the chord line converging to the main flow or the flightpath, and is the reason for observing the stagnation point on the underside of the leading edge and causes reverse flow from the stagnation point forward and up over the wing since pressure is higher in the direction backward from the stagnation point. The stagnation point is actually a line of points on the leading edge where the air split and some of the air moves over the wing and some moves under the wing. Parcels far ahead of the aircraft waiting for the wing to pass under them are pushed by the upward forward moving parcels in the crossflow and accelerated upward and forward away from the wing thus fewer parcels end up down close over the wing surface and then lower pressure over the wing. At higher angles of attack also lower pressure slightly forward of the wing.

Parcels like to go in straight lines (Newtons first law) especially when at high speed so they are not gonna follow the leading edge curvature voluntarily.

At the stagnation point pressure builds up with the shape of a ball, oncoming parcels slam into the frontal part of this high pressure area and via elastic collisions transfer their dynamic energy to the particles in the outer perimeter of the ball and a resulting diffusion flux from mainly the upper part of the ball will create a pressure field acting normal to the flightpath (Fig. 1). In the backward direction the pressure field pushes against the leading edge creating drag and in the forward direction it deflects the incoming flow upward.

Parcels hitting the boundary layer on the leading edge in the area above the stagnation point accelerate away from the high pressure area and will try to leave along a straight line tangential to the point on the leading edge close to where they hit. This will create a pressure field pushing parcels in the main flow away from the wing, and the flow direction and speed of the parcels accelerating from the leading edge in combination with the air viscosity will entrain parcels close to the wing surface and accelerate them away from the wing. (This is sometimes referred to as the Coanda effect though according Wikipedia definition it's not.) All resulting in a lower density which in turn result in lower temperature and thus lower pressure close around the curved leading edge surface.

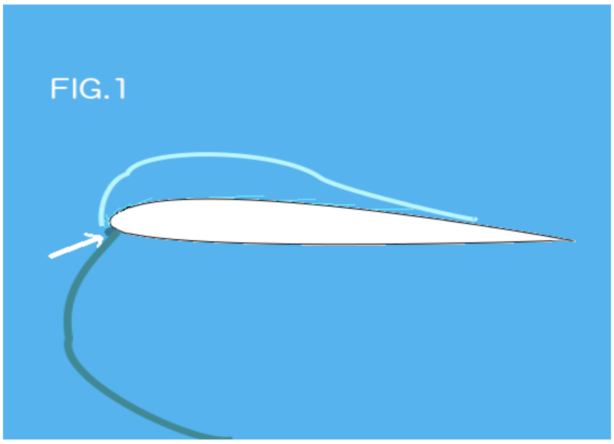
The theory stresses the importance of the shape and condition of the leading edge. Parcels hitting below the stagnation point only try to leave the leading edge surface at small angles due to the soft curvature from stagnation point and backward. Furthermore the pressure differential force below the wing is not very strong so little acceleration of parcels will take place and the resulting pressure field will be acting almost parallel to the flightpath.

Approximately one quarter of the wing cord aft from the leading edge the upper wing surface has a predominantly downward-sloping contour and Newton's first law does not allow the flow to alter the flow direction necessary to follow the downward-sloping contour this leaves room for the parcel to expand downward and that will lower the density temperature and pressure over the mid and aft part of the wing.

Parcels further up above the wing, once they have passed the pressure field at the leading edge will accelerate down toward lower pressure with a converging angle to the flightpath and push down on parcels flowing almost parallel to the flightpath. The effect is a slight downward flow tendency where the low pressure over the mid and aft part of the wing gradually diminishes toward the trailing edge and the flow ending up following the wing profile aft and causes downwash behind the trailing edge.

The wing or Coanda is not *pulling* down on the air above the wing. Particles from above the wing is *pushing* down on other particles flowing parallel to the flightpath and that is the Coanda effect.

While the shape of the pointed nose of a submarine is important for drag the forward pressure profile created by the shape of the wing is important for drag on the aircraft!



Let's sum up:

Speed over the wing is not the direct (Bernoulli) reason for lower pressure over the wing.

The generation of crossflows, one caused by the pressure wave below the wing (upwash) the other caused by the leading edge curvature. The crossflows deflect particles away from an area close over the wing. The cross flows and the predominantly downward-sloping contours of the wing in combination with Newton's first law cause the pressure drop over the wing which makes the aircraft fly.

III. How the boundary layer is created

When particles hit the stagnation point they initially take the same velocity vector as the wing.

The relationship between air viscosity and electrostatic forces between the wing and the air molecules cause close-in molecules to stay attached to the wing, they maintain low velocity relative to the wing and as they slowly creep backwards from the stagnation point the boundary layer is generated and maintained.

Electrostatic force may be recognized by observing water running slowly from a kitchen faucet it doesn't always fall vertically but often creeps around the orifice surface area.

As mentioned previously particles want to go in straight lines, so at the point where the molecules in the boundary layer take the steepest turn on the leading edge where the angle-change per travelled distance is greatest they become vulnerable. The velocity vector of the flow can be broken into two vectors, a shear vector and an impact vector. At the stagnation point the shear vector is nil. As angle of attack increases the shear vector acting on the leading edge where the angle-change per travelled distance is greatest increases toward 100% (impact vector nil) and at some point the shear vector becomes too strong and the boundary layer breaks up, the wing stalls. It's a bit more complicated than that, but I do not want to go into more details here.

Why is the boundary layer so important?

The boundary layer is the grease on the wing, without the boundary layer drag would increase significantly and the particles would not be able to accelerate and keep high speed on the leading edge or the upper wing surface and much of the lift would then be lost.

Furthermore high drag on the wing surface create turbulence which spoils the laminar flow.

Appendix

Boeing 737. Weight: 60.000kg, Altitude: 31.000', Speed: 200 m/s

Educated guessed values:

Average chord length: 4.5 m (4.3 m from wing apex to trailing edge)

Average drop from wing apex to trailing edge: 0.3 m

Air density: 0.433 kg/m^3

Assuming the air follows the wing curvature 100 %.

The wing chord flies 200 m/s pulling down 0.3 m in (4.3 divided by 200) second

The equation $d = ½at^2$ is used: $0.3 = a\ ½(4.3/200)^2$ » $a = 1.298$ m/s^2

60.000 kg * gravity => 588.000 N force to lift the B737.

1.050 m^3 of air at 31.000' weighs 455 kg

To accelerate 455 kg by 1.298 m/s^2 takes 455*1.298 = 590.000 N of force.

And of cause the air cannot follow wing curvature 100 %, which means that 1.298 m/s^2 is higher than maximum achievable acceleration.

Coanda Effect

If you look it up on Wikipedia you will learn that the Coanda effect is the tendency of a fluid jet to be attracted to a nearby surface. Though this is true it may be a little misleading.
Check out the youtube video here
https://www.youtube.com/watch?v=rsM0hy7W55A
which is a perfect explanation of the Coanda effect.

New scientific ideas never spring from a communal body, however organized, but rather from the head of an individually inspired researcher who struggles with his problems in lonely thought and unites all his thought on one single point which is his whole world for the moment.
Max Planck
And that may include new bad scientific ideas.
Martin Damkjaer

References

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