Lift is best explained by Newtonian mechanics.

Aircraft and wing design has stagnated for over 50 years due to the continued use of incorrect theories of lift (fluid mechanics).

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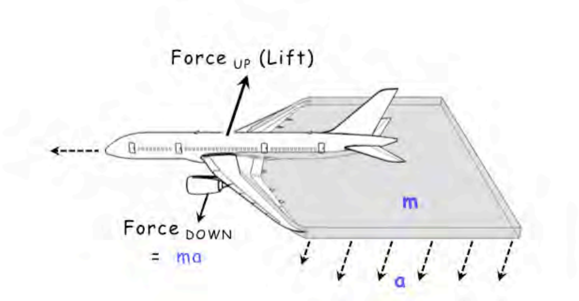

Fig. 1a Newtonian forces acting on an airplane.

Abstract

A re-evaluation of evidence indicates that Newtonian mechanics (Force = ma) based on actual airflow analysis provides a more simple, straightforward and accurate explanation of how lift is generated than currently available. According to this novel Newtonian approach, wings with a positive AOA fly through a thin mass of air (m), which they accelerate (a) downwards, to create a downward force (Force $_{\mathrm{DOWN}}$). The inertia of the air allows for a reactive equal and opposite upward force to be generated (Force $_{\mathrm{UP}}$), which provides lift. See Fig. 1a.

Taken a step further, Newtonian mechanics based on the mass flow rate (Lift = ma = m/dt * dv) better explains active lift generation using actual airflow analysis. This Newtonian approach differs significantly from existing theories of lift based on fluid mechanics or the old Newtonian change in momentum (flow turning) theories, which use relative airflow analysis.

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1. INTRODUCTION

A. *Wrong theory = Little progress.*

New technology has made airliners more efficient today with better materials and engines. However, there has been little change in basic aircraft and wing design, or the approach to aeronautics, particularly since 1970.

The incorrect use of fluid dynamics and relative airflow analysis (i.e. wind tunnels) to explain the physics of how lift and drag are generated, has restricted progress in commercial passenger aviation. The stagnation is evident as airliners flying today are fundamentally the same designs and airspeeds as the B-747 that flew in 1969, over fifty years ago. See Fig. 1b.

Fig. 1b. Airliner designs in 1969 and 2010. [19]

B. *Flying (blended) wings.*

The Newtonian approach to lift presented in this paper offers to launch a new phase in technological progress in aviation, permitting improved wing design, piloting skills, and safety. In particular, flying wings appear to be the next logical step in aeronautical development due to the potential drag and lift efficiency gains. See Fig. 1c.

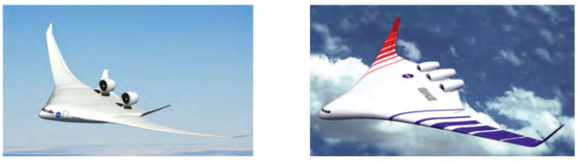


Fig. 1c. Blended wing designs. [1]

In other words, the lack of progress in developing and adopting flying wing designs has resulted from using the wrong method to explain how a wing generates lift. To understand the physics of flying wings, first the Newtonian explanation of lift needs to be mastered. Flying wing designs are examined in more detail in a separate paper. [2][4]

C. *Significance of the Newtonian approach.*

This novel Newtonian approach is extremely significant as lift is of fundamental importance to aviation. This aspect is explained in more detail in ‘Discussions of Results’, Section 11 on page 29.

D. *Unresolved theory of lift.*

The theory of lift and the physics of how airplanes stay airborne remains unresolved and debated (see Appendix I). There is no accepted and conclusive experiment on a real aircraft in realistic conditions that proves any theory of how lift is generated to be correct. [5]

The Newtonian approach based on the mass flow rate described in this paper can be tested and verified. Consequently, it offers the opportunity to resolve the 100-year-old debate of how wings generate lift.

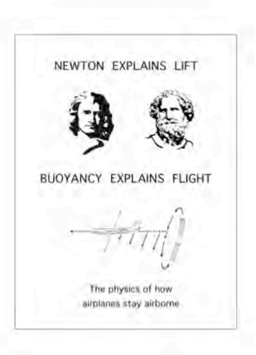
E. *Newton vs. Fluid mechanics.*

The Newtonian approach best explains how the lift generated by a wing is affected by flight manoeuvers and practical aspects of flight; such as: : airfoil thickness, wing AOA, airspeed, aircraft momentum, aspect ratio, flight manoeuvers (e.g. inverted flight, …), and practical aspects of flight (e.g. ground effect, ….).

In contrast, fluid mechanics (Navier-Stokes equations) cannot provide this detailed level and breadth of explanations of how lift is generated. Also, a summary critique of NS equations is provided in Appendix III. **[3]**

F. *Main research paper.*

The analysis and research presented in this paper is provided in much more detail in the main paper (450+ pages) by the same author “Newton explains Lift, Buoyancy explains Flight.” [2] See Fig. 1d.



NEWTON EXPLAINS LIFT

BUOYANCY EXPLAINS FLIGHT

The physics of how airplanes stay airborne

Fig. 1d. Newton explains lift.
Buoyancy explains flight. [2]

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2. THE NEWTONIAN ARGUMENT SUMMARISED

(A one-page overview)

A. Newtonian mechanics.

Newtonian mechanics based on the mass flow rate is used to explain **active lift generation** using **actual airflow analysis**. Simply put, the wings fly through a mass of air each second (m/dt), which is accelerated to a velocity downward (dv). This action creates a downward force. The inertia of the air allows for a reactive equal and opposite upward force, which provides lift; as this process is summarised by the equations: See Fig. 2a.

$\text{Force}_{\text{DOWN}} = ma = m/dt * dv = \text{Force}_{\text{UP}}$ (Lift)

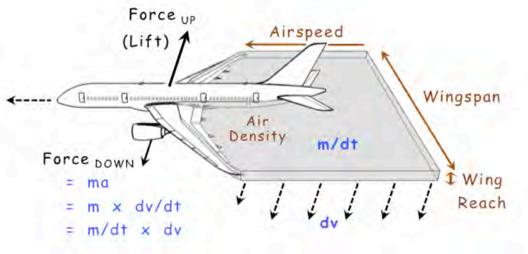

Fig. 2a. Newtonian forces acting on an airplane.

B. Passive vs. Active lift generation

Wings can create forces in two ways: (1) passively re-direct a relative airflow (headwind); or (2) actively displace the thin slice of static air flown through downwards and slightly forward. See Fig. 2b-i.

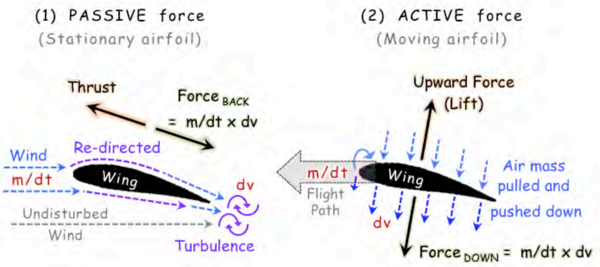

Fig. 2b-i. Active and passive force creation.

This paper argues that the wing airflows and resultant forces observed in practice, are not accurately depicted using relative airflow diagrams used by fluid mechanics. But wing airflows are more accurately depicted by absolute airflow analysis and Newtonian mechanics. See Fig. 2b-ii.

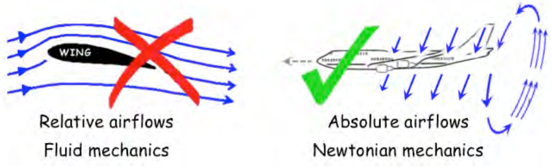

Fig. 2b-ii Relative and absolute wing airflow diagrams.

No downwash in wind tunnels?

A wing is observed to produce lift in a wind tunnel without generating net downwash. The lack of downwash is taken to indicate that no Newtonian forces are present to create lift. However, the observation above can be explained by passive force generation from relative airflows in wind tunnels, according to Newtonian mechanics.

C. New analysis.

The Newtonian approach allows lift (Lift = m/dt * dv) to be analysed separately between the mass of air flown through by the wings each second (m/dt) and the velocity (dv) to which this air is accelerated. No one has done this previously.

This new approach better explains how lift is generated, as well as providing solutions to long-standing aeronautical enigmas and paradoxes. The analysis of 'm/dt' and 'dv' separately also provides novel and useful insights, including:

- How wingspan and wing depth (chord) affect lift.
- How engine thrust and induced drag affect lift.
- How 2D and 3D lift distribution varies across a wing.

D. Newton applied to explain lift.

The Newtonian approach allows for a better explanation of all aspects of lift generation, including:

- Stalls and flight manoeuvers; which includes: cruise flight, flaps, slow-flight, take-off, final approach, landing, descent, inverted flight, banking, adverse yaw, …
- Practical aspects of lift; which includes: engine positions, gliding, anhedral vs. dihedral wings, winglets, Prandtl flying wing, canards, variable-sweep wings, biplanes, airfoils generate only lift, airfoil thickness, delta wins, ground effect, supersonic flight, ….
- How aircraft momentum and the kinetic energy used to generate lift can be assessed, which affects the optimal aspect ratio for a wing.
- The Newtonian approach can be applied to explain the empirical equations lift and drag for an airplane in flight:

$$\text{Lift} = 0.5\,(\text{Aircraft Velocity}^2 * \text{Air Density} * \text{Wing Area} * \text{Coefficient of Lift})$$

$$\text{Drag} = 0.5\,(\text{Aircraft Velocity}^2 * \text{Air Density} * \text{Surface Area} * \text{Coefficient of Drag})$$

E. Summary.

Newtonian mechanics provides a better and more comprehensive description of all aspects of lift generation than currently exists. This paper is extremely significant as it is the first time the Newtonian approach based on the mass flow rate has been presented in any detail to explain how lift is generated by a wing.

3. PASSIVE AND ACTIVE FORCES

A. *Analysis of actual airflows.*

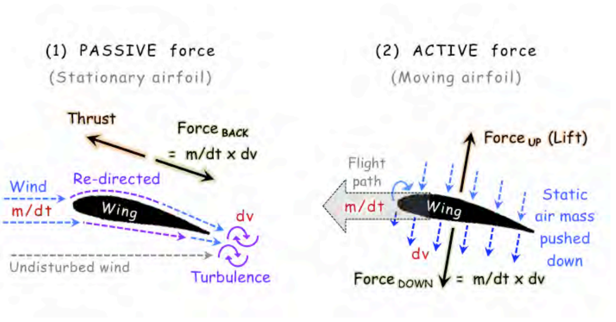

Fig. 3a-i. The passive and active creation of forces based on actual airflows.

This paper argues that based on **actual airflows** that occur, a stationary airfoil exposed to a moving relative airflow (wind) produces different airflows and forces; as compared to the reverse of an airfoil moving through static air. All forces can be calculated based on the same Newtonian equation (Force = m/dt * dv) as explained below. See Fig. 3a-(i-iii).

1) A mass of air each second (m/dt) from oncoming **relative airflow** (headwind) can be **passively** re-directed by a stationary airfoil. This airflow decelerates (dv) on contact with the undisturbed wind at the trailing edge of the airfoil to produce **turbulence.** This action creates a backward force (Force $_{\textbf{BACK}}$ = m/dt * dv), and therefore, a reactive equal and opposite **forward thrust** is also generated.

   For example, a boat sailing or a glider soaring into the wind can passively generate forward thrust by re-directing a relative airflow (headwind).

2) A moving airfoil can **actively** accelerate a mass of static air each second (m/dt) flown through to a velocity (dv) diagonally down and slightly forwards. This action creates a downward force (Force $_{\textbf{DOWN}}$ = m/dt * dv). The reactive equal and opposite upward force generated (Force $_{\textbf{UP}}$) provides lift. For example, this is how an airplane wing can generate lift.

   This paper describes airflows actively created as **absolute airflows**, which are different to the relative airflows.

The key differences between passive and active forces include:

- **The direction of the force generated** by an active force is almost perpendicular to the wing's alignment. But passive forces generate thrust in a similar direction as the wing.
- **Momentum** is transferred from the relative airflow (wind) to the wing in passive force generation, and vice versa in active force generation.
- The **passive forces** arise due to the decrease in velocity of the relative airflow (wind) at the trailing edge of the wing, which produces **turbulence** and no wake vortices.

  In contrast, **active forces** arise from static air accelerated by a wing, which produces laminar wake airflow circulated around wingtip vortices. See Fig. 3a-ii.

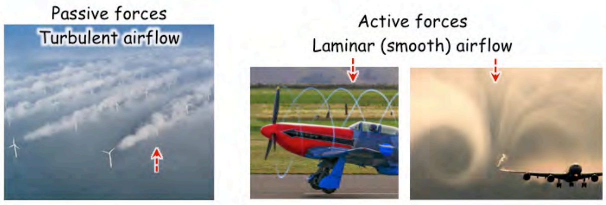

Fig. 3a-ii. Turbulent vs. smooth wake airflows. [19][51]

Relative airflow diagrams

Wing airflow diagrams are critical as they provide the basic model to analyse how wings create airflows and generate forces. The difference between relative and absolute wing airflow diagrams can be seen by comparing the airflows from wind tunnel experiments and aircraft in flight. See Fig. 3a-iii.

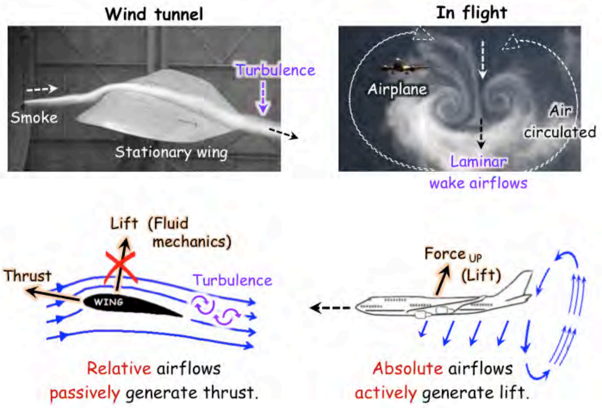

Fig. 3a-iii. Relative and absolute airflow analysis based on actual airflows. [12][11]

Relative wing airflow diagrams based on wind tunnel experiments have been used for the last hundred years by fluid mechanics to analyse how airplane wings interact with airflow to (actively) generate vertical lift in flight. However, this approach **is flawed**, for the reasons described below:

- Relative wing airflow diagrams and analysis fail to explain the actual wing airflows observed in flight and the resultant forces generated. [7]

  In particular, wake airflow turbulence observed in wind tunnel experiments is absent from the corresponding relative airflow diagrams and absent in flight.
- A re-evaluation of wind tunnel experiments shows that the prevailing view of how a wing accelerates the upper and lower airflows is false. [8]

In other words, the prevailing method by fluid mechanics to analyse how an airplane wing generates vertical lift in flight, using relative wing airflow analysis (which is based on wind tunnel experiments) is flawed. Instead, analysis of actual relative airflows over a wing are shown to passively generate turbulence and forward thrust. See Fig. 3a-iii.

These insights are extremely significant.

B. Relative airflow analysis problems – summarized.

Wing airflow diagrams are critical as they provide the basic model to analyse how wings create airflows and generate forces.

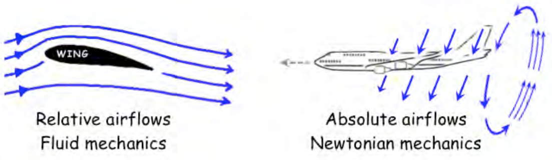

Fig. 3b. Relative and absolute wing airflow diagrams compared.

In flight, a moving wing flies through static air. The air flown through is accelerated downward to actively generate lift, according to Newtonian mechanics. In contrast, relative airflow diagrams and wind tunnel experiments show the reverse: moving air passing around a stationary wing. See Fig. 3b.

Relative wing airflow diagrams based on wind tunnel experiments have been used for the last hundred years by fluid mechanics to analyse how airplane wings interact with airflow to (actively) generate vertical lift in flight.

For practical reasons it was easier and cheaper to construct a small wind tunnel with a stationary wing or airplane, rather than an airplane that moved through stationary air. However, this simplicity comes at the cost of a less realistic analysis of lift.

Additional evidence of wing downwash

For the benefit of any people who are sceptical that wings generate downwash in flight. A video of a large blue balloon being accelerated downwards by the downwash from the wing of an A-380 on approach to landing is referenced below.

The balloon is observed to cross in front of the Airbus' wing, accelerate upwards with the upwash at the leading edge of the wing. Then the balloon is aggressively accelerated downwards with the downwash behind the trailing edge of the wing at an estimated 12.5 m/s. See Fig. 3b-ii.

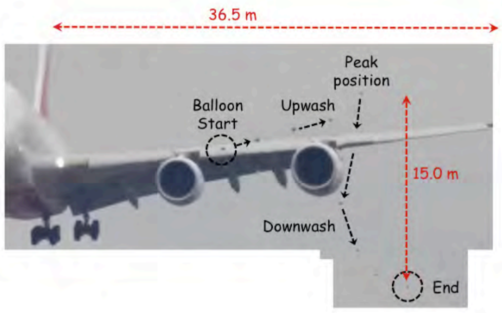

Fig. 3b-ii. Image sequence of a large blue balloon travelling in the wing airflows of an A-380. [56]

The amount of downwash observed in the video of the A-380 above, is not evident in the corresponding wing relative airflow diagrams or wind tunnel experiments.

C. Critique of relative airflow analysis. [7]

Contrary to the prevailing view, this paper asserts that relative airflow diagrams and wind tunnel experiments do not accurately describe how a wing generates lift in flight. This dynamic is evident when comparing the details of relative airflow diagrams and wind tunnel experiments to observations of a wing in flight.

Cars are used as a proxy to demonstrate this assertion above, due to a lack of appropriate images for wings. For example, a car driving on a dirt road pushes the air passed through in all directions away from it and produces significant wake turbulence. This airflow pattern is very different to the neat, streamlined laminar airflows produced in a wind tunnel. See Fig. 3c.

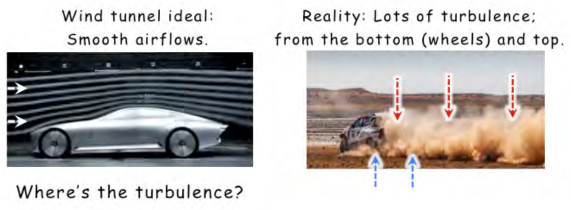

Fig. 3c. A car in a wind tunnel vs. on a dirt road.

The same principle applies to wings; the relative airflows analysis based on wind tunnel experiments differ significantly from what occurs in practice. This example is not claiming that the airflows for cars are similar to those for wings; either in a wind tunnel or in practice. This paper is only asserting that the airflows experienced in wind tunnels differ from what is seen in practice.

The deficiencies of relative airflow analysis and wind tunnel experiments that render them inadequate to explain the lift generated by a wing, can be split into several broad sections, as follows: [7]

- Problems with relative airflow diagrams.
- Problems with wind tunnel experiments.
- Pressure is consequence of lift, and not a cause. [8]
- Galilean relativity revisited.
- Passive vs. Active forces.

D. Significance.

The analysis challenges the prevailing method used by engineers to assess the forces generated based on fluid mechanics (Navier-Stokes equations), using relative airflows analysis of wind tunnel experiments; and/or CFD analysis (Computational Fluid Dynamics).

The importance of these conclusions cannot be overstated as almost all explanations of how lift is actively generated in the last 100 years have relied on relative airflow diagrams and fluid mechanics.

4. NEWTON EXPLAINS LIFT

A. *Lift = m/dt * dv*

Newtons Laws of Motion describe the relationship between the motion of an object (airplane wing) and the forces acting on it. Newtonian mechanics can be applied in three ways to explain the lift generated by a wing: See Fig. 4a.

1) Lift = ma (simple explanation)
2) Lift = ma = d(mv)/dt (momentum theory)
3) Lift = ma = m/dt * dv (mass flow rate)

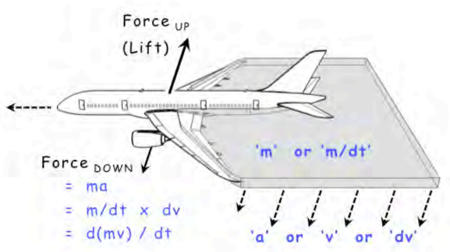

Fig. 4a Newtonian forces acting on a wing shown by three equations.

All three equations above are based on Newtons 2nd Law of motion (Force = ma). All equations are correct, complimentary, and produce the same values for lift. The equations describe the same process of a wing generating lift in different ways.

Other equations:

- Kinetic Energy = K.E. = 0.5 mv^2 [1]
- Momentum = mv [1]

Definitions:

- m = Mass of air the wings fly through.
- m/dt = Mass per unit time. The mass flow rate.
- dt = Change in time (i.e. per second).
- dv and v = Change in velocity of the air; and the velocity that the air flown through is accelerated to in one second (downwash velocity). i.e. dv = v.
- a = dv/dt (acceleration).

B. *Three Newtonian equations for lift.*

(1) The simple Newtonian explanation (Lift = ma)

According to Newtonian mechanics, wings with a positive angle-of-attack (AOA) fly through a mass of air (m) in flight. This thin slice of air is accelerated (a) downwards to create a downward force ($\text{Force}_{\text{DOWN}}$ = ma). The reactive equal and opposite upward force generated (Force_{UP}) provides lift; as summarised by the equations: See Fig. 4b-i.

$\text{Force}_{\text{DOWN}} = ma = \text{Force}_{\text{UP}}$ (Lift)

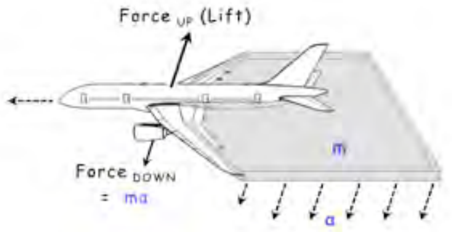

Fig. 4b-i Newtonian forces acting on a wing.

(2) Momentum theory: Lift = d(mv)/dt

There is no net gain or loss of momentum, energy and mass in the process of generating lift. In flight, wings transfer momentum and kinetic energy from the aircraft to the air, by accelerating the air flown through downwards to a velocity (v) to generate lift, which can be expressed by the equations: See Fig. 4b-ii.

$\text{Force}_{\text{DOWN}} = ma = m * dv/dt = d(mv)/dt$ [1]

$K.E. = 0.5\,mv^2$ [1]

The momentum and kinetic energy used to generate lift are calculated using the same factors; 'm' and 'v'.

The downward force generates a reactive equal and opposite upward force, which provides lift. Combining the equations above allows lift to be expressed as the change in momentum of the air accelerated downwards:

$\text{Force}_{\text{DOWN}} = \text{Force}_{\text{UP}}$ (Lift) $= d(mv)/dt$

Or simply: Lift $= d(mv)/dt$

Units: N $= (kg\ m/s)\,/s$

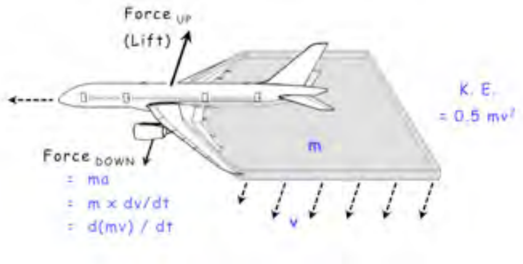

Fig. 4b-ii. Lift generated by transferring momentum and K.E. to the air.

(3) The mass flow rate: Lift = m/dt * dv

Newtonian mechanics based on the mass flow rate is used to explain **active lift generation** using **actual airflow analysis**. Simply put, the wings fly through a thin layer of air that is accelerated downward. The reactive equal and opposite force pushes the wings and aircraft upward. See Fig. 4b-iii.

For an airplane in stable flight through static air, wings with a positive angle-of-attack (AOA) fly through a mass of air each second (m/dt), which is accelerated to a velocity (dv) downward. This action creates downwash and a downward force (Force $_{DOWN}$), as summarised by the equation:

$$Force_{DOWN} = ma = m * dv/dt = m/dt * dv \quad [1]$$

The inertia of the air provides resistance to the downward force, producing a reactive equal and opposite upward force (Force $_{UP}$) that provides lift, as shown by the equation:

$$Force_{DOWN} = Force_{UP} \ (Lift)$$

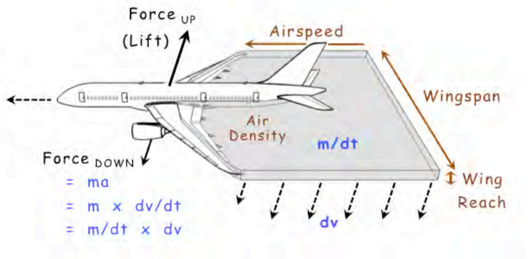

Fig. 4b-iii. Newtonian forces acting on an airplane.

Lift is defined as the vertical component of the upward force, in the opposite direction to gravity. Lift is just the vector in the vertical direction. See Fig. 4b-iv.

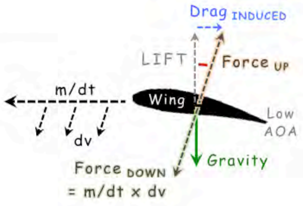

Fig. 4b-iv. Forces acting on a wing.

For simplicity, it is assumed that an airplane in flight at a very low wing AOA, the upward force is close to the vertical direction. Therefore, induced drag is negligible, and lift equals the upward force, as shown by the equation:

$$Force_{UP} = Lift$$

The equations above for the momentum transferred from the wings to the air (i.e. the change in momentum of the air) are combined as follows:

$$\begin{aligned} &Force_{DOWN} = Force_{UP} \ (Lift) &&= m/dt * dv \\ &Simplified\ to: \quad Lift &&= m/dt * dv \\ &Units: \quad N &&= kg/s * m/s \end{aligned}$$

The Newtonian approach based on the mass flow rate is a different approach to the old Newtonian explanations of lift based on a change in momentum or flow turning.

Mass flow rate (m/dt)

'm/dt' is a product of the volume of air flown through each second by the wings and air density. The volume of air flown through depends on airspeed, wingspan, and wing reach (i.e. wing AOA and wing thickness). 'm/dt' is also the downwash created by the wings.

'm/dt' increases with airspeed. Therefore, lift is expressed as the mass flow rate 'm/dt', and not 'm', because this factor of lift is time-dependent. i.e. Lift depends on the amount of air flown through by the wings each second.

Downwash velocity (dv)

'dv' depends primarily on aircraft momentum (airspeed and mass), wing AOA, and wing depth (chord). Slower and lighter aircraft have less momentum. Their wings strike each air molecule in their path with less force, which accelerates the air to a lower velocity (lower dv).

'dv' is caused by a one-off force (impulse) from the wings, which accelerates the air. Therefore, 'dv' is not time-dependent; and not expressed as acceleration 'dv/dt'. 'dv' does not change if the time period is altered.

Evidence of downwash

A wing can only generate lift if it accelerates a mass of air downward, which creates downwash and a pressure impulse as observed behind airplanes. The evidence is more evident from heavier and faster aircraft, which need to accelerate air down aggressively in order to generate the significant lift needed to fly. See Fig. 4b-(iii-v).

Fig. 4b-iii. Downwash evident behind airplanes.

Fig. 4b-iv. A-380 flying through clouds. [51]

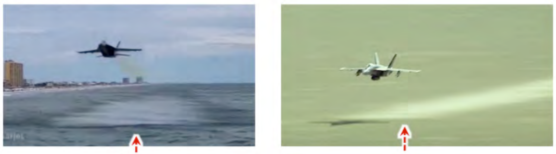

Fig. 4b-v. Pressure impulse below jets. [28]

C. *Additional considerations.*

Newtons Laws of Motion

Strictly, Newtons 2nd Law of Motion does not specifically state that force equals mass times acceleration (Force = ma). "Newton's second law …. states that the time rate of change of the momentum of a body is equal in both magnitude and direction to the force imposed on it. The momentum of a body is equal to the product of its mass and its velocity." [44]

Therefore, the equation describes force as a product of the mass flow rate and its velocity (Force = m/dt * dv), which is a generally accepted derivation of Newtons 2nd Law. [1]

This difference may have arisen because the mass of the object was assumed to be fixed by Newton and others. Only later the equation was adjusted to account for how the mass flow rate exerts a force. Consequently, the Newtonian equation for the mass flow rate could also be written using 'dm/dt'; as summarised by the equation:

$$Force_{DOWN} = ma = dm * dv/dt = dm/dt * dv$$

However, in this paper for simplicity the terminology 'm/dt' is used, rather than 'dm/dt', because in most situations the mass flow rate is only time-dependent. The surface area facing the direction of travel (flight) is constant. i.e. The wingspan and wing reach is fixed, while airspeed varies.

Therefore, it is easier and less confusing to express the lift generated as a function of 'm/dt', rather than as 'dm/dt'. However, this issue is only a presentation consideration, the physics associated with the terms 'm/dt' and 'dm/dt' is the same.

Supplementary information:

- Fluid viscosity is not significant to the forces applied by the wings to the air. Viscosity is only important to the behaviour of the air once accelerated by the wings, and therefore largely irrelevant to the calculation of lift.
- This analysis of lift is only related to the wings. It does not include the potential effects on lift from the tail and horizontal stabilizers, or the fuselage for simplicity.
- The lift required to fly depends on the aircraft's mass, which is pushed upward against gravity.
- The faster and heavier aircraft have greater momentum available to be transferred to the air to generate lift.
- In the lift generation process, 'dv' acts like an accelerator pedal for the mass of air flown through (m/dt).
- Newtonian mechanics can be used to explain the forces created by airplane wings, propellers, jet engines, and rotors, which have similar shapes, designs and functions.
- A transfer of momentum from the aircraft to the air to generate lift causes the aircraft's velocity (v) to decline, as the aircraft's mass (m) is constant.
- The kinetic energy required to generate lift is proportional to the velocity of the downwash squared (K.E. = $0.5\ mv^2$).

D. *Old Newtonian theories of lift.*

Applying Newtonian mechanics to explain lift is not a new concept. But applying Newtonian mechanics based on the mass flow rate in detail and depth is innovative. In addition, using actual airflows and a focus on the circulation of the air behind the aircraft to explain lift is entirely unprecedented.

The old Newtonian 'momentum' and 'flow turning' theories of lift asserted that wings re-direct relative airflow downwards, which transfers momentum from the aircraft to the air. The equal and opposite force pushes the aircraft up. [1] See Fig. 4d-i.

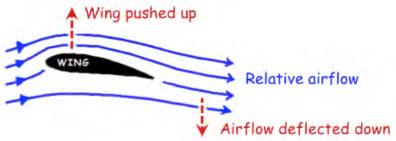

Fig. 4d-i. Wing airflow diagram
– momentum theory.

NASA's website states that both Bernoulli (fluid mechanics) and Newton (momentum theory) provide correct explanations for lift. [1] However, NASA's approach is impossible and illogical, as these are two incompatible and non-complementary theories. Also, NASA fails to specify what proportion of lift is explained by fluid mechanics and what proposition is explained by Newtonian mechanics; 50%/50% or 70%/30% ? No attempt is made to combine the equations from Newtonian and fluid mechanics, to provide one equation for lift.

The book 'Understanding Flight' [10] uses Newtonian mechanics to explain lift. It states: "In the simplest form, lift is generated by the wing diverting air down, creating the downwash." The author also stated: "We did the calculation for a 250 ton airplane at 35,000 feet, and it is diverting (downwards) its own weight per second to keep in the air." [45]

The book: "Stick and Rudder" by Wolfgang Langeweische (1944) [9], in Chapter 1 states: " The wing keeps the plane up by pushing air down. …. In exerting a downward force on the air, the wing receives an upward counterforce – by the same principle, known as Newton's law of action and reaction, …. " See Fig. 4d-ii.

Fig. 4d-ii. Books: 'Understanding Flight' & 'Stick and Rudder.'

A paper "A comparison of explanations of aerodynamical lifting force" (1987) [18] calculated lift using Newtons 2nd Law, based on the change in momentum of the air and the mass flow rate of the air pushed downwards by the wing; using the equation: Force = d(mV)/dt = dm/dt * V ; where: V = Velocity of the airstream. However, the approach above relies on relative airflow analysis, not actual airflow analysis.

E. The analysis of lift generation is complex.

The analysis of how lift generation changes with the different variables such as airspeed and wing AOA is complex. -The extent to which a change in one factor can affect lift varies a lot, depending on the starting and ending aircraft configuration, and how factors are inter-related.

- Many key variables (e.g. airspeed, momentum, aspect ratios, flaps, wing AOA, ….) **can affect both 'm/dt' and 'dv' factors in a linear and non-linear manner**.
- Changes in factors can cause a significant or a minor change in lift **depending on the initial aircraft configuration and the initial mix of how lift is generated from 'm/dt' and 'dv'.**
- Many **factors are inter-dependent**. A change in one variable can affect 'm/dt' and 'dv', and therefore lift.

  Changes in 'm/dt' and 'dv' can then have a **secondary effect** on how other factors affect 'm/dt' and 'dv', and therefore lift. The secondary changes can be in positive or negative direction; potentially leading to **positive or negative feedback loops**.

For example, for an airplane in stable flight, a small change in wing AOA can cause:

- A significant change in the Coanda effect and 'm/dt' generated by the topside of the wing. In turn, this change causes the lift generated (Lift = m/dt * dv) to change dramatically.

  However, this is not always the case. A small change in wing AOA can cause only a small change in the Coanda effect, depending on the circumstances.
- An increase in wing reach, which then increases 'm/dt', and therefore, increases lift.
- Assuming no change in engine thrust (throttle), the higher wing AOA causes an increase in induced drag, which then causes a reduction in airspeed and aircraft momentum. These changes have a secondary effect of reducing 'm/dt' and 'dv', and therefore reducing lift, which limits the primary effects of increased lift.

This complexity of lift generation means that during flight manoeuvers pilots maintain lift by altering different aircraft controls simultaneously. Rather than just changing one control at a time. For example, to increase airspeed and maintain altitude in cruise flight. A pilot can increase engine thrust and reduce the wing AOA simultaneously. Only increasing engine thrust and not altering the wing AOA would cause the airplane to gain altitude.

Significance

Lift analysis is complex. However, Newtonian mechanics significantly improves the methods available to analyse lift. In turn, this dynamic permits improved explanations of how the different variables (e.g. airspeed, momentum, aspect ratios, flaps, wing AOA, ….) affect lift, by allowing for the analysis of the components parts 'm/dt' and 'dv' separately.

F. Wing design according to Newtonian mechanics.

Wings come in all shapes and sizes, each with their own particular advantages and disadvantages in how they push air down to create lift. See Fig. 4f.

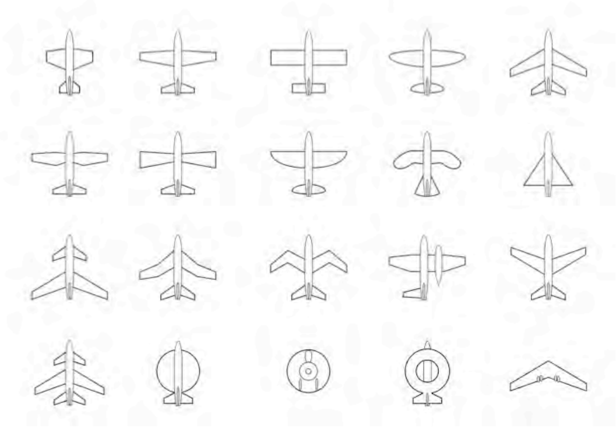

Fig. 4f. Examples of different wing designs – top view. [19]

Given a strong enough engine thrust, airspeed and a positive AOA, even a barn door could theoretically generate sufficient lift to fly. In fact, some fighter jets have flown with only one wing on one occasion, and with their wings folded (unextended) on another occasion. In both cases significantly higher airspeed and AOA than usual was required to maintain flight. This implies that the engines were used to help compensate for the loss of lift from a reduced wingspan. For example:

- In 2016, a F-15 fighter jet landed with only one wing following a mid-air collision with an A-4 Skyhawk during training.
- In 1960, a US Vought F-8 Crusader took-off from Naples, Italy with its wings still folded (unextended). It later landed safely.

Some wing design considerations include:

- The need to maintain laminar airflow over the wing.
- Wing curvature and the Coanda effect.
- Wing design needs to be supported by sufficiently strong and light materials to maintain the aircraft's integrity.
- The features of the aircraft (e.g. engine power, aspect ratio, momentum, propeller or jet, fuel and lift efficiency, location of the engines on the aircraft, ….),
- The circumstances (e.g. maintenance issues, runway conditions, airport restrictions, regulations, ….).
- The purpose of the aircraft (commercial passenger transport, cargo, private business passenger transport, private leisure, military, STOL, VTOL, ….), as well as
- The preferences and priorities of the owners and pilots.

G. *Paper airplanes.*

The same Newtonian mechanics that explains how conventional airplanes generate lift to fly, can also be used to explain how paper airplanes fly.

The wings of a paper airplane with a positive AOA fly through a mass of air each second (m/dt) that they accelerate downwards to a velocity (dv). This action creates a downward force (Force $_{\text{DOWN}}$). The inertia of the air allows for a reactive equal and opposite upward force to be generated, which provides lift. This process can be described by the equations: See Fig. 4g-(i-ii).

$$\text{Force}_{\text{DOWN}} = m/dt * dv = \text{Force}_{\text{UP}} \text{ (Lift)}$$

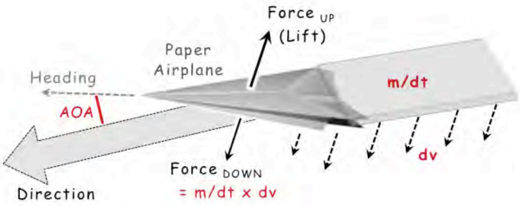

Fig. 4g-i. Newtonian forces acting on a paper airplane.

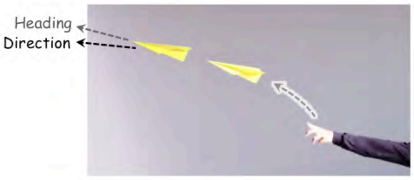

Fig. 4g-ii. Paper airplane trajectory. [43]

Momentum is transferred from the paper airplane to the air to generate lift, causing the paper airplane's velocity to fall during flight. This means that as the paper airplane descends it trades altitude for airspeed, and airspeed for lift.

Paper airplanes are also noteworthy due to their ability to fly and glide despite their flat (straight) wings, as compared to the curved wing design seen on conventional airplanes. Flat wings produce a minimal Coanda effect, which restricts the amount of air pulled down by the topside of the wings. Consequently, the flat wing design explains why paper airplanes are prone to stall easily. They fly best at a high airspeed and/or high wing AOA.

Additional key features of paper airplane flight include:

- Paper airplanes are uncontrolled and lack a vertical tail and horizontal stabiliser.
- Paper airplanes typically lack structural stiffness, and therefore, cannot withstand large forces.
- Paper airplanes lack mass, and therefore, lack momentum that can be transferred to the air to generate lift. This limits the distance that they can be thrown.
- The low mass means that little lift is needed to fly.
- Paper airplane lacks an engine, and therefore, must glide and cannot sustain flight for long.

H. *Frisbees.*

The same Newtonian mechanics that explains how airplanes fly, can be applied to explain the flight of a frisbee. Simply put, the frisbee pushes air down as it flies forwards, causing the frisbee to be pushed up.

A frisbee in stable flight through static air, which has a positive angle of attack (AOA), flies through a mass of air each second (m/dt), which it accelerates to a velocity (dv) downward and slightly forward; to create a downward force (Force $_{\text{DOWN}}$). The inertia of the air allows for a reactive equal and opposite upward force (Force $_{\text{UP}}$) to be generated, which provides lift; as described by the equations: See Fig. 4h-(i-ii).

$$\begin{aligned}\text{Force}_{\text{DOWN}} &= m/dt * dv \\ &= \text{Force}_{\text{UP}} \text{ (Lift)}\end{aligned}$$

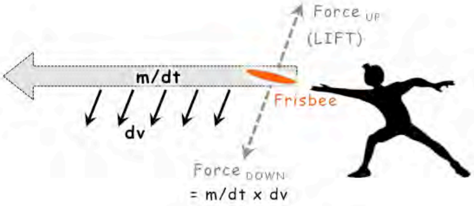

Fig. 4h-i. Newtonian forces acting on a frisbee.

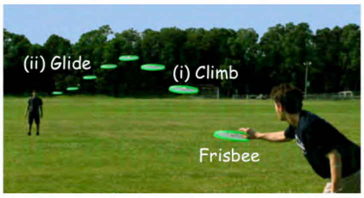

Fig. 4h-ii. Typical frisbee trajectory.

Momentum is transferred from the frisbee to the air, causing the frisbee's velocity to fall during flight.

The reactive equal and opposite upward force (Force $_{\text{UP}}$) can be split between the two perpendicular vectors: lift and induced drag. Lift is simply the vertical part of the upward force. Induced drag is the horizontal and backward component of the upward force. See Fig. 4h-iii.

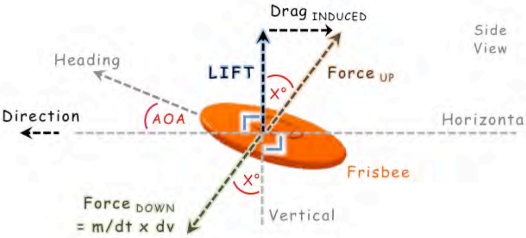

Fig. 4l-iii. Key forces acting on an airplane.

The angle that the downwash is pushed down determines how the upward force is split between lift and induced drag. If induced drag is negligible, then lift equals the upward force.

5. MORE ON NEWTON

A. *Key forces.*

Different experts define the forces acting on an airplane differently. To avoid confusion with these other definitions and due to the need to be precise, this paper introduces new terms. The equation for the forces produced by the propellers (or jet engine) is as follows:

Thrust PROPELLERS = Engine Thrust

Engine Thrust is the backward force created by the propellers (or jet engine), from accelerating air backwards. The reactive equal and opposite forward force is **Thrust PROPELLERS**. See Fig. 5a-i.

Fig. 5a-i. Key forces acting on an airplane in level flight.

Thrust PROPELLERS is applied in two ways:

- To push the airplane horizontally forwards through the static air (Thrust § PROPELLERS), to overcome parasitic drag and provide airspeed.
- To push air downwards (Force DOWN), using the wings. In addition, as the downward and upward forces on the wings are equal, (Force DOWN = Force UP).

These dynamics are shown by the equations:

Thrust PROPELLERS = Thrust § PROPELLERS + Force DOWN
Thrust PROPELLERS = Thrust § PROPELLERS + Force UP
(Forwards) *(Upwards)*

Thrust § PROPELLERS is defined as the residual force left from **Thrust PROPELLERS**, after the wings have diverted some of the Engine Thrust downwards (Force DOWN), in order to generate lift. See Fig. 5a-i.

In other words, the force exerted by the wings to accelerate air flown through downward to generate lift, reduces the amount of Thrust PROPELLERS (Engine Thrust) applied to push the airplane forwards (Thrust § PROPELLERS).

This explanation of the forces acting on an airplane is consistent with how momentum is transferred from the wings to the air to generate lift, which reduces the aircraft's momentum.

In this example above of stable, level flight, almost all engine thrust is used to generate forward motion. Negligible amounts of engine thrust are directed downwards to boost the total amount of lift generated. Only the wings are used to generate lift.

Downward and upward forces

The **downward force** (Force DOWN) exerted by the wings on the air from accelerating the air flown through downwards, as described in the previous Section.

The **upward force** (Force UP) is the reactive, equal and opposite upward force to the downward force, as summarised by the equation: Force DOWN = Force UP

Force UP can be split between the two perpendicular vectors: the vertical part (Lift), and the backward horizontal part (Drag INDUCED), shown by the equation: See Fig. 5a-i

Force UP = Lift + Drag INDUCED
(vertical) *(horizontal)*

The **induced drag** acts horizontally, in the opposite direction to the forward force, to reduce the airplane's airspeed. The relationship between induced drag and the other forces (e.g. Lift, etc…), is complex and depends on the circumstances. See Fig. 5a-iii.

Fig. 5a-ii. Key forces acting on an airplane.

Key forces (on the x and y axis):

The forces above depend on the direction that the propellers (or jet engine) are pointed. A separate set of terms are used to describe the key forces acting on the airplane in absolute terms, fixed to the horizontal and vertical directions: See Fig. 5a-iii.

Force FORWARD = Total force applied **horizontally**.
= Drag PARASITIC
Lift = Total force applied **vertically** to counter gravity.
Gravity = A force vertically downward.

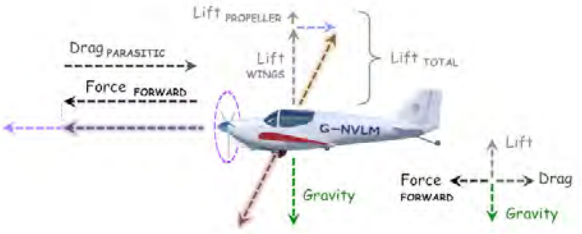

Fig. 5a-iii. Forces acting on an airplane defined by the two axis.

In level flight:

- Thrust § PROPELLERS = Force FORWARD.
- Thrust PROPELLERS contributes little to lift.

B. Total lift generated.

The **total lift** ($\text{Lift}_{\text{TOTAL}}$) generated is the total vertical force generated directly upwards against gravity by the wings ($\text{Lift}_{\text{WINGS}}$) and the propellers ($\text{Lift}_{\text{PROPELLERS}}$), as shown by the equations: See Fig. 5a-iii and 5b-(i-iv)

$$\text{Lift}_{\text{TOTAL}} = \text{Lift}_{\text{WINGS}} + \text{Lift}_{\text{PROPELLERS}}$$

In slow-flight, the wings and propellers (or jet engines) both accelerate a mass of air each second (m/dt) to a velocity (dv). Therefore, the equation for lift above can be broken down into the factors 'm/dt' and 'dv' as follows:

$$\text{Lift}_{\text{TOTAL}} = (m/dt * dv)_{\text{WINGS}} + (m/dt * dv)_{\text{PROPELLERS}}$$

$$\text{Lift}_{\text{TOTAL}} = (m/dt * dv)_{\text{TOTAL}}$$

Where:

$$\text{Lift}_{\text{PROPELLERS}} = (m/dt * dv)_{\text{PROPELLERS}} = m/dt_{\text{PROPELLERS}} * dv_{\text{PROPELLERS}}$$

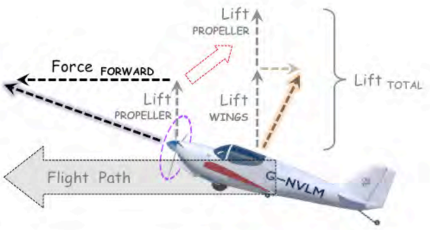

Fig. 5b-i. Total lift generated by wings and propellers in slow-flight – simplified.

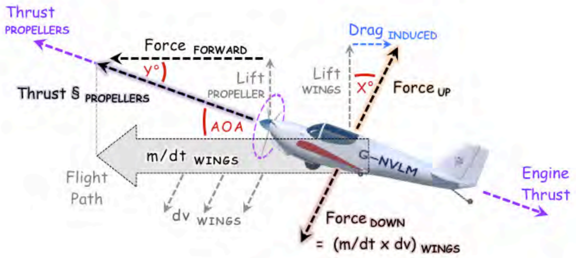

Fig. 5b-ii. Key forces acting on an airplane in level flight with a nose-up configuration (slow-flight).

Angle Y°

The angle Y° that the propeller thrust is directed depends on the wing AOA and the angle that the propellers are attached to the fuselage. Propellers are often designed to be angled slightly upwards for an airplane in cruise flight, in order to boost lift slightly.

This dynamic means that as the wing AOA increases, the lift generated from the wings typically declines, while the lift generated from the propellers (or jet engines) increases.

Thrust generated by the propellers (or jet engines)

Similar to the lift generated by the wings, the airflows from the propellers (or jet engines) can be assessed according to Newtonian mechanics based on the mass flow rate. The same logic shown for propellers can be applied to explain the forces acting on a jet engine.

The propellers accelerate a small mass of air each second ($m/dt_{\text{PROPELLERS}}$) to a high velocity ($dv_{\text{PROPELLERS}}$). This action creates a force (Engine Thrust). The reactive equal and opposite force provides thrust ($\text{Thrust}_{\text{PROPELLERS}}$) to push the airplane forwards, as summarised by the equations: See Fig. 5b-iii.

$$\text{Engine Thrust} = (m/dt * dv)_{\text{PROPELLERS}} = m/dt_{\text{PROPELLERS}} * dv_{\text{PROPELLERS}} = \text{Thrust}_{\text{PROPELLERS}}$$

Fig. 5b-iii. Thrust generation by a propeller. [19]

As explained above, for an airplane $\text{Thrust}_{\text{PROPELLERS}}$ can be split into the two forces that push the airplane forwards and upwards by the wings, as shown below:

$$\text{Thrust}_{\text{PROPELLERS}} = \text{Thrust §}_{\text{PROPELLERS}} + \text{Force}_{\text{DOWN}}$$

$$\text{Thrust}_{\text{PROPELLERS}} = \text{Thrust §}_{\text{PROPELLERS}} + \text{Force}_{\text{UP}}$$

(Forwards) *(Upwards)*

In addition, if the propellers are angled upwards in flight (e.g. nose-up configuration with a high wing AOA), then the engine thrust ($\text{Thrust §}_{\text{PROPELLERS}}$) can also be split into vertical and horizontal vectors, as shown by the equation: See Fig. 5b-iv.

$$\text{Thrust §}_{\text{PROPELLERS}} = \text{Force}_{\text{FORWARD}} + \text{Lift}_{\text{PROPELLERS}}$$

(horizontal) *(vertical)*

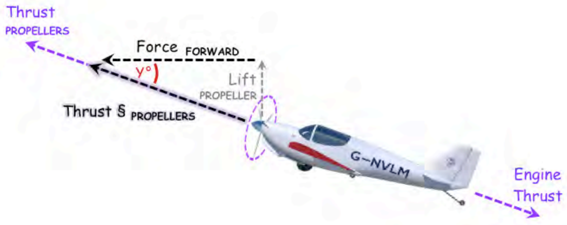

Fig. 5b-iv. Force acting on the airplane due to the forces from the propellers.

These horizontal and vertical forces can also be expressed using the trigonometry of a right-angled triangle and Pythagoras theorem, as shown by the equations:

$$\text{Force}_{\text{FORWARD}} = \text{Thrust §}_{\text{PROPELLERS}} * \text{Cos}(Y°)$$

$$\text{Lift}_{\text{PROPELLERS}} = \text{Thrust §}_{\text{PROPELLERS}} * \text{Sin}(Y°)$$

C. *Induced drag.*

The dynamics of induced drag is a controversial subject, and therefore, merits additional and extensive explanations.

The Newtonian approach presented in this paper is significant because:

- It differs significantly from the prevailing view by experts such as NASA. NASA's explanation of induced drag is provided separately below.
- It makes induced drag easier to understand, apply to flight conditions, and explain changes in the lift generated.
- It is easier to calculate induced drag more accurately, as compared to the prevailing methods.

According to Newtonian mechanics, induced drag is the backward horizontal component of the upward force generated by the wing.

Wings generate downward and upward forces at oblique angles, which depend on the angle that the downwash is accelerated down. In turn, this angle depends on factors such as the wing AOA and the wing shape. See Fig. 5c-(i-ii).

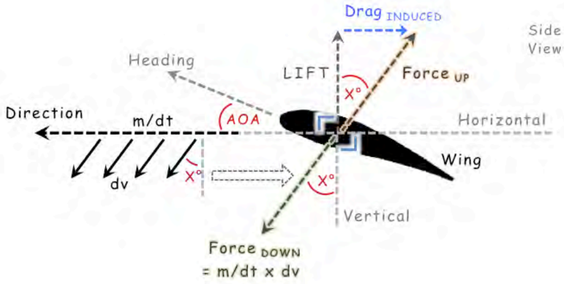

Fig. 5c-i. Forces acting on a wing.

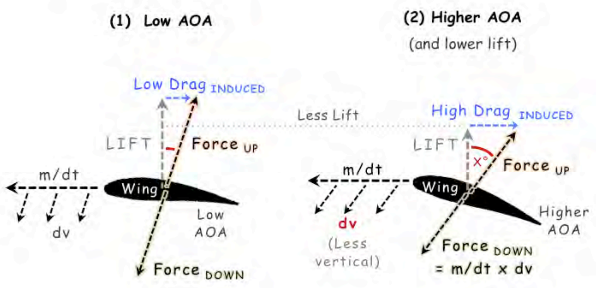

Fig. 5c-ii. Induced drag at different wing AOAs.

Assumptions of induced drag

For simplicity, the analysis compartmentalises induced drag elsewhere in this paper and assumes that induced drag is negligible or not significant to the analysis. This means that induced drag is only taken into account when it is significant to the analysis or if the amount of induced drag changes in the analysis described.

D. *'m/dt' and 'dv' analysed separately.*

A benefit of the Newtonian approach is that 'm/dt' and 'dv' can be analysed separately to understand better how lift (Lift = m/dt *dv) is generated. Different factors affect 'm/dt' and 'dv' differently. See Fig. 5d-(i-ii).

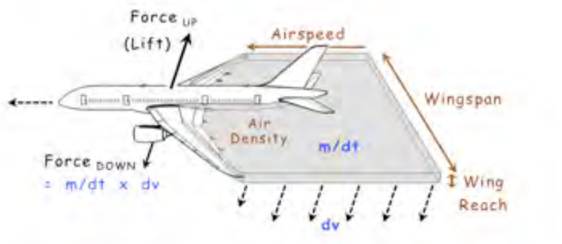

Fig. 5d-i. Newtonian forces acting on an airplane; showing 'm/dt' and 'dv' analysed separately.

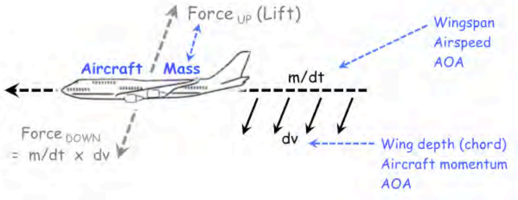

Fig. 5d-ii. 'm/dt' and 'dv' analysed separately.

For example, analysis of the factors that influence lift shows:

- Wingspan affects 'm/dt' but not 'dv'.
- Wing depth (chord) and aircraft momentum have a significant impact on 'dv', but a much lesser impact on 'm/dt'.
- Wing AOA affects 'm/dt' and 'dv', but to different extents, in a non-linear manner.

Consequently, it is beneficial to analyse 'm/dt' and 'dv' separately.

The Newtonian approach allows for the lift generated by different aircraft configurations, wing shapes, flight conditions, etc….. to be compared and analysed in new ways based on how each factor affects 'm/dt' or 'dv'.

E. *Constant lift curve.*

The two key components that determine lift, ‘m/dt’ and ‘dv’, can be analysed graphically. On the graph, the lift generated that maintains stable flight is represented by a constant lift curve. Each point on the constant lift curve represents a different mix or combination of ‘m/dt’ and ‘dv’ that generates sufficient flight to fly. See Fig. 5e-i.

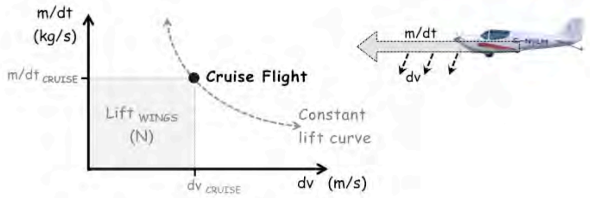

Fig. 5e-i. Graph comparing ‘m/dt’ and ‘dv’,
generated by the wings,
shown on the constant lift curve.

Additional considerations for the constant lift curve analysis include:

- Alternative combinations of ‘m/dt’, ‘dv’, and the propeller thrust exist to produce the same total amount of lift (Lift = m/dt * dv) needed to fly. Nonetheless, the mix of how lift is generated from ‘m/dt’ and ‘dv’ is restricted to the constant lift curve.
- The area under the curve represents the lift generated.
- The constant lift curve provides an entirely new method to analyse lift, which has not been presented before. It is extremely significant as it enables new analysis of stalls and flight manoeuvers.
- The constant lift curve is convex due to the inverse relationship between ‘m/dt’ and ‘dv’; and as lift generation is less efficient at high values of ‘m/dt’ and ‘dv’.
- Any point to the left of the constant lift curve represents an amount of lift that is insufficient to maintain flight, and the airplane stalls. Whereas, any point to the right of the constant lift curve represents an excess of lift generated as compared to the amount needed to maintain flight, and the airplane gains altitude. See Fig. 5e-ii.

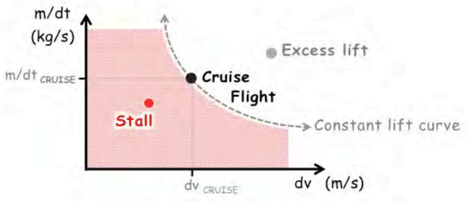

Fig. 5e-ii. Graph comparing ‘m/dt’ and ‘dv’,
for stalls, excess lift and the constant lift curve.

Propellers (engine thrust)

The graph above only shows the lift generated by the wings. The propellers are included in the analysis by the constant lift curve, where they contribute towards lift. See Fig. 5e-iii.

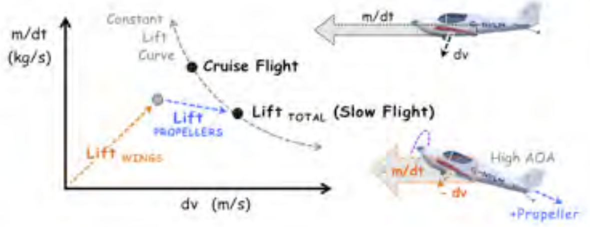

Fig. 5e-iii. Graph showing ‘m/dt’ and ‘dv’,
for the wings and propeller combined,
on the constant lift curve.

The propellers accelerate a relatively small mass of air each second (low m/dt) to a high velocity (high dv), which boosts the total lift generated.

For example, when the ‘m/dt’ and ‘dv’ generated by the propellers and wings are combined, such as in slow-flight with a nose-up configuration, then the following dynamics are observed: See Fig. 5e-iii.

- The total lift generated (Lift $_{\text{TOTAL}}$) increases, as compared to the lift generated by the wings (Lift $_{\text{WINGS}}$).
- The average ‘m/dt’ (m/dt $_{\text{TOTAL}}$) decreases, as compared to the ‘m/dt’ of the wings (m/dt $_{\text{WINGS}}$).
- The average ‘dv’ (dv $_{\text{TOTAL}}$) increases, as compared to the ‘dv’ of the wings (dv $_{\text{WINGS}}$).

Flight manoeuvers displayed and analysed

A key benefit of this approach is different flight manoeuvers, such as high-speed, cruise, and slow-flight can be shown and compared on the constant lift curve. See Fig. 5e-iv.

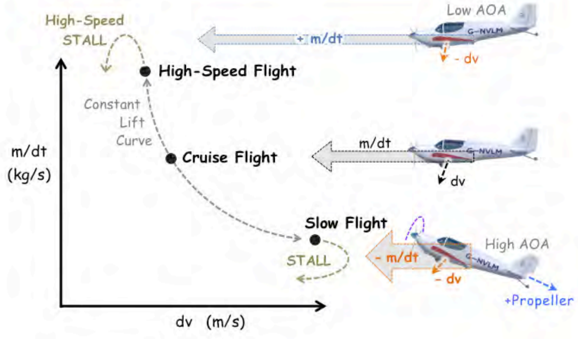

Fig. 5e-iv. Lift composition – ‘m/dt’ and ‘dv’
compared on a constant lift curve.

F. Lift distribution: Glider vs. Harrier.

Newtonian mechanics is used to illustrate the lift distribution across different wings. In this example, a slow and light glider is compared to a fast and heavy Harrier (fighter jet), as they have significantly different aspect ratios and aircraft momentum.

It is assumed that:

- The glider's wingspan is about 3 times longer than the Harrier's wingspan. More precisely, in this example the glider has a 30 meter wingspan, which is about 3.2 times greater than the Harrier's 9.2 meter wingspan.
- The glider flies at about one-third (1/3) the airspeed, as compared to the Harrier.
- The glider has thinner wings (smaller chord), but the same wing area as compared to the Harrier.
- The glider and Harrier have the same wing reach.

Consequently, the data above used in this example means that the absolute mass of air flown through each second (m/dt) is the same for the glider and Harrier, which is a 'modest m/dt'.

- It is significant that the mass of air flown through each second (m/dt) by a fast jet can be comparable to the m/dt of a slow glider.
- Even though 'm/dt' is the same for both aircraft in absolute amounts (in this example), the total lift generated is very different due to different values for downwash velocity (dv). This dynamic provides a significant insight into how lift is generated.

Glider

A glider's long wingspan (high aspect ratio wings) flies through a large mass of air each meter (mass/meter). But its slow airspeed means that it manages to fly through only a relatively modest mass of air each second (modest m/dt). This air is accelerated downward at a low velocity (low dv) due to the aircraft's limited momentum. Overall the glider generates a small amount of lift required to fly. This dynamic is summarised by the equation:

Modest m/dt = long wingspan * low airspeed

Low LIFT = modest 'm/dt' * low 'dv'

Harrier (fighter jet)

The Harrier's short wingspan (low aspect ratio wings) fly through a small mass of air each meter flown (low 'm'). However, the Harrier's high airspeed means that it manages to fly through a relatively modest mass of air each second (modest m/dt), despite the short wingspan. This dynamic is summarised by the equations:

Modest m/dt = short wingspan * high airspeed

Modest m/dt = low ('m' / meter) * high (meter / second)

This air flown through each second (modest m/dt) is accelerated downward at a high velocity due to the Harrier's significant momentum (high dv). Overall, the much heavier Harrier generates a significantly greater amount of lift required to fly, as compared to the lighter glider. This dynamic is summarised by the equation:

High LIFT = modest m/dt * high dv

In this example, the glider and Harrier wings fly through the same mass of air each second (modest m/dt). However, the glider and the Harrier generate very different downwash velocities (dv), which are shown graphically in Fig. 5f-i.

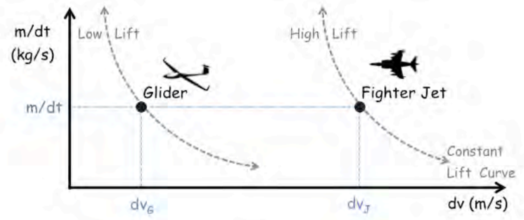

Fig. 5f-i. Constant lift curves compared
for a glider and Harrier.

The different lift distributions generated by the Harrier and glider are illustrated in Fig. 5f-(ii-iii).

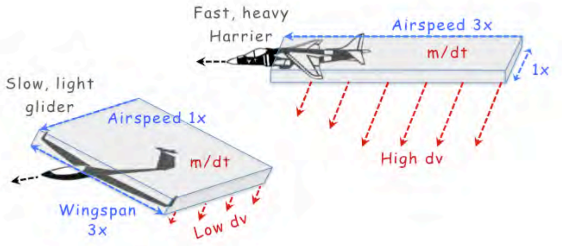

Fig. 5f-ii. 3D lift generation
for a glider and Harrier compared.

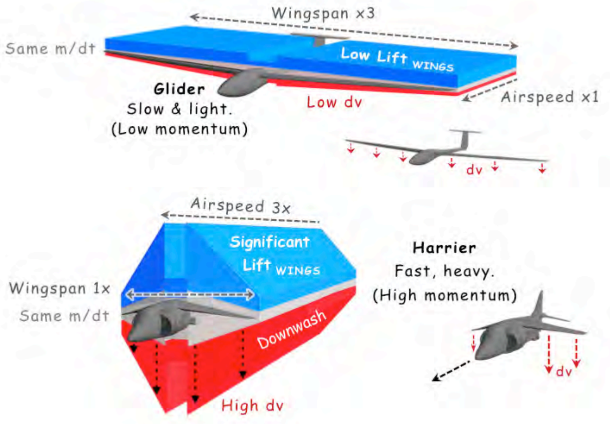

Fig. 5f-iii. 3D lift distribution
for a glider and Harrier compared.

The Harrier's 3D lift distribution above is spread out over a long horizontal distance due to the Harrier's high airspeed.

For simplicity, the 3D lift distribution above only shows the underside of the wing accelerating air downwards to create downwash. In practice, the topside and underside of the wings accelerate air downward.

6. ACTUAL WING AIRFLOWS

A. Two wing airflows.

The actual airflows actively generated by a wing in flight are described by the term ‘absolute airflow analysis’. These airflows differ from the relative airflows that passively generate forces.

A wing in forward flight with a positive wing AOA, accelerates the static air above and below the wing downwards and slightly forwards, creating two distinct airflows See Fig. 6a-(i-ii).

1) The **underside** of the wing directly **pushes** air down.

2) The **topside** of the wing indirectly **pulls** air down, helped by the Coanda effect and gravity.

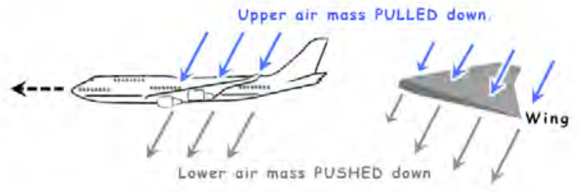

Fig. 6a-i. Two actual airflows on a wing.
(Absolute airflow analysis)

Fig. 6a-ii. 2D diagram of actual wing airflows.
(Absolute airflow analysis.)

The wing airflows generated can be illustrated by the path of air molecules above and below the wing. See Fig. 6a-iii.

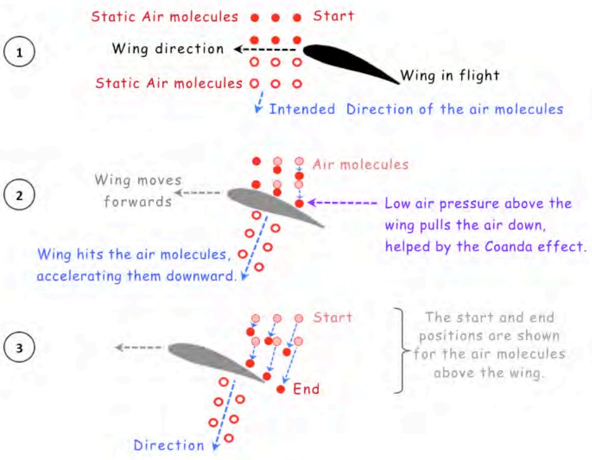

Fig. 6a-iii. Actual path of air molecules
as the wing moves forwards in flight.
(Absolute wing airflows analysed.)

The two wing airflows are described in more detail below:

1) The **underside** of the wing directly **pushes** air down. See Fig. 6a-iv.

The force exerted by the wing on the air creates high pressure on the underside surface of the wing, as described by the equation for pressure (Pressure = Force /Area).

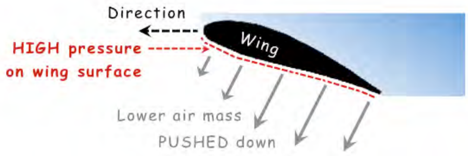

Fig. 6a-iv. The underside of the wing
directly pushes air down.

2) The forward movement of the wing creates a zone of low pressure (vacuum) behind it on the **topside** of the wing. See Fig. 6a-v.

The low-pressure zone indirectly **pulls** air above the wing downwards, helped by:

- Any wing curvature due to the Coanda effect.
- The weight of the atmosphere (i.e. gravity) pulls the air above the wing downwards, into the area of low pressure on top of the wing created by the forward movement of the wing.

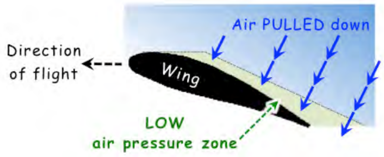

Fig. 6a-v. The topside of the wing
indirectly pulls air down.

Additional considerations include:

- The leading edge of the wing initially pushes the air up and forwards, creating upwash.
- If the air above the wing pulled down does not reach the trailing edge of the wing by the time that the wing has moved forwards. Then turbulence can arise, triggering airflow separation and a **stall**. This dynamic explains why stalls always arise at the trailing edge of the wing.
- After the wing has passed forwards, the lower and upper air masses accelerated by the wing continue to descend due to the momentum gained.
- The generation of lift produces a **pressure difference on the wing**; Low pressure on the topside of the wing and high pressure on the underside of the wing.

  Contrary to the prevailing view, this paper argues that wing the pressure patterns observed are a **consequence** of the airflows and resultant process that generates lift, and **not a direct cause** of lift.

  As the airflows have been accelerated, they both have low internal air pressure.

B. *Wing airflow considerations.*

Additional considerations: See Fig. 6b-i.

- The airflows created depend on factors such as the airfoil size and shape, airspeed, and wing AOA.
- Aircraft momentum affects the velocity that the air flown through is accelerated to (dv), particularly for the lower air mass.
- The higher the airspeed, then the stronger the area of low air pressure on top of the wing, and the faster the upper mass is pulled down (higher 'dv' above the wing).
- 'dv' varies across the wingspan due to differences in wing thickness and depth (chord). Consequently, 'dv' is least at the wingtips and greatest at the wing root.
- The upper and lower airflows can have different velocities (dv) as they have different causal factors. Their velocities are likely to be similar as they are accelerated by the same wing with the same airspeed.

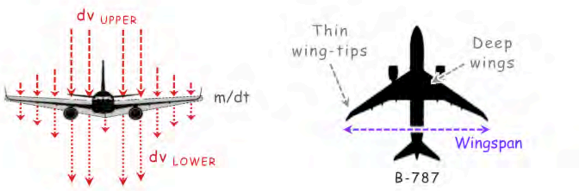

Fig. 6b-i. Wing airflows and downwash velocities (dv).

- The mass of air accelerated by the wing each second (m/dt) can be different above and below the wing.
- After the wing has passed forwards, the lower and upper air masses accelerated by the wing continue to descend due to the momentum gained.
- This action pushes and pulls the surrounding air to circulate the air behind the aircraft. See Fig. 6b-ii.

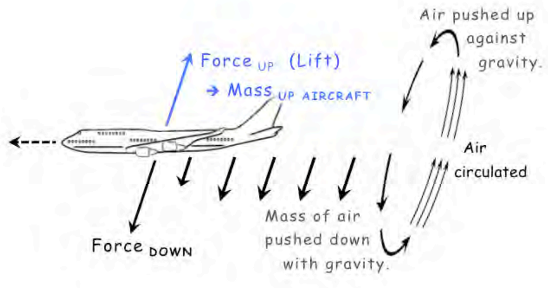

Fig. 6b-ii. Wings circulate air in their wake.

- Any curvature on the topside of the wing can enhance downward airflows of the air above the wing due to the Coanda effect, as explained below.
- Slats, flaps slots, and air brakes also affect wing airflows, and therefore, the forces generated.

C. *The topside of the wing is critical for lift.*

The optimum wing AOA maximizes the combined airflow re-directed or accelerated downwards by the underside and topside of the wing, and therefore, the generated force.

The top airflow is sensitive to changes in wing AOA due to the Coanda effect. Whereas, the lower airflow does not rely on the Coanda effect, which makes it more stable and less sensitive to changes in the wing AOA. Stalls arising due to disrupted airflow on the topside of wings provide evidence of this difference in airflow sensitivity.

Consequently, attention is focused on the upper airflow when analysing how changes in AOA or other wing characteristics affect lift. The implication is that the topside of the wing can displace a much greater airflow under ideal conditions, as compared to the underside of the wing.

In other words, the lift generation of the topside of the wing is considered to be a lot more variable, as compared to the underside of the wing. However, experiments need to be done to confirm this assertion.

For example, as the wing AOA increases (at constant airspeed), more air is displaced down by both sides of the wing. But the increase is greater on the topside of the wing, due to the Coanda effect; until a stall is triggered. See Fig. 6c.

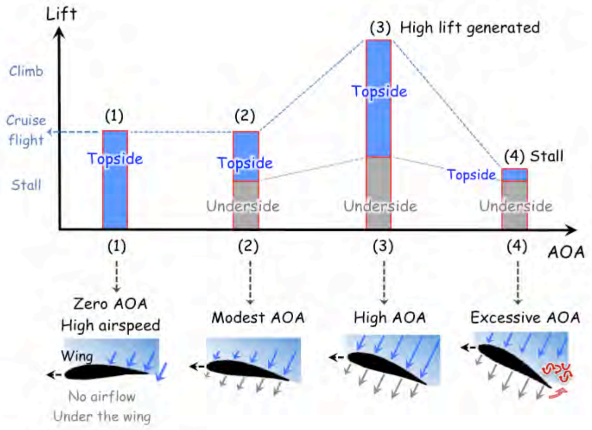

Fig. 6c. Upper wing airflow is highly sensitive to changes in wing AOA.

The bar graph in the image above represents the mass of air flown through and accelerated down each second (m/dt); for each wing configuration. Consequently, it is a key factor that directly affects the amount of lift generated.

This analysis is extremely significant.

D. The Coanda effect – Spoon experiment.

Fluid flow naturally follows a curved surface due to the Coanda effect.

For example, water falling from a tap is passively re-directed to the right (and slightly up) by the curved side of a spoon due to the Coanda effect. According to Newtonian mechanics, this action creates a small turning force, due to the change in momentum of the water flow. The reactive equal and opposite force pushes the spoon sideways to the left (and slightly downwards). See Fig. 6d-i.

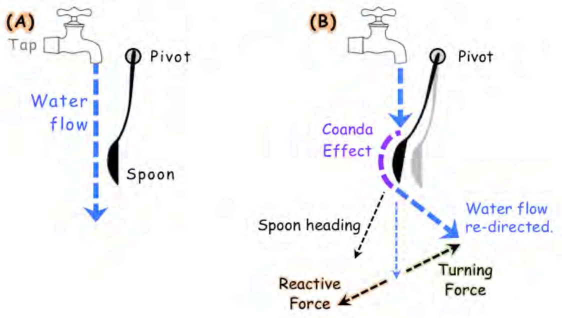

Fig. 6d-i. Spoon experiment demonstrating the Coanda effect.

Wind tunnel experiments

Wind tunnel experiments demonstrate airflows arising due to the Coanda effect on the topside of a curved airplane wing, as well as the turbulence that arises on a flat wing. See Fig. 6d-ii.

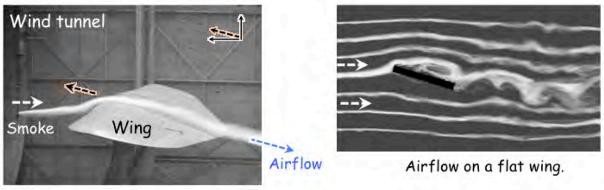

Fig. 6d-ii. Airflow on curved and flat wings. [12]

In general, wings produce a stronger Coanda effect with laminar (smooth/non-turbulent) airflow at a lower AOA, higher airspeed, and where the wings are deepest (largest chord, such as near the fuselage). Conversely, the Coanda effect is weakest at high AOA, slower airspeeds, and where the wings are narrow (small chord, such as at the wing tips). See Fig. 6d-iii.

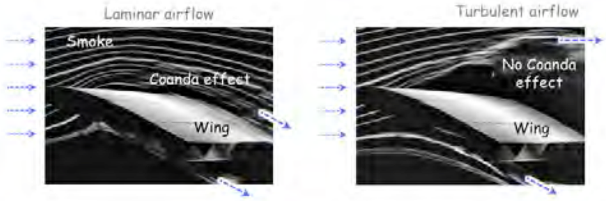

Fig. 6d-iii. Smooth vs. turbulent airflows on a wing. [15]

The flat undersides of wings are typically designed to push air down without inducing any Coanda effect.

Coanda effect and fighter jet wings

Some fighter jet wing and fuselage designs show pronounced curvature that maximizes the Coanda effect. See Fig. 6d-iv.

Fig. 6d-iv. Curved fuselage designs of jets. [13][14]

The Coanda effect helps to explain why airplanes keep the topside of wings clear of any obstructions that could disrupt the upper airflows. For example fighter jets almost always carry their payloads under their wings. There are usually other reasons for this as well (eg. ease of maintenance, many bombs are dropped so cannot be on the top of wings, ….). See Fig. 6d-v.

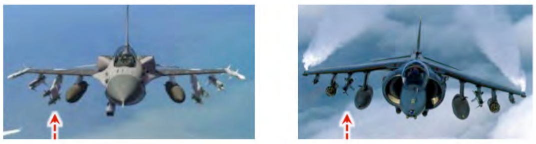

Fig. 6d-v. Fighter jet payloads. [19]

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7. AERODYNAMIC STALLS

A. Newtonian explanation of a stall.

Brief summary

An aerodynamic stall occurs when the wings cease to generate enough lift for an airplane to continue to fly.

The analysis below shows that the stall and stall recovery process are consistent with Newtonian mechanics. Therefore, the analysis supports the argument that Newtonian physics and actual airflow analysis explain lift.

A new insight gained from this analysis is that stalls and stall recovery are shown to depend critically on how the downward acceleration of the air (dv) is affected **by the wings**.

The Newtonian approach provides a methodology to improve pilot training and wing design for stall avoidance; as well as a method to better predict stalls. Consequently, these developments can provide advantages for safety and aircraft performance.

It is fundamentally flawed to use relative airflows to analyse stalls. Consequently, it is also flawed to use relative airflows and fluid mechanics (Navier-Stokes equations) to explain the lift generated by an airplane wing in flight.

The Newtonian explanation in more detail

A stall typically occurs in a slow-flight configuration, with a high wing AOA and/or low airspeed. The wings are generating low ‘m/dt’ and ‘dv’. The propeller also boosts the lift generated. Consequently, the lift composition for slow-flight and a stall is shown graphically in Fig. 7a-i.

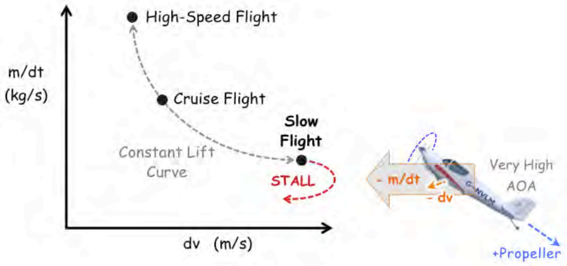

Fig. 7a-i. Lift composition for slow-flight relative to the constant lift curve.

The high overall downwash velocity (dv) in slow flight on the constant lift curve above, is due to the combined effects of wings and propellers. In slow-flight the wings generate low ‘dv’.

The total lift ($\text{LIFT}_{\text{TOTAL}}$) generated in slow-flight is the sum of the lift from the wings ($\text{LIFT}_{\text{WINGS}}$) and propellers ($\text{LIFT}_{\text{PROPELLERS}}$), as shown by the equations:

$$\text{LIFT}_{\text{TOTAL}} = \text{LIFT}_{\text{WINGS}} + \text{LIFT}_{\text{PROPELLERS}}$$

$$\text{LIFT}_{\text{TOTAL}} = (\text{Low } m/dt \ * \ \text{low } dv)_{\text{WINGS}} + \text{LIFT}_{\text{PROPELLER}}$$

A high wing AOA configuration pre-stall can produce significant induced drag, and is inefficient at generating lift. Consequently, a high wing AOA can trigger a stall despite significant throttle (engine thrust) being applied. See Fig. 7a-iv.

For an aircraft in slow-flight (high wing AOA and low airspeed), a stall can be triggered when the upper air mass is no longer accelerated downwards fast enough (low dv) to reach the trailing edge of the wing.

Consequently, at the trailing edge the low air pressure on top of the wing now pulls air from below the wing, to the topside of the wing. This action causes airflow separation and turbulence at the trailing edge, which disrupts laminar (smooth) airflow on top of the wing See Fig. 7a-(ii-iii).

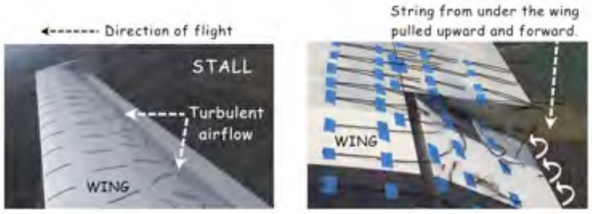

Fig. 7a-ii. Actual wing airflows in a stall.

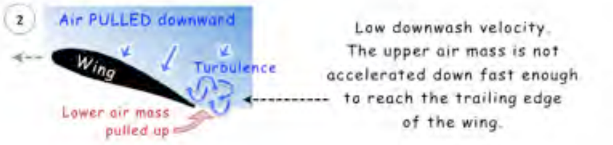

Fig. 7a-iii. Wing airflows
– lower air mass is pulled up.

Airplanes can fly with a certain amount of wing turbulence. However, if enough turbulence arises and enough lift is lost, the entire wing can stall, and cease to generate lift.

According to Newtonian mechanics, the increased airflow separation and turbulence cause reduced ‘m/dt’ and ‘dv’, and therefore, a loss of lift (Lift = m/dt * dv). If lift declines enough. Then the aircraft can cease to fly, and falls like a stone. See Fig. 7a-iv below.

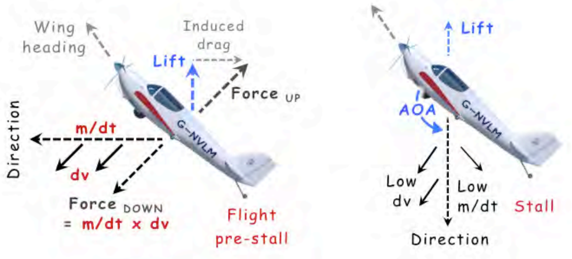

Fig. 7a-iv. Actual airflows and Newtonian forces acting on a wing, pre- and post stall.

As the airplane descends vertically after a stall, the wing AOA increases due to the change in the direction of the relative airflow, which is now from below the wing upward. See Fig. 7a-iv above.

8. EQUATIONS FOR DRAG AND LIFT

A. Empirical equations for drag and lift.

Newtonian physics explains the empirical equation for drag: [1]

Drag = 0.5 (Aircraft Velocity^2 * Surface Area
* Air Density * Drag Coefficient)

The empirical equation for drag is simply a mathematical description of how drag is observed to vary in practice with different parameters. Until now there has been no adequate explanation of the physics involved.

All parameters of the empirical equation for drag (aircraft velocity, air density, surface area, and drag coefficient) affect the mass of air flown through each second by the fuselage ($\text{m/dt}_{\text{DRAG}}$); and/or the velocity to which this air is accelerated away from the aircraft (dv_{DRAG}). Therefore, the drag equation can be explained by Newtonian mechanics based on the mass flow rate (Force = ma = m/dt * dv); as shown by the analysis below. In subsonic flight, drag arises primarily from the fuselage, vertical tail section, engines, and spanwise wing airflow. See Fig. 8a-i.

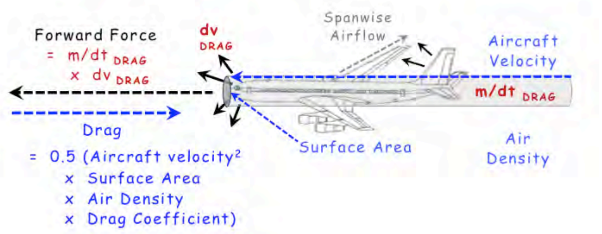

Fig. 8a-i. The empirical and Newtonian equations for drag.

The analysis is provided in three steps:

(i) The Newtonian and empirical equations are equated:

Newtonian = Empirical equation
$\text{Force}_{\text{FORWARD}}$ = Drag
$\text{m/dt}_{\text{DRAG}}$ = 0.5 (Velocity^2 * Surface Area
x dv_{DRAG} * Air Density * Drag Coefficient)

(ii) The equation above is revised as follows:

$\text{m/dt}_{\text{DRAG}}$ = (Velocity * Surface Area * Air Density) (a)
x dv_{DRAG} * 0.5 (Velocity * Drag Coefficient) (b)

(iii) Then the two parts of the Newtonian equation ($\text{m/dt}_{\text{DRAG}}$ and dv_{DRAG}) are correlated to two different parts of the empirical equation of drag, (a) and (b):

$\text{m/dt}_{\text{DRAG}}$ = Velocity * Surface Area * Air Density (a)
= (Velocity * Surface Area) * Air Density
= **$\text{Volume}_{\text{DRAG}}$ /dt** * Air Density
= $\text{m/dt}_{\text{DRAG}}$

dv_{DRAG} = 0.5 * Velocity * Drag Coefficient (b)

Where: Velocity = Aircraft velocity.
Surface Area = Surface area of the aircraft fuselage, engines, and tail in the direction of travel.

It is no coincidence that the empirical equations for lift and drag are similar, as they are explained by Newtonian mechanics.

Newtonian physics explains the empirical equation for lift: [1]

Lift = 0.5 (Aircraft Velocity^2 * Wing Area
* Air Density * Lift Coefficient)

The empirical equation for lift is simply a mathematical description of how lift is observed to vary in practice with different parameters. Until now there has been no adequate explanation of the physics involved.

All parameters of the empirical equation for lift (aircraft velocity, air density, surface area, and drag coefficient) affect the mass of air flown through each second by the wings (m/dt); and/or the velocity to which this mass of air is accelerated downward (dv). Therefore, the empirical equation for lift can be explained by Newtonian mechanics based on the mass flow rate (Force = m/dt * dv); as shown by the analysis below: See Fig. 8a-ii.

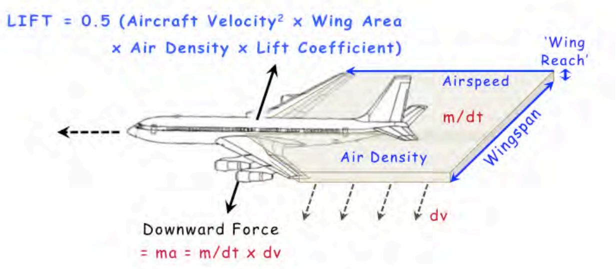

Fig. 8a-ii. The empirical and Newtonian equations for lift.

The analysis is provided in three steps:

(i) The Newtonian and empirical equations are equated:

Newtonian = Empirical equation
$\text{Force}_{\text{DOWN}}$ = Lift
m/dt * dv = 0.5 (Velocity^2 * Wing Area
* Air Density * Lift Coefficient)

(ii) The equation above is revised as follows:

m/dt * dv = 0.5 (Velocity * Wing Area * Air Density) (a)
* (Velocity * Lift Coefficient) (b)

(iii) Then the two parts of the Newtonian equation (m/dt and dv) are correlated to two different parts of the empirical equation of lift, (a) and (b):

m/dt = 0.5 * Velocity * **Wing Area** * Air Density (a)
= 0.5 * Velocity * (**Wingspan * Chord**) * Air Density
= (Velocity * Wingspan * (**0.5 * Chord**)) * Air Density
= (Velocity * Wingspan * **Wing Reach**) * Air Density
= **Volume /dt** * Air Density
= m/dt

dv = Velocity * Lift Coefficient (b)

Where: Velocity = Aircraft velocity.
Wing Area = Wingspan * Chord
Wing Reach = 0.5 * Chord * [Lift Coefficient]

(Wing reach includes part of the lift coefficient. For simplicity, the lift coefficient element is not shown in equation (a) above. See the full explanation. [2])

Summary

The analysis above shows that Newtonian mechanics can explain the empirical equations for drag and lift. In addition, the analysis demonstrates that the drag and lift coefficients depend on 'dv', the velocity to which the fuselage or wings accelerates the air.

B. Why lift increases with airspeed.

The Newtonian approach can be used to better explain all aspects of lift generation. For example, if two almost identical light aircraft (A) and (B) are compared. Where Aircraft (B) has a higher mass, it needs to generate more lift to fly. See Fig. 9b.

Aircraft (B) can generate extra lift (Lift = m/dt * dv) by increasing its airspeed and engine power, while maintaining its wing AOA. As a result, it flies through a greater mass of air each second (higher m/dt); which it accelerates downwards to a higher velocity (higher dv).

Therefore, lift increases in the heavier Aircraft (B), due to higher 'm/dt' and higher 'dv', as shown by the equation:

Higher Lift = higher m/dt * higher dv

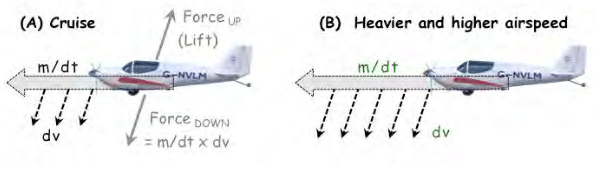

Fig. 9b. Two aircraft compared.

Also, Aircraft (B) has a greater momentum, and therefore, it has more momentum to transfer to the air to generate lift.

C. Why lift quadruples if airspeed doubles.

The Newtonian explanation for lift based on the mass flow rate (Lift = m/dt * dv), can be used to explain why vertical lift is proportional to the square of horizontal aircraft velocity, as described by the empirical equation for lift, for an airplane in flight, as follows: Fig. 9c-i.

$$\textbf{Lift} = 0.5\ (\textbf{Aircraft Velocity}^2 * \text{Air Density} * \text{Wing Area} * \text{Lift Coefficient})$$

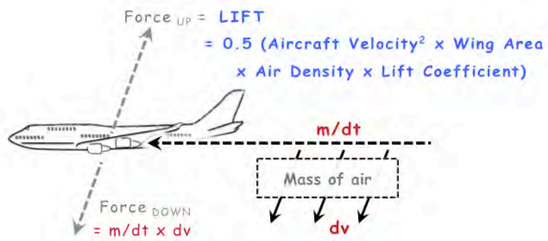

Fig. 9c-i. Newtonian forces acting on an airplane.

According to Newtonian mechanics, if the aircraft's velocity doubles, then lift quadruples as explained below:

- An aircraft travelling twice as fast, so the wings fly through twice the mass of air each second (2x m/dt);
- The wings accelerate this air to twice the velocity downward as before (2x dv), as aircraft momentum has also doubled (Momentum = mass * velocity).

The combined effect of these two changes above is to quadruple the Force $_{\text{DOWN}}$, and therefore, also quadruple the reactive Force $_{\text{UP}}$ as well as the lift generated. This dynamic is summarised by the equations: See Fig. 9c-ii.

$$\begin{aligned} 4 * \text{Force}_{\text{DOWN}} &= (2 * m/dt) * (2 * dv) \\ &= 4 * (m/dt * dv) \\ &= 4 * \text{Force}_{\text{UP}}\ (\text{Lift}) \end{aligned}$$

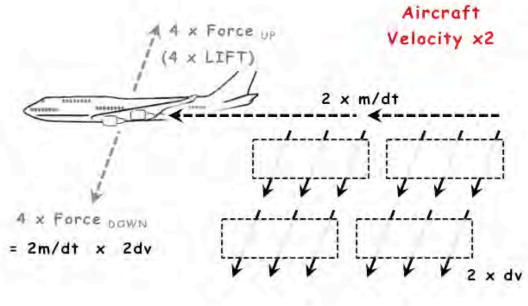

Fig. 9c-ii. Lift ⇔ Aircraft Velocity^2

9. FLIGHT MANOEUVERS

A. *Overview.*

Newtonian mechanics based on the mass flow rate is used to explain lift during all flight manoeuvers, using the equation:

$$Lift = m/dt \ x \ dv \qquad (5)$$

Flight manoeuvers can be shown to affect lift (Lift = m/dt * dv), depending on how the mass of air flown through each second (m/dt) and/or the velocity to which this air is accelerated downwards (dv) change with the alterations in aircraft orientation and circumstances (e.g. airspeed, wing AOA, …). See Fig. 9a-i.

Fig. 9a-i. Newtonian forces acting on a wing.

The flight manoeuvers analysed below include: [2]

- Cruise flight.
- Increased airspeed.
- Inverted flight.
- Take-off/'nose-up' climb.
- Flaps.
- Slow-flight.
- Change in aircraft mass.
- Final approach to a runway.
- Landing.
- Vertical climb.
- Vertical descent.
- Steep descent.
- Power-off descent.
- Wing AOA.
- Banking and adverse yaw.
- Side slipping.
- Propeller forces.

Flight manoeuvers can be accurately described using Newtonian explanation for lift (Lift = m/dt * dv). Variations in 'm/dt' and 'dv' change how the lift is generated based on aircraft configuration changes. The composition of lift between 'm/dt' and 'dv' can be shown graphically for different configurations. See Fig. 9a-(ii-iii).

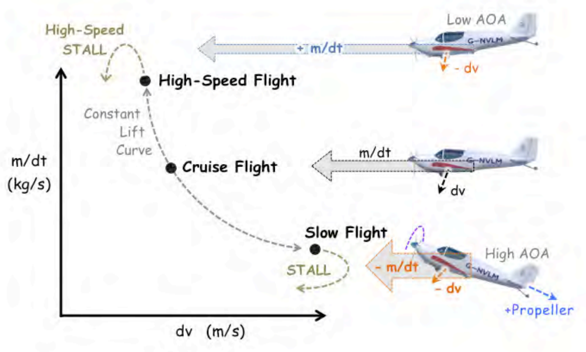

Fig. 9a-ii. Lift composition – 'm/dt' and 'dv' compared.

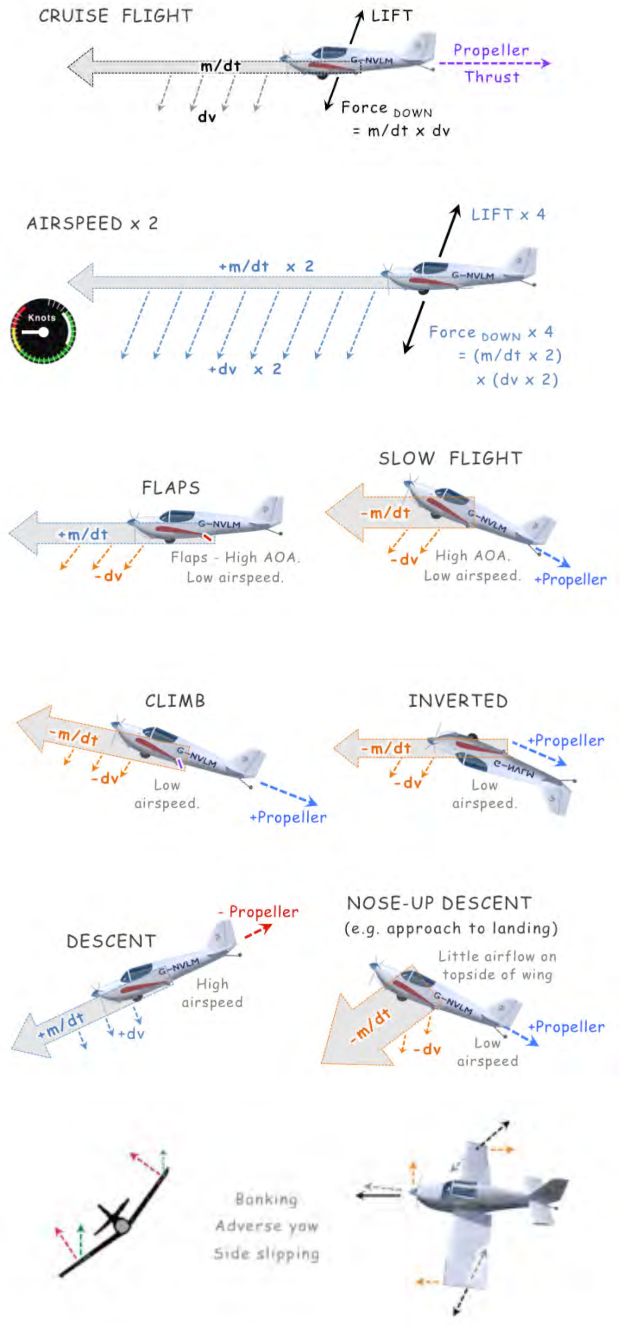

Fig. 9a-iii. Key flight manoeuvers summarized. [2]

B. Example Newtonian explanations of manoeuvers.

Inverted flight and take-off are provided as examples of flight manoeuvers analysed according to Newtonian mechanics.

Inverted flight

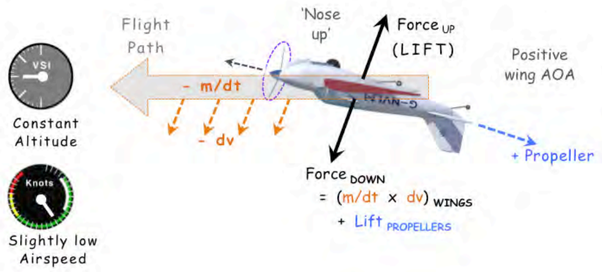

Fig. 9b-i. Inverted flight.

In an inverted flight at constant altitude and slightly lower airspeed. The airplane's configuration needs to be slightly raised for the wings to have a positive AOA. Consequently, this configuration means that: See Fig. 9b-i.

- The airplane's orientation is less aerodynamic to the direction of flight, which increases drag. Higher engine power is required to compensate for this extra drag.
- Any wing curvature is now facing downwards, reversing the benefits of any Coanda effect, and reducing 'm/dt' and the lift generated. Aerobatic airplanes tend to have symmetrical wings to negate this problem.
- Lift is increased by a higher wing AOA and 'nose up' attitude. This increases m/dt, 'dv' and the contribution towards lift by the engines (propellers) as they are angled slightly upwards.

In short, to maintain airspeed and altitude, additional engine power and increased wing AOA are needed to offset the overall negative aerodynamic effects of flying inverted (higher drag). See Fig. 9b-(ii-iii).

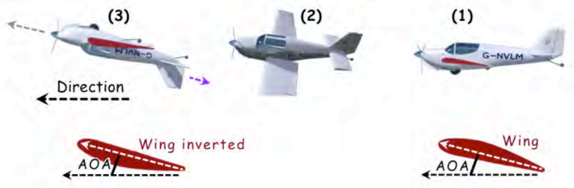

Fig. 9b-ii. Transition from cruise to inverted flight.

Fig. 9b-iii. Inverted flight at extremely low altitude.

Take-off/climb

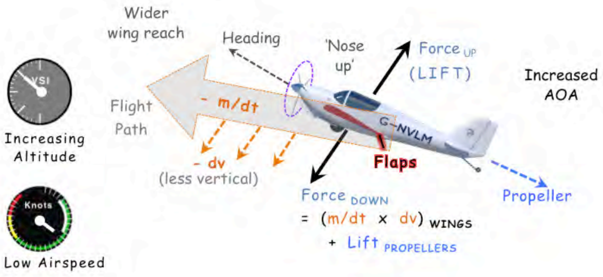

Fig. 9b-iv. Take-off and 'nose-up' climb with flaps extended.

A typical take-off or 'nose-up' climb uses high (maximum) engine power, flaps, and wide wing AOA. Lift is prioritised over airspeed in this configuration. Ideally, the aircraft gains altitude as much altitude as possible, providing a steep ascent at a low airspeed. As compared to cruise flight: See Fig. 9b-iv.

- 'm/dt' is lower due to lower airspeed, despite an increased wing reach from a higher wing AOA. The wings are flying through less air each second, as it is flying more slowly.
- 'dv' is slightly lower due to the slightly lower airspeed and decreased aircraft momentum. The airplane has less momentum to transfer to the air, and less capacity to accelerate the air downwards.
- Also, an increased wing AOA means that the wings push the air down at a less vertical angle, reducing 'dv' and lift, while increasing induced drag.
- The engines (propellers) are angled upwards to boost lift, at the cost of lower airspeed.
- Extending the flaps can increase the wing AOA, curvature (camber), wing reach, induced drag, and lift.

The configuration described above is a typical climb after take-off when the aircraft is fully laden and therefore, has a low airspeed. In contrast, a climb at a high airspeed can increase 'm/dt' and 'dv', and therefore, boost the rate of climb.

The significant difference between the aircraft's heading and actual direction flown, which provides a high AOA, can be observed in airliners taking-off. When airliners take-off close to their maximum take-off weight (MTOW) they struggle to climb and gain altitude. See Fig. 9b-v.

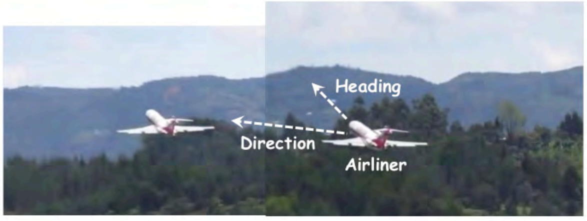

Fig. 9b-v. Example of an airliner taking-off badly; and gaining altitude very slowly.

10. PRACTICAL ASPECTS OF FLIGHT

A. *Overview*

The different practical aspects of flight are explained by Newtonian mechanics based on how the mass of air flown through (m/dt) and the velocity to which this air is accelerated (dv), vary to affect lift (Lift = m/dt * dv), based on the conditions involved. See Fig. 10a-(i-ii).

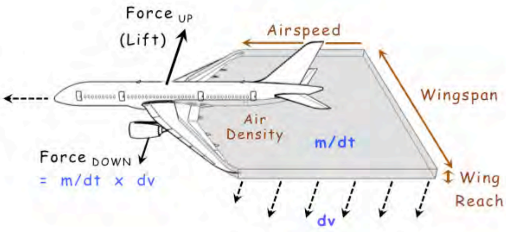

Fig. 10a-i. Newtonian forces acting on an airplane.

The practical aspects of flight include: [2]

- Airfoil thickness.
- Engine positions on the wings.
- Altitude.
- Wind and air currents.
- Hovering.
- Gliding.
- Anhedral vs. Dihedral wings.
- Winglets.
- Pitch control.
- Canards.
- Variable-sweep wings.
- Biplanes and box-wings.
- Delta-wing aircraft.
- Ground effect.
- STOL and VTOL aircraft.
- Supersonic flight and sonic boom.
- Ground spoilers.
- Aircraft carrier ski jumps.
- Angle of incidence (AOI) and wingspan twist.
- Drogue parachutes.
- Wingless aircraft and lifting bodies
- Wing morphing.
- Flexible wings.

Key conclusions:

All practical aspects of flight can be accurately described using the Newtonian explanation for lift (Lift = m/dt * dv). Variations in 'm/dt' and 'dv' change how the lift is generated depending on the circumstances.

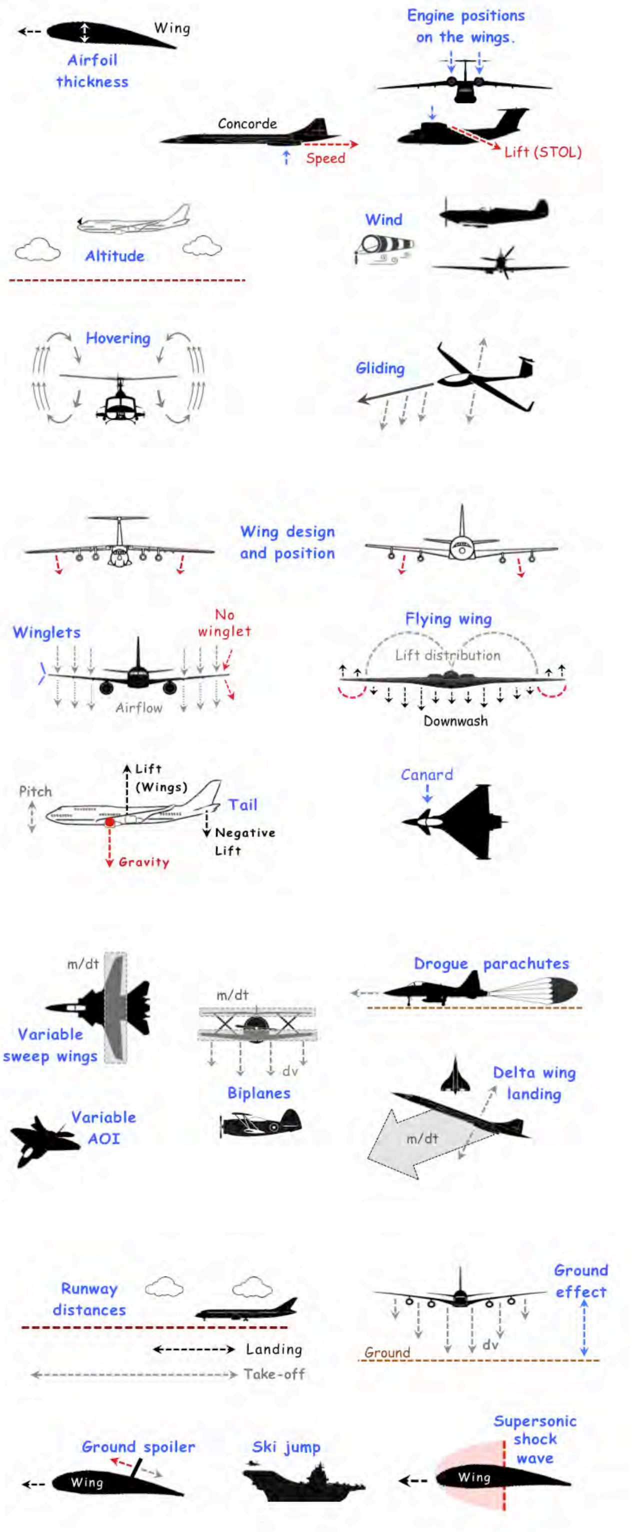

Fig. 10a-ii. Some practical aspects of flight. explained by Newtonian mechanics.

See the full report for the detailed explanations [2]

B. *Examples of practical aspects of flight.*

The ability of Newtonian mechanics to provide simple and straightforward explanations for the practical aspects of flight observed, is particularly significant because fluid mechanics (Navier-Stokes equations) fails to do this.

Consequently, the key insights that highlight the usefulness of the Newtonian approach to understand the practical aspects of flight are summarised below, which include:

- Winglets.
- Airfoil thickness.
- Flying (blended) wing designs.
- Variable-sweep wings.
- Biplanes.
- Delta-wing aircraft landing.
- Ground effect.

These key practical aspects of lift are summarised below:

C. *Winglets.*

The prevailing view is that wingtip (wake) vortices are a by-product of flight arising due to high-pressure air under the wings moving towards the low-pressure air above the wings. Wingtip vortices are seen as a cause of extra drag (especially induced drag) and are detrimental to flight. Consequently, winglets are seen beneficial to lift and flight as they reduce induced drag. [1][47] See Fig. 10c-i.

Fig. 10c-i. Wing-tip vortices. [47]

In contrast to the prevailing view, according to Newtonian mechanics, winglets can be beneficial if they improve the efficiency at which air is displaced downward by the wings. See Fig. 10c-ii.

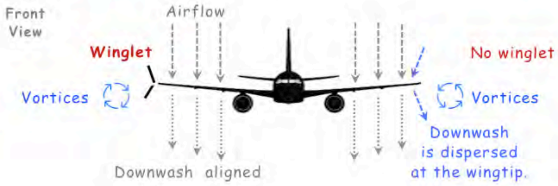

Fig. 10c-ii. Different airflows at the wingtips due to winglets.

D. *Airfoil thickness.*

The importance of wing thickness to the amount of lift generated has been overlooked in the empirical equation for lift and fluid mechanics (Navier-Stokes equations).

In addition, aspect ratios, which are commonly used to measure how efficiently wings generate lift, are inaccurate and flawed because it fails to consider how wing thickness affects lift. Identical aircraft having wings with the same aspect ratio but different wing thicknesses, produce different 'm/dt', and therefore, different lift profiles.

Thin airfoils were common only in the early 20th Century and disappeared quickly afterwards. See Fig. 10d-i.

Fig. 10d-i. Old and modern airfoils compared. [19]

The WWII B-24 bomber was fitted with a relatively thick wing (the Davis wing). It achieved low drag with a short chord and high aspect ratio. See Fig. 10d-ii.

Fig. 10d-ii. Davis wing of the B-24 bomber. [19]

The Newtonian approach solves this problem by taking wing thickness into account, via the wing reach used to calculate lift.

The mass of air flown through each second (m/dt) depends on wing thickness and wingspan, among other things. In turn, wing reach depends on wing thickness and AOA.

Longer wingspans and thicker airfoils (higher wing reach) fly through a greater mass of air each second (higher m/dt), which generates more lift (Lift = m/dt * dv) at subsonic airspeeds. See Fig. 10d-iii.

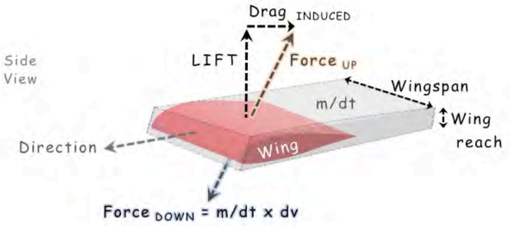

Fig. 10d-iii. Forces on a wing.

E. Flying (blended) wing designs.

According to Newtonian mechanics, flying wings are more efficient than conventional aircraft because wings generate negligible parasitic drag in flight. Integrating the fuselage into the wing and removing the tail section removes the main sources of drag on the aircraft.

More precisely, the lift and drag generated in subsonic flight can be analysed separately between the wings and fuselage: See Fig. 10e-i.

- The **wings** push almost all the air flown through downwards to generate lift, and negligible parasitic drag. However, the wings generate a small amount of induced drag, spanwise drag, and upwash drag.
- The **fuselage** pushes air flown through in all directions, generating parasitic drag and negligible lift.

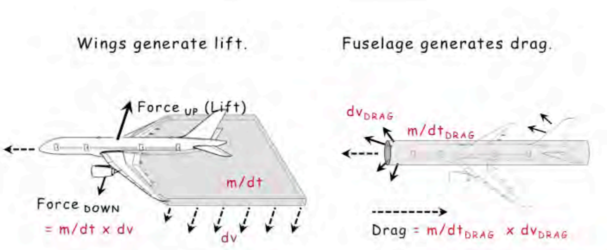

Fig. 10e-i. Wings generate lift, and the fuselage generates drag.

At subsonic speeds, the fuselage of the flying wing acts like part of the wing, reducing parasitic drag and boosting lift, as compared to conventional aircraft. See Fig. 10e-ii.

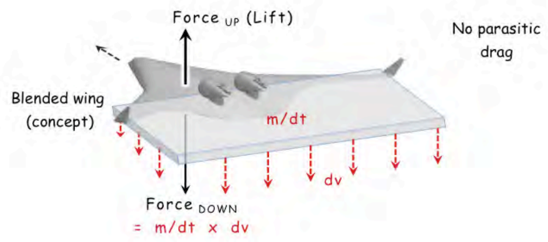

Fig. 10e-ii. Newtonian forces acting on a flying wing.

Flying wing design generates significantly less drag due to the lack of a prominent fuselage and tail section; as compared to a conventional airplane with a tubular fuselage. The flying wing simply removes the main sources of drag from the aircraft. See Fig. 10e-iii.

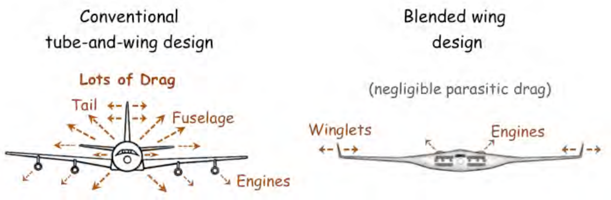

Fig. 10e-iii. The fuselage and tail generate parasitic drag.

The argument above is supported by the analysis of the empirical equations for drag and lift (see Section 8 above), and provides insights, including:

- How a frisbee (disc or flying wing) can be thrown multiple distances further than a baseball (sphere) of similar mass and surface area facing the direction of travel.
- How a swordfish can swim in water at over 110 km/hr, which is faster than a cheetah can run on land at 90 km/hr. In addition, this logic also explains Grays paradox; how dolphins can swim as fast as 40 km/hr.
- This aspect of flight helps to explain why no airspeed or momentum is lost on take-off flare, as airplanes transition from ground roll (generating parasitic drag) to flight (generating lift). See Fig. 10e-(iv-v).

Fig. 10e-iv. Little airspeed is lost on take-off flare.

Fig. 10e-v. Floatplane taking-off from a trailer.

The analysis above also provides the insight that the **Lift/Drag ratios** (L/D ratios), which are commonly used to measure how efficiently wings generate lift are inaccurate and flawed. L/D ratios mostly measure 'Lift / Induced Drag', which is primarily a function of the wing AOA, and not a true measure of wing efficiency due to wing design. This dynamic is evident from the forces on a wing, See Fig. 10e-vi.

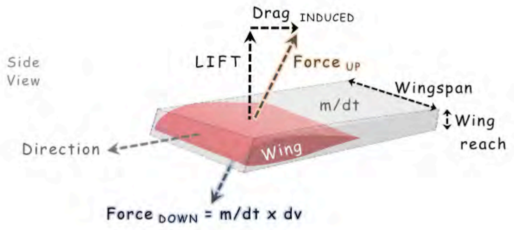

Fig. 10e-vi. Forces on a wing.

F. *Variable-sweep wings.*

Variable-sweep wing designs allow aircraft to adjust the contributions made from ‘m/dt’ and ‘dv’ to generate lift (Lift = m/dt * dv) and to suit the aircraft’s performance requirements.

For example, the US Navy’s F-14 Tomcat uses minimum wing-sweep (maximum wingspan, with the wings fully extended), for low-speed manoeuvers such as short take-offs or landings (STOL) from aircraft carriers. See Fig. 10f-i.

Fig. 10f-i. Variable wing-sweep wing design.

According to Newtonian mechanics, at low airspeeds, a lack of aircraft momentum limits the wing’s capacity to accelerate the air downwards (low dv) to generate lift.

Therefore, to maximize the lift generated and enable flight at low airspeeds, the wings are extended to maximize ‘m/dt’. The increase in ‘m/dt’ compensates for the low ‘dv’. Low-speed flight is important as it allows the F-14 to limit the runway distance required on landing. See Fig. 10f-ii.

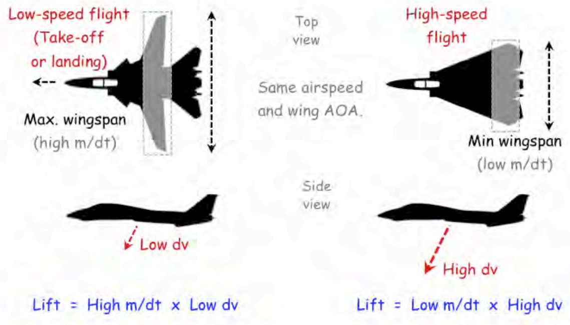

Fig. 10f-ii. F-14 Tomcat wing-sweep positions.

Conversely, in high-speed flight the wing-sweep is maximised (and the wingspan minimised, with the wings retracted close to the fuselage), due to the following benefits provided:

- In high-speed flight lift is not a restriction, as it flies through a high mass of air each second (high m/dt).
- The min. wing-sweep configuration minimizes aerodynamic drag from spanwise flow, and delays the shock waves that arise from supersonic flight.
- At high-speed, the F-14 has significant momentum, and therefore, significant capacity to accelerate air down aggressively (high dv).

G. *Biplanes.*

Biplanes generate significantly less lift per m^2 of wing area, as compared to a monoplane with the same overall wingspan, wing area, and basic wing design. A problem is that there is currently no explanation for this phenomenon and no equation to quantify the effects of a second wing.

According to Newtonian mechanics, this phenomenon arises because a biplane’s wings are aligned above/below each other. The top wing is accelerating the same vertical section of air downwards as the bottom wing. The biplane has half the effective wingspan, which limits the total mass of air displaced down each second (low m/dt). See Fig. 10g-(i-ii).

Fig. 10g-i. Wings accelerate air downwards. [19]

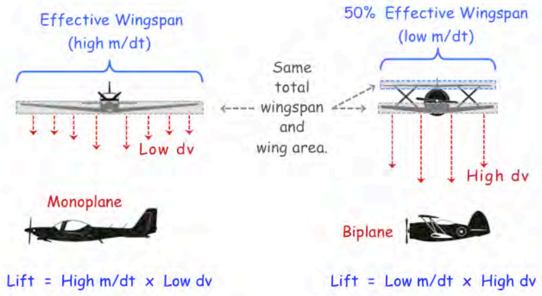

Fig. 10g-ii. ‘m/dt’ and ‘dv’ of a monoplane and biplane.

For example, if a biplane and monoplane’s wings have the same wingspan, wing area, wing AOA, and airspeed; then both aircraft’s wings fly through the same mass of air each second (m/dt). However, the biplane accelerates an air mass that is roughly half as wide (in horizontal distance) as compared to the monoplane.

To generate lift, the biplane has no choice but to accelerate the low mass of air flown through each second (low m/dt) to a high velocity (high dv), as compared to the monoplane; as summarised by the equations:

Monoplanes: Lift = high m/dt * low dv

Biplanes: Lift = low m/dt * high dv

Biplanes’ method of lift generation, which generates lift proportionately more on ‘dv’ than ‘m/dt’, as compared to monoplanes, is energy-inefficient because kinetic energy is proportional to the downwash velocity squared (K.E. = 0.5 mv^2).

H. Delta-wing aircraft landing.

High-speed aircraft favour delta-wing designs, as they prioritize drag minimization over lift generation. The drawback is high stall airspeed arising due to poor lift generation at low-speed manoeuvers such as landing and taking-off. Consequently, delta-wing aircraft can only generate enough lift to land or take-off at high wing AOA, as compared to swept-wing airliners. See Fig. 10h-i.

Fig. 10h-i. Delta-wing aircraft landing at high AOA. [19]

The problems for delta-wing at low airspeeds include:

- The wings fly through a low mass of air each second (low m/dt).
- The aircraft has little momentum, and therefore, little capacity to accelerate downwash (low dv).

Landing at a high wing AOA maximizes the 'm/dt' and allows more of the engine power to be directed downwards to boost the lift generated. See Fig. 10h-ii.

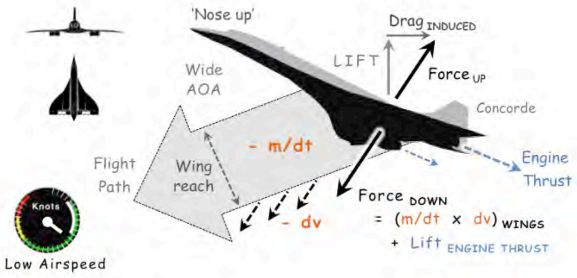

Fig. 10h-ii. Newtonian forces acting on Concorde on approach to landing at low airspeed.

The downside of this high wing AOA configuration is that the downwash is pushed downwards at a more oblique (or less vertical) angle. This dynamic increases induced drag, and therefore, reduces the lift generated. This is because the amount of downwash accelerated in the vertical direction is reduced.

I. Ground effect.

Ground effect is a phenomenon seen where airplanes benefit from extra lift close to the ground. For example, on landing airplanes appear to float temporarily just above the runway; causing the airplane to cover relatively longer distances prior to touching down. See Fig. 10i-i.

Fig. 10i-i. Ground effect observed on landing.

Ground effect can also boost lift on take-off.

Currently, there is no equation available than can quantify aspects of ground effect such as: the vertical distance at which ground effect is significant, how much extra lift is generated, and the extra runway distances needed.

Newtonian mechanics provides a framework to quantify ground effect, based primarily on the downwash velocity (dv) generated by the wings. The ground provides the wings with a more solid surface to push against, to generate lift. See Fig. 10i-ii.

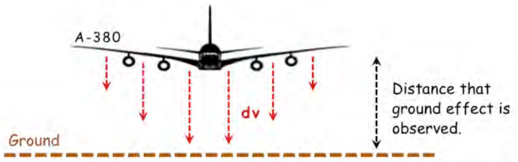

Fig. 10i-ii. Calculation of ground effect distances.

The Newtonian explanation is consistent with the sensation that with ground effect, the airplane seems to float on a cushion of air close to the ground.

The Newtonian approach explains why: See Fig. 10i-iii.

- A glider that generates low downwash velocity (low dv), experiences ground effect only a short distance above the ground, despite its long wingspan.
- A fighter jet (Harrier) that generates high downwash velocity (high dv), experiences ground effect a long distance above the ground, despite it short wingspan.

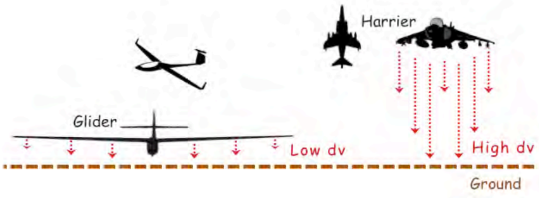

Fig. 10i-iii. Ground effect distances compared.

11. Discussion of Results

A. *Historical perspective.*

Since 1903, commercial aviation grew as aircraft have continuously become better in almost every sense; lighter, faster, bigger, more reliable, more efficient, better controls, cheaper, ….. However, technological progress can be split into two broad periods: 1903-1947, and post 1947.

In the period 1903-1947, airplane performance and design evolved at an accelerated pace, going from simple machines to complex jets with swept-wings capable of supersonic flight.

Biplanes were flying in WWI, in the 1920's monoplanes with thicker wings became the norm, the first jet flew in 1939, the first flying wing flew in 1945, and supersonic flight was achieved in 1947.

After 1947 fundamental technological progress slowed dramatically. Most developments such as VTOL, variable-sweep wings, flexible wings, and hypersonic flight were not incorporated into commercial airliners. This means that the new technology has not been sufficiently economic or beneficial to be used commercially for a profit. Also, many developments merely improved on what already existed.

Aerodynamics and the theories of lift have also not fundamentally changed much since 1947. Thinking has remained dominated by fluid mechanics. Wind tunnels have been replaced by Computerised Fluid Dynamics (CFD), enabled by computers with the software to model airflows. Flying wings appear to be the next logical step in aeronautical development.

B. *Significance of the Newtonian approach.*

Newtonian mechanics based on the mass flow rate (Lift = m/dt * dv) provides a new method to assess how wings produce lift. See Fig. 12b.

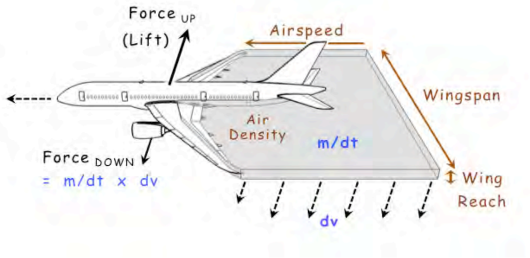

Fig. 12b. Newtonian forces acting on a wing.

This novel approach to lift and flight has not been proposed previously. It provides new and useful insight, including:

- It differentiates between **actively and passively generated forces,** and therefore, the process and direction of the forces generated.
- It identifies that **actual airflows** is better than relative airflow analysis and wind tunnels to analyse lift.
- **It provides an equation for lift that can be applied universally** to all aircraft, birds, insects, and objects that fly by pushing air downwards.
- Identifies that **wings circulate a large mass of air** in flight.
- There's no evidence that disproves these assertions.
- The argument for lift and buoyancy can be tested by experimentation, and therefore, verified or rejected.
- No other theory of lift provides this depth of analysis of lift that is consistent with all the aspects of flight above. For example, fluid mechanics typically only attempts to explain lift for an airplane in a stable cruise flight.

This new Newtonian approach fundamentally changes the prevailing views held for the last 100 years that fluid dynamics explains lift based on relative wing airflow analysis; and that lift must equal the weight of the aircraft (Lift = Weight) to fly. Previous research appears to have simply overlooked key aspects of how lift is generated by an airplane wing,

C. *Benefits.*

The benefits of the Newtonian approach include:

- Allows **lift** (Lift = m/dt * dv) to be more accurately calculated and analysed by differentiating between 'm/dt' and 'dv'.
- Fewer resources wasted on inaccurate methods used to assess lift, such as fluid mechanics (NS equations).
- Provides a method to calculate the **kinetic energy** used to generate lift, which is shown to be proportional to velocity square of the downwash (K.E. = 0.5 mv^2).
- Provides significant **cost savings** by reducing the amount of trial and error involved in **aircraft and wing design,** as well as the extensive amounts of **performance testing** associated with new aircraft. It is possible to more accurately predict wing performance under different conditions (bank angle, AOA, airspeed, ….).

  For example, aircraft manufacturers rely on intuition, trial and error to design and build airplanes. [33] They do not use any one theory or equation for lift. This is partly why Boeing's latest airliners (e.g. B-787) look so similar to their previous models (e.g. B-747). Boeing just tries to improve on the designs that they know work.
- **Avoid costly new aircraft failures** from making inefficient aircraft, such as Concorde and the A-380.
- Better assess proposed new technologies, such as supersonic and hypersonic aircraft, wing morphing, flying wings, ….
- **Design a more fuel-efficient wing.** Aircraft manufacturers can more easily and accurately assess the most fuel-efficient aspect ratio and flight configuration (e.g. wing AOA, airspeed, …) for wings to generate lift under different conditions and priorities.

  For example, at present airliners fly at a standard cruise speed for an entire flight. However, as aircraft mass varies significantly during flight due to fuel burn, the optimum flight configuration varies a lot during the flight. It may be more efficient to fly at a slower airspeed in the earlier stages of a long haul flight.

- **Improve pilot training and aviation safety** by providing a simple, intuitive, and easily understood explanation for lift and flight. If pilots are taught the correct physics of flight, they are likely to crash.

  A better understanding of how airplanes fly could improve pilot responses to a loss of control in-flight and equipment failure. This could reduce the number of uncontrolled descents into terrain; which remain a significant cause of fatal aviation accidents.

- Provide improved **flight instruments**.

  For example, wing AOA is closely related to both 'm/dt' and 'dv', and therefore, the lift generated (Lift = m/dt * dv). Newtonian mechanics provides the intellectual explanation for flying based on AOA indicators, which provide an improved measure of the lift generated. AOA indicators are already installed in many military and commercial aircraft, but are not installed in all aircraft.

- **New developments** can be gained by applying the Newtonian approach described in this paper.

  For example, it is proposed that a glider could circumnavigate the globe against the jet stream, by passively re-directing the relative airflow to generate thrust. In addition, this approach could also be applied to generate thrust by boats or air transport vehicles such as rigid airships (blimps).

- Improve the **reputational image** of aeronautical engineers, physicists, and the aviation industry by resolving the debate on the physics of lift and flight, after over one hundred years of heavier-than-air flight.

- The Newtonian approach **solves a variety of enigmas and conundrums**, including:
  - How a wing generates lift.
  - Why lift quadruples if aircraft velocity doubles.
  - How a glider can soar into wind (dynamic soaring).
  - The lift paradox (thrust-to-weight ratios of 0.3).
  - DDWFTTW.
  - d'Alembert's paradox 1752.

- The Newtonian principles for lift can be applied to **other related areas,** where surfaces (airfoils) actively or passively generate a force. For example designing better propellers, rotors, wind turbine blades, and sails.

No serious attempt to resolve this dispute on the causes lift has been made for a very long time. However, after a hundred years of designing and building airplanes, it is reasonable to expect that academics and engineers should have solved the physics by now. Better late than never?

D. Pilots become better aviators.

The Newtonian approach to lift is extremely useful to enable pilots to become better aviators. Pilots are taught a variety of incorrect theories of lift at present.

Aviation authorities (e.g. FAA, CAA, EAA; …) recommend that pilots are taught a theory of flight based on the Venturi effect and Bernoulli's principles of fluid dynamics. NASA describes this and some theories commonly believed to be true as 'incorrect'. [1] In addition, some academics discredited Bernoulli's theorem as an explanation for lift in airplanes at least as early as 1972. [41]

NASA's website states: "There are many explanations for the generation of lift found in encyclopaedias, in basic physics textbooks, and on web sites. Unfortunately, many of the explanations are misleading and incorrect. Theories on the generation of lift have become a source of great controversy and a topic for heated arguments." [1]

Pilots aren't even taught the prevailing view theory of lift based on fluid mechanics, which is used by most engineers and academics. This aspect is partly because fluid mechanics is mathematically complex and difficult to explain in simple terms.

On the other hand, the Newtonian approach to lift is simple and easy to understand. It is also in line with the Newtonian physics advocated by Wolfgang Langeweische in the book: "Stick and Rudder" (1944). [9] This book is famous among pilots for its accurate, practical and common-sense advice on how to fly an airplane.

E. Newtonian and fluid mechanics are complimentary?

Newtonian and fluid mechanics are often presented as adversarial positions, by offering different explanations for lift. However, they could be used to complement each other.

For example, if fluid mechanics (e.g. CFD) was adapted to measure the mass flow rate (m/dt) and the velocity of the downwash (dv) from an airplane. Then it could be used to help measure lift based on Newtonian mechanics (Lift = m/dt * dv), for each stage of flight, any flight manoeuvre, or any wing design This approach would open up a new area for fluid mechanics and enhance its usefulness to aircraft manufacturers. This is currently not done by fluid mechanics, but it would add significantly to improving wing design and efficiency.

This paper argues that fluid mechanics can explain fluid flow but not the resultant forces, which are explained by Newtonian mechanics. Airflow and the lift force are related but separate. The argument is illustrated by the example of water falling against the ground. In respect of the falling water: See Fig. 12e.

- Fluid mechanics can describe and explain how the fluid flows (e.g. turbulent or laminar, viscosity, ….), but not the resultant force arising.
- Whereas, Newtonian mechanics explains the force exerted by the water on the ground (Force = ma = m/dt * dv), based on the mass flow rate (m/dt) and the deceleration of the water (dv) as it hits the ground.

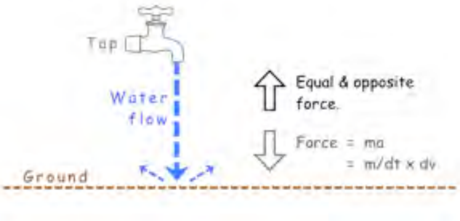

Fig. 12e. Water flowing from a tap.

12. CONCLUSIONS

A. Résumé.

Applying Newtonian mechanics based on actual airflow analysis and the mass flow rate provides a better explanation of how lift is actively generated by wings, than is currently available. This novel approach has not been proposed previously and provides new and useful insight into the physics of lift.

The new Newtonian explanation allows lift to be better understood and more accurately measured. In turn, it can be used to improve: aircraft and wing design, pilot training, computer simulations, and aviation safety.

The consequent financial and economic benefits could be substantial. For example, better wing design could provide large fuel savings. Less time and resources would be wasted on incorrect theories of lift, which provide sub-optimal solutions. Investments to build aircraft that generate lift inefficiently could be avoided. For example, the EUR 25 bn loss associated with the development of the A-380, could have been avoided.

13. ADDITIONAL INFORMATION

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Author Contributions: This paper is entirely the work of the author, Mr. Nicholas Landell-Mills.

Affiliations: None.

Acknowledgements: None.

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Request for financial support: This paper could not have been produced through the established academic and scientific systems. There is no intention to publish this paper or its contents in an academic journal, as then it would no longer be available for free to all. If you found this research to be useful, valuable, informative, entertaining, or otherwise worthy. Then kindly thank, support, and encourage the author with a financial donation via:

- PayPal.com at: https://paypal.me/landell66

Thank you.

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APPENDIX I – UNRESOLVED THEORY OF LIFT

A. The theory of lift remains unresolved. [5]

Fig. I-a. Unknown.

The physics of lift is disputed. There is no scientific experiment on a real aircraft in realistic conditions that conclusively proves any theory or equation of how a wing generates lift to be true.

Experts still cannot agree whether aircraft generate lift by being pulled upwards according to fluid mechanics, or pushed upwards according to Newtonian mechanics; nor exactly what role vortices play. This is surprising given airplanes have been flying for over a hundred years.

Academics, engineers, aircraft manufacturers, pilots, aviation authorities, and other pundits (e.g. NASA) promote over twelve diverse theories of lift. New theories are occasionally proposed.

Worse, there is no accepted universal theory of how lift is generated that applies to all objects that fly. Airplanes, helicopters, birds and insects each have their own unique explanations. Different theories are used to explain lift in different insects. This aspect is highly inconsistent.

B. Media and academic commentary.

The media occasionally comment on the on-going debate about the mysterious, unproven and unknown causes of lift:

- "Staying Aloft; What Does Keep Them Up There?" in New York Times, 2003. [29]
- "How Do Airplanes Fly?" in Live Science, 2006. [30]
- "The secret to airplane flight. No one really knows." in the National Newspaper, 2012. [31]
- "There's No One Way to Explain How Flying Works," in Wired Magazine, 2018. [32]
- "No One Can Explain Why Planes Stay in the Air." in the Scientific American magazine, 2020. [33]

Academic journals occasionally address this issue as well:

- "Quest for an Improved Explanation of Lift," in the AIAA journal, 2012. [34];

The physics of how birds fly is also debated:

- "….to date, flapping flight is not fully understood." [35]
- "….there are still myriad open questions about how animals fly with flapping wings," [36]

C. Academics, engineers, pilots, pundits, …..

Various groups promote at least twelve radically different theories of flight, which include:

- **Academics and engineers** prefer complex models based on **fluid mechanics** (e.g. Bernoulli, Navier-Stokes, Euler, ….). They frequently confuse mathematical proof, wind tunnel experiments or computer simulations (e.g. CFD) for scientific evidence.
- **Aircraft manufacturers and designers** (e.g. **Burt** Rutand) design wings by **intuition, trial and error,** rather than by any particular theory or equation for lift. [33][38][39][40] This aspect is evident from the long list of failed wing designs as well as the unresolved debate on how wing design affects lift performance.

  Similarly, micro unmanned vehicles (drones) are simply built to **mimic bird and insect flight**, without the designers fully understanding the physics involved.
- **Pilots** prefer **Newtonian-based theories of lift**, which correlate to what they experience in practice. Wings push air downward and the reactive equal and opposite force pushes the airplane upwards. Momentum is transferred from the airplane to the air.
- **NASA** sits on the fence in this debate and supports both explanations of lift. "So **both Bernoulli and Newton are correct**." [1] NASA fails to state what proportion of lift is explained by Bernoulli and Newton; 50/50? Or 70/30?

  However, both Newtonian and fluid mechanics cannot be true as they provide very different and incompatible explanations of lift. How can NASA not know which theory of flight is correct?
- **Aviation authorities** (e.g. FAA, CAA, EAA; …) recommend that pilots are taught a theory of flight based on the **Venturi effect and Bernoulli's principles** of fluid dynamics. NASA describes this theory to be incorrect' [1] and academics discredited Bernoulli's theorem as an explanation for lift at least as early as 1972. [41]
- **Other groups** promote a mixture of different theories of lift based on vortices, the Magnus effect, the Coanda effect, …..
- Some experts advocate that the **pressure differential** on a wing explains lift. However, the correlation of pressure and lift on a wing does not prove causality. Pressure is the result of a force (Pressure = Force/Area), not a cause.
- **Empirical observation:** The **factors** that affect lift in practice have been observed and measured; as summarized by the empirical equation for lift: [1]

$$\text{Lift} = 0.5\,(\text{Aircraft Velocity}^2 * \text{Air Density} * \text{Wing Area} * \text{Lift Coefficient})$$

However, this equation only describes the factors that affect lift; it does not explain why these factors affect lift.

In particular, fluid mechanics fails to explain the physics of the empirical equation for lift, but Newtonian mechanics can. For example, only Newtonian mechanics can explain why lift quadruples if aircraft velocity doubles.

APPENDIX II – DEFINITIONS

A. Abbreviations for aircraft.

- A-380 – Airbus 380
- A-320 – Airbus 320
- B-787 – Boeing 787
- B-747 – Boeing 747

B. Abbreviations and definitions of terms.

- AOA – Angle-of-Attack.
- Aspect ratio. Wingspan divided by wing depth (chord). See Fig. II-b-i.

$$\text{Aspect Ratio} \;=\; \frac{\text{wingspan}}{\text{mean wing depth (chord)}}$$

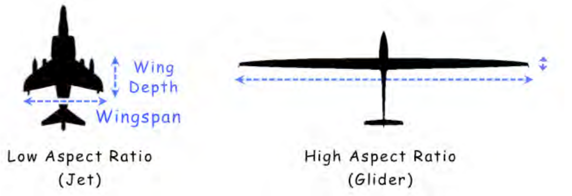

Fig. II-b-i. Aircraft with different wing aspect ratios.

- Chord – Wing depth.
- Engine Thrust – The force generated by the propeller of jet engines by accelerating air backwards, to create backwash and a backward force.
- Flight – when the aircraft or object is airborne (flying).
- The glide ratio is the horizontal distance travelled divided by the vertical distance (altitude) lost an unpowered downward glide, as shown by the equation:

  Glide ratio = Horizontal / Vertical distance
- Gravity – A force towards the ground (or centre of the earth) equal to 9.8 m/s^2 [1].
- Lift – Vertical force pushing the airplane up against gravity; in the direction away from the ground.
- Lift v. Flight. Lift is a force that pushes an aircraft up against gravity. Whereas flight describes the conditions when lift is sufficient for an aircraft to be airborne. It is important to note that an aircraft can generate lift but not fly.
- MTOW – Maximum Take-Off Weight
- STOL – Short Take-Off and Landing.
- Thrust-to-weight ratio – The maximum engine thrust divided by the aircraft's maximum take-off weight (MTOW).

  i.e. Maximum Engine Thrust / MTOW
- Thrust – Engine thrust.
- Weight – Mass multiplied by gravity. [1]

  i.e. Weight = Mas * Gravity (9.8 m/s^2)
- Wing reach = This is a new term that includes the vertical distance facing the direction of travel that the wing influences the air. See Fig. II-b-ii.

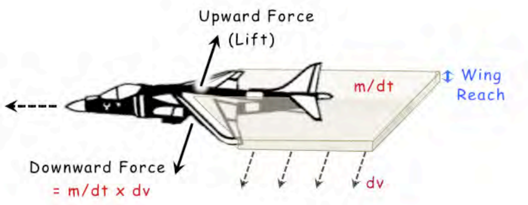

Fig. II-b-ii. Wing reach diagram.

Wing reach includes the air that the wing directly pushes out of its path due to the volume of space that the wing passes through. Therefore, wing reach depends on:

- Airfoil's thickness.
- Wing AOA.
- The air above and below the wing that is directly affected by the wing's path through the air.

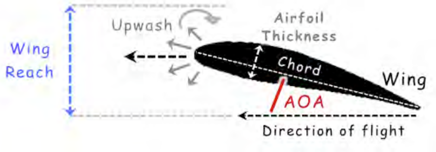

Fig. II-b-ii. Wing reach in a wing cross-section.

Wing reach does not include the air indirectly affected by the wing, which is the air displaced by the air that the wing directly flies through.

Wing reach is a key assumption in the calculation of the air flown through each second (m/dt) by a wing. The greater the wing reach, the greater the 'm/dt', and therefore, the greater the lift generated (Lift = m/dt * dv).

- Wingspan loading. – The amount of aircraft mass (kg) supported by 1 meter of wingspan. This is a similar concept to wing loading, but different. Wingspan loading is a new concept that arises due to the method in which Newtonian mechanics calculates lift (Lift = m/dt * dv).

$$\text{Wingspan Loading } (kg/m) \;=\; \frac{\text{Aircraft Mass } (kg)}{\text{Wingspan } (m)}$$

$$\text{Wing Loading } (kg/m^2) \;=\; \frac{\text{Aircraft Mass } (kg)}{\text{Wing Area } (m^2)}$$

Appendix III – Critique of NS Equations

Overview [3]

The long list of material criticisms shown below makes it is extremely puzzling that anyone would use NS equations or fluid mechanics to explain lift. NS equations are limited as they are simplifications of reality. Therefore, they are only as good as how well the model reflects reality. The NS equations are based on a number of false assumptions, theoretically faults, and (unsurprisingly) fail to adequately explain what is observed in practice. See Fig. III-i-a.

$$\rho \left(\frac{\partial V}{\partial t} + V \cdot \nabla V \right) = \nabla P + \rho g + \mu \nabla^2 V$$

Fig. III-i-a. Part of the Navier-Stokes equations.

NS equations are widely critiqued in publications such as the Quanta magazine, for their theoretical problems and limitations in explaining lift. [55][53][54]

The criticisms are particularly significant given that NS equations have been applied to airplanes for over a hundred years. It is reasonable to expect that solutions and proof should have been found by now.

The high degree of uncertainty surrounding the theoretical basis for NS equations is highlighted by the $1 million award offered by the Clay Mathematical Institute since the year 2000. The award is for anyone who can prove that Navier-Stokes equations explain fluid flow and turbulence. [53]

"Since we don't even know whether these (Navier-Stokes) solutions exist, our understanding is at a very primitive level. Standard methods from PDE appear inadequate to settle the problem. Instead, we probably need some deep, new ideas." [53] This paper asserts that there is no solution to the Navier-Stokes problem identified by the Clay Mathematical Institute.

Despite the criticisms, fluid mechanics (NS equations) is the prevailing method used to model airflows and explain lift by engineers, academics, and pundits.

Description vs. Explanation

There is a subtle but critical difference between being able to describe the dynamics of the lift observed in practice and explaining the physics for why and how lift occurs. For example, the empirical equation for lift:

Lift = 0.5 (Aircraft Velocity^2 * Air Density
* Wing Area * Lift Coefficient)

For example, this empirical equation for lift above describes the relationship between lift and aircraft velocity; where lift is related to the square of aircraft velocity. But the equation does not explain the physics for why lift quadruples if aircraft velocity doubles. Similarly, a significant criticism of NS equations is their failure to explain what is observed in practice.

The criticisms of Navier-Stokes equations (NS equations) fall into the following broad categories: [3]

A. General criticisms.

A.1. NS equations are unproven.
A.2. Multiple NS used to explain lift.
A.3. No agreement on the physics that explain lift.
A.4. No general theory of lift for all objects.
A.5. No universal theory or equation of lift.
A.6. NS equations focus on fluid flow.
A.7. The existence and smoothness problem.
A.8. Excessively complex.
A.9. Little practical benefit to pilots or manufacturers.
A.10. Excessively abstract.
A.11. Cannot compare efficiency of lift generation.

B. False assumptions.

B.1. Low air pressure explains lift.
B.2. 2D models are sufficient.
B.3. Fluid mechanics can explain lift.
B.4. Fluids can be described by a Reynolds number.
B.5. Airflow accelerates due to wing curvature.
B.6. The fuselage is excluded from lift calculations.

C. Faulty logic.

C.1. Logic contrary to how other things move.
C.2. Inconsistent logic with rotors and fan blades.
C.3. Inconsistent logic for thrust, drag, weight, and lift.
C.4. Why the aerodynamic force has a backward angle.
C.5. Exclude wing AOA, induced drag, and stalls.
C.6. Relative wing airflow diagrams.
C.7. Focus on immediate wing airflows.
C.8. Bernoulli and the Venturi effect.

D. NS equations fail to adequately explain:

D.1. Flight manoeuvers. e.g. Inverted flight, ...
D.2. Practical aspects of lift. e.g. Ground effect, …
D.3. Stalls, turbulence, and supersonic shock waves.
D.4. How aircraft momentum can affect lift.
D.5. Dynamic soaring by gliders and albatrosses.
D.6. How bees can fly.
D.7. Prandtl's lifting line theory.
D.8. The empirical equation for lift.
Lift = 0.5 (Aircraft Velocity^2 * Air Density
* Wing Area * Lift Coefficient)
D.9. Optimal wing design – Aspect ratios, wing shape and the energy used to generate lift.
D.10. Aircraft performance data.
D.11. The lift paradox – How airplanes fly with a thrust-to-weight ratio as low as 0.3.
D.12. How vortices affect lift.
D.13. Other enigmas NS equations fail to solve.