

# Describing aerodynamic lift fundamentally wrong for eight decades – Bernoulli reversed

Martin Ingelman - Sundberg

The ICAO/FAA version of "Bernoulli's principle" implies denial of the inertia of mass i.e. of every possibility for lift. Follower theoreticians' misunderstandings of Ludwig Prandtl's geometrical definition of incompressibility caused it.

## 1. A contradiction problem

ICAO DOC 7192, 1985 states that: "increase in velocity causes decrease in pressure". It implies denial of the inertia of mass and Newton's 1st law. (ICAO = The International Civil Aviation Organisation). FAA = Federal Aviation Administration US).

**Daniel Bernoulli, "Hydrodynamica" (p. 258) (1738):** "Hic non tam pressio ex velocitate quam reciproce velocitas si foraminulum in lateribus canalis fiat ex pressione definitur polost".

"Here the pressure can be defined, not so much from velocity, as reciprocally the velocity from the pressure if there is a small hole in the side of the canal". (Bernoulli knew the Newton's 1st law and the concept "inertia of mass").

The lift explanations today are all based on some kind of argument about why the velocity above the wing should be increased and below it decreased, after which the reversed Bernoulli motivates the pressure. The most common ones are

- "Longer distance to travel over the top side in the same time".
- "Squeezing the flow between the top side and infinity compared to a half venturi tube".
- "Circulation" around the wing related to an 1870 misinterpretation of the cut tennis ball".

### Faults:

- No reason why the time should be the same. Lift will itself create a time difference.
- The percentage squeezing will be zero.
- Instead it is the lift that initiates the motions mathematically described as circulation

All those explanations contradict the basic fundament for all aerodynamic effects - the concept of inertia of mass.

Inertia is a daily life experience and it makes understanding lift easy, if denied it will be impossible

Galileo Galilei (1564 - 1642) first observed it and pointed out this property of mass

and Isaac Newton (1642 - 1727) formulated it as his "1st law of mechanics" - "the law of inertia" in 1687. I.e. it means that "every mass will keep its state of motion if not acted upon by an external force".

If you suddenly move a plate with soup to the side, it is the soup inertia that causes it to remain where it was, but now without any plate to support it. When standing in a bus, it is your own 60 - 80 kg mass inertia you feel the effects of, when the bus changes direction or speed. You have to grab a handle not to fall and can feel the necessary reaction force. A cube with side 4 m contains at sea level 80 kg mass of air with the same inertia you felt the effects of in the bus. When two cars collide it is the inertia of their masses that causes forces to occur.

If you move a vertical plate (for example a cutting board through water in your dish basin or bath tube inclined 5 - 10 degrees ("angle of attack") to the direction of motion, both sides of it will be active in accelerating water mass crosswise, one side will get a pressure increase, the other a pressure decrease. You will experience the reaction forces from inertia in both "the pressure side water" and "the suction side water" to start their crosswise motions. If you round the "leading edge" of the board you will see that the flow will follow the suction to higher angles and larger forces. If you put some white peppercorns as indicator on the surface you can learn much about fluid flows.

Already Leonardo da Vinci (1452 - 1519) understood how sails pull the ships

by changing the direction of the (inertial) wind mass. Cayley (1821 - 1895), Lilienthal, Lanchester, Prandtl, Munk and others understood the importance of mass. Also Wolfgang Langewiesche's physically correct pilot book "Stick and Rudder" (1945) should be mentioned here. It seems however as if Prandtl's application of classical hydrodynamic calculation methods became misunderstood by some leading follower theoreticians. Translation errors in a NACA report 116, 1921, can have contributed.

The wingsection in figure 1 was specially selected to show the falseness in explanation a) above.

The physics will be as follows:

- The crosswise accelerations (=flow direction changes), due to inertia forces create transverse pressure gradients, which at the surface add to or subtract from the atmospheric pressure.
- As a result of this, also longitudinal gradients will form and the local longitudinal velocity along a streamline will vary as function of local pressure.
- This, in its turn, initiates variations in the distance between the smoke lines -- observe in that order.
- The flow elements nearest above and below the leading edge will never meet again. A "phase shift" proportional to the lift coefficient will always be created.
- The downward direction change between the leading and trailing edges gives the total lift.

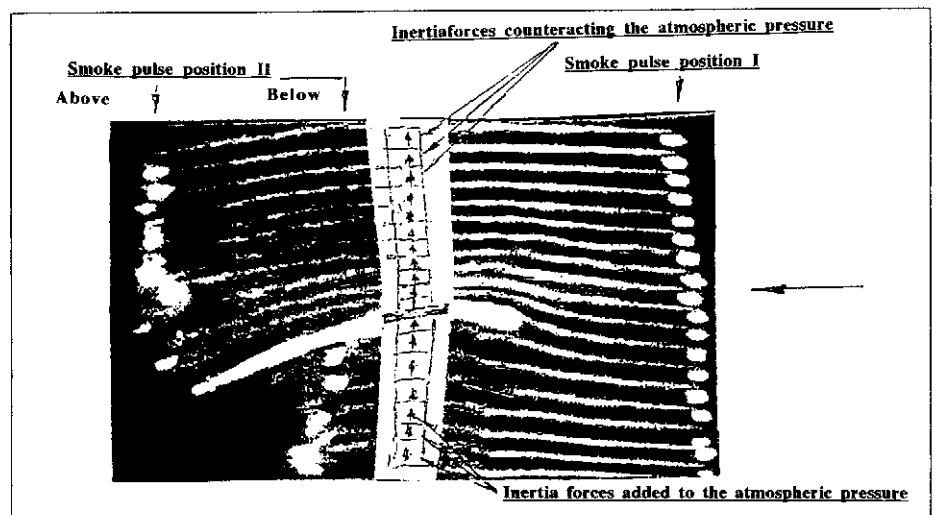


Figure 1. How a wing section works in principle. Photo by the author from the smoke tunnel at The Royal Institute of Technology, Stockholm, 1992.

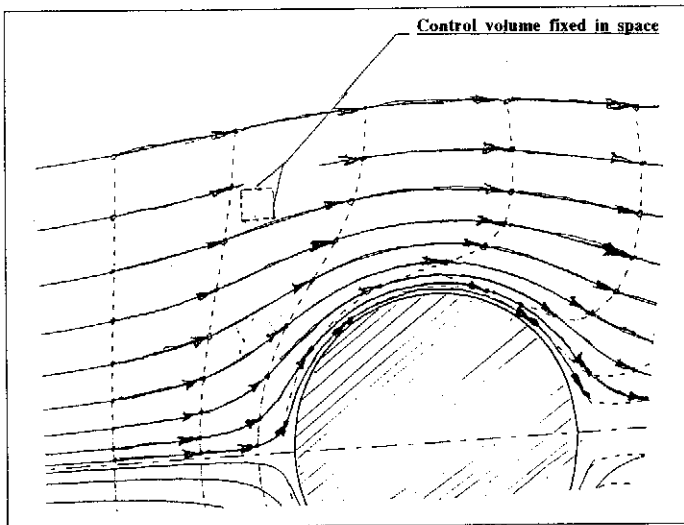


Figure 2. The basic "Euler equation"  $dp = -\rho v dv$  (It is a vector)  
 $\rho$  = local air density,  $v$  = local air velocity,  $d$  = differential

Before any incompressibility mathematics had been misunderstood, Otto Lilienthal, already in 1895, excellently described the physics:

"The air which above the wing flows past in a curved path will through centrifugal forces cause a suction against the surface and thereby create a slight thinning of air. The air which flows along the bottom side will due to its centrifugal "striving" experience a slight compression, which will act as a pressure from below against the surface. Air thinning above and air "thickening" below, or what is the same, the "outward" -force from the above and below in curved path by-flowing air will be the lift force acting on the surface".

("Die Profile der Segelflächen und ihre Wirkung". Zeitschrift für Luftschiffart. 1895, s. 42 - 57.)

### 3. How can the mistake with Bernoulli relation denying inertia have emerged

The air flow around wings and bodies is governed by the laws of mechanics of the general gas law and of the air viscosity in a very complicated manner. For every small air package in the flow field there must be a balance between its inner inertia and external forces acting on it.

Already 1750 Leonhard Euler (1707 - 1783), a friend of Daniel Bernoulli, defined the equations of motion for the flow field (neglecting viscosity) by introducing a kind of fixed "control volume" through which the fluid flows. That the air according to the gas law changes its density made however even these equation impossible to solve before the supercomputer age.

Figur 2

If one only considers a limit case with velocity going to zero the density would be constant and for that special case already a constant volume flow field would satisfy the mechanics. That was shown by Lanchester in England ("Aerodynamics" in

English 1907 and in German 1909). L. Prandtl and F.W. Lanchester met in Göttingen 1908. Even Th. von Kármán was in this meeting. *That this Lanchester knowledge - the basic fundament for the whole linear potential theory - neither was transferred by Prandtl or by von Kármán must be the real cause for the fluid mechanics people overlooking of the concept of the inertia of mass.*

After WW I Prandtl 1918 - 1921 published his wing theory. In this he bypasses the mechanics and goes directly to the criteria of constant volume. He however points out a difference and that the real case is governed by inertia and mechanics but does seemingly not treat this matter sufficiently. He writes that it would correspond to an ideal incompressible inviscid fluid although it can be nothing but a mathematical limit case. No fluid can accelerate without pressure density gradients. The calculations adapt constant volume velocity fields to be tangential to the wing surface and from those velocities pressures are derived via a physically reversed use of the Bernoulli relation.

Very soon after his publication other theoreticians started to talk about Prandtl's ideal flow as if it was a really existing flow of mass. Prandtl's clear warning that the real flow is governed by mechanics seems generally overlooked. Even accepting the constant volume approximation the calculations get extremely complicated and the active persons more mathematically inclined than interested in the physics.

In the US Theodore von Kármán in a trendsetting book "Aerodynamic Theory. Perfect fluids" (1936) leaves the mechanics of his "perfect" very unclear and the impression of an existing fluid becomes enhanced. His lift is based on "circulation" and the reversed Bernoulli and connected to physics with lord Rayleigh's incorrect interpretation, 1870, of the Magnus effect (of the cut tennis ball). In the book "Aerodynamics of the aeroplane" (1941) Millikan and von Kármán gives the "squeezed stream tubes lift explanation" a misleading strength. It was a milestone down.

Both Lanchester and Prandtl, who understood "the moving wall effect" on the boundary layer separation said that "lift must cause circulation". Von Kármán instead turns this all around and writes "the

circulation creates the pressures that gives the lift". It is a kind of "logic somersault" only thinking inside the mathematical model.

### 4. Conclusions

The university teaching in both aerodynamics and fluid mechanics must be reformed. The physics behind the mathematics must be taught. Today aerodynamicists excellently calculate a local pressure change but few can describe the physics. The reason is that the fiction named "perfect fluid" has worked so good for calculations that it has replaced the reality in their mind.

For physical descriptions this "missed knowledge link" however has led to a number of directly misleading "plausible falsehoods" crowned by the inertia denying falsehood contradicting Bernoulli's own writing. When those falsehoods then got prescribed by the aviation authorities they directly have blocked all correct pilot teaching.

It is an irony of fate that all talk about Bernoulli is caused only by the fact that it was not possible mathematically to calculate better. It was accepted although no one ever will get a pressure change from his bicycle pump without changes of its air volume.

The author hopes that this article by connecting lift to everyday life will help the university teachers to see and teach the physical reality. Then today's unnecessary mysticism about lift and flying can be eliminated to the general public. Probably it also can prevent an accident now and then.

### The author

Martin Ingelman - Sundberg was examined from the Royal Institute of Technology, Stockholm, 1947, in Aeronautics. In 1948 he moved to The Aeronautic Research Institute of Sweden, the Low speed Aerodynamics Section with a 3,6 m diameter tunnel, in which most of the development testing for the Swedish Aircraft has been done. During the years 1951 - 1983 he was Head of the section. After his retirement he has performed an extensive literature study to find out how the completely false Bernoulli relation could have got such an immense impact for eight decades. He also continuously has been private pilot during the years of 1947 - 1996 and before that he was glider pilot since 1939.

The background report to this short summary: "The denial of the inertia of mass - a fundamental mistake in eight decades of aerodynamic university teaching" can be purchased for SEK 150 plus tax from the author at address Smedsbacksgatan 5, 115 39 Stockholm, Sweden. Tel/Fax: +46 8 663 66 49