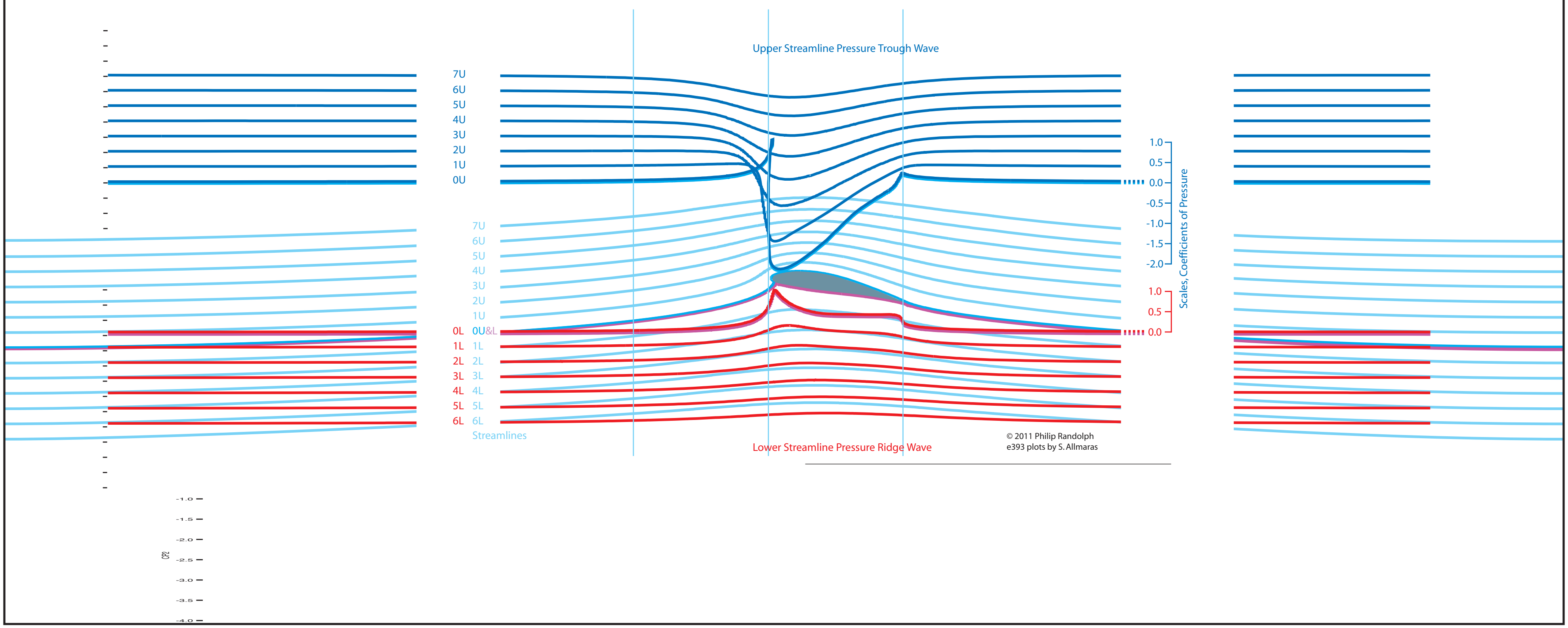
Radio Controlled Soaring Digest

May 2012 Vol. 29, No. 5



Upper and lower pressure waves along streamlines. Energy in springs is stored either by compression or stretch. Waves along a spring are an exchange of momentum for tension or compression. It's the same for pressure gradients — raised or lowered, they store energy, that around a wing is temporarily exchanged for velocity of air, kinetic energy. Such energy patterns are "carried along" in constant relation to the wing, though leaking a little to wingtip vortices. The pressure gradient down toward the low pressures above the wing bends flows down, and keeps flows "attached" to the wing. The equal and opposite force, the difference between low-pressures above the wing and slightly raised pressures below, is lift.

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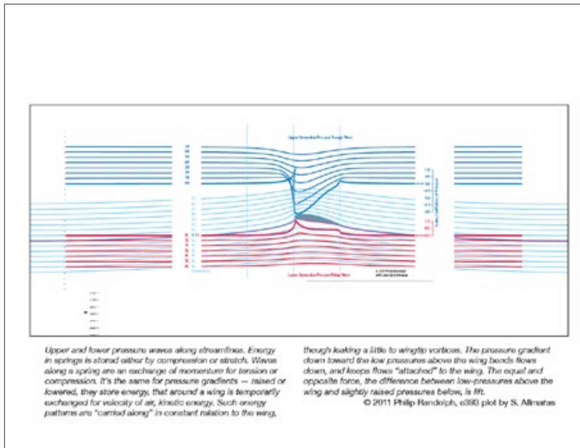

Front cover: A bit different than the usual RCSD cover.
Figure 22: Upper and lower pressure waves along streamlines.
© 2011 Philip Randolph, e393 plot by S. Allmaras.
From the feature article in this issue, starting on page 4.

Back cover: Another shot of Thomas Truffo's Supra soaring over the gentle slopes of Pianoro, Bologna, Italy.
Photo by Francesco Meschia.
Nikon D70s, ISO 200, 1/400 sec., f10, 70mm

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In the Air

Philip Randolph, long time contributor to *RCSD* with articles on dynamic soaring, CEWAMS journals, and other miscellaneous topics, is the author of the feature article for this issue. As is usual with Philip's material, the illustrations are extremely well done and help immensely in getting concepts across to readers. This treatise has been a "work in progress" for more than year, and it truly is an honor for *RCSD* to publish this material.

A couple of upcoming events are worthy of note:

First on the calendar is the Black Eagle Trophy PSS Festival put on by the Two Oceans Slope Soarers, Cape Town, South Africa. PSS or Power Scale Soaring is a description of a non-powered slope soaring glider that is modelled after a real, full size aeroplane that required a power plant for sustained flight and has flown a manned flight as a full size aircraft. This event will consist of the following four classes: Expert Class, Sportsman's Heavy Class, Sportsman's Light Class, and Combat Class. See page 55 <http://www.toss.co.za/index.php/black-eagle-pss-festival/23-black-eagle-pss-festival/18-pss-festival-2012> for more information.

And this year is the first year for a World Championships in F3F Slope Soaring Model Aircraft. It is to be held in Germany in October of this year. See Bulletin 1 <http://www.f3f.de/fileadmin/user_upload/f3f/WC_F3F_2012/12_F3F_WCh_Bulletin_1.pdf>, reproduced in full in this issue starting on page 55.

Time to build another sailplane!

B²

“the wave on the crest of which the aerofoil rides…”

Frederick William Lanchester’s phenomenal, 1894,

WAVE THEORY OF LIFT

Philip Randolph, amphioxus.philip@gmail.com ©2011

The physical-intuitionist who theorized the upwash ahead of a wing, trailing vortices, and vortex drag, who provided the correct explanation for the lift of travelling spinning spheres, first observed by Newton, and who conceptually applied similar ‘circulation’ lift to wings, had one more, incredibly important notion.

Never completely lost, but mainly viewed as a quaint by-product of more influential thinking, it failed to reach public consciousness. It is, literally, the other half of aerodynamics. Supported here by five other wave analyses, it is fact: A wing creates (forces) a wave that both recovers and recycles pressure and velocity energies. In pattern and forces it is oddly similar to surface waves, with upwash ahead rising to a crest, downwash behind. The wing, much like wave-riding canal boats of 1830s Scotland, essentially surfs within these flows.

Lost discoveries of the nineteenth century? Isn’t that like something out of Jules Verne? A superb, physical, intuitive, theory of lift, a theory mathematically compatible with modern, applied aerodynamics — missed, dismissed, and with only a couple exceptions, forgotten? A theory that explains wing energy recovery and efficiency like no other? A tragic turning point in aerodynamic history? A scientist embittered as credit for his ideas went to others, the stature he should have enjoyed perhaps posthumously redeemable by the one invaluable idea to which the aerodynamic paid little attention?

Let’s go straight to conclusions: The modern, ‘bound-vortex/circulation’ theory of lift gave us excellent, applied, mathematical aerodynamics, yet is terrible for understanding flight forces, lift and drag. The more ways one can grasp something, the better. Wave approaches to lift are physically and intuitively excellent for understanding flight, and are consistent with the same applied mathematics. There are also a number of other excellent ways to understand flight, including centripetal/centrifugal forces; most are beyond the scope of this article.

Abandonment of a theory

As the nineteenth century verged into the twentieth, the beginnings of our rather counterintuitive, modern theory of ‘bound-vortex circulation’ lift briefly had a twin. They might have merged into a more complete aerodynamics, for a then-century-old paper could have shown their equivalence. But, as with some newborn bird chicks, hyena cubs, and parasitic wasps, in which siblicide is common, the firstborn theory dominated. The mathematics of ‘vortex-circulation’ lift worked, although conceptually, ‘circulation’ was so difficult to correctly visualize that, for the better part of the twentieth century, wild myths (‘equal transit times,’ the ‘longer-path notion, and associated Bernoulli misinterpretations) persisted. What was more accurate, and invaluable, did not.

For the first four years of developing what has partly turned out to be reinvention,[1] and what he often thought of as '19th century science,' your author wondered why a wave theory of lift wasn't published long ago. It had been. Frederick William Lanchester (1868 - 1946), an English automobile manufacturer, and later the co-developer of military game theory, or 'operational systems, presented his concept of a "supporting wave" as part of his 1894 talk to the Birmingham Natural History and Philosophical Society. A version of the diagram in Figure 1 hung on the wall.[1] Rewritten as the most prescient aerodynamics paper of all time, in 1897 the prestigious Physical Society of London rejected it.[2 3] As did Lanchester, in a longer, slower process.

Lanchester had brilliantly mapped out the forces and flows around wings, his 'peripteral system,' from which the wave and trailing vortex systems were conclusions. Lanchester asserted that the wing wave, like all waves, salvages and recycles energy, greatly decreasing the energy required for flight. He came very close — he had the elements — to describing how it does so, and to assembling his elements into a coherent picture of flight. How he got lost, and where he nearly went, is part of the story.

Lanchester's 1897 paper, with its wave theory, is approximately preserved as the first half of Chapter IV in his *Aerodynamics, Constituting a First Volume*, of two, published in 1907 and 1908. His second book was devoted to stability issues based on models he called 'aerodromes' or 'aerodones' — hence its awkward name, aerodonetics. In these two volumes, dwarfed by 875 pages of erudite verbal haze,[4] are a few time capsules of productively isolated thinking and ideas

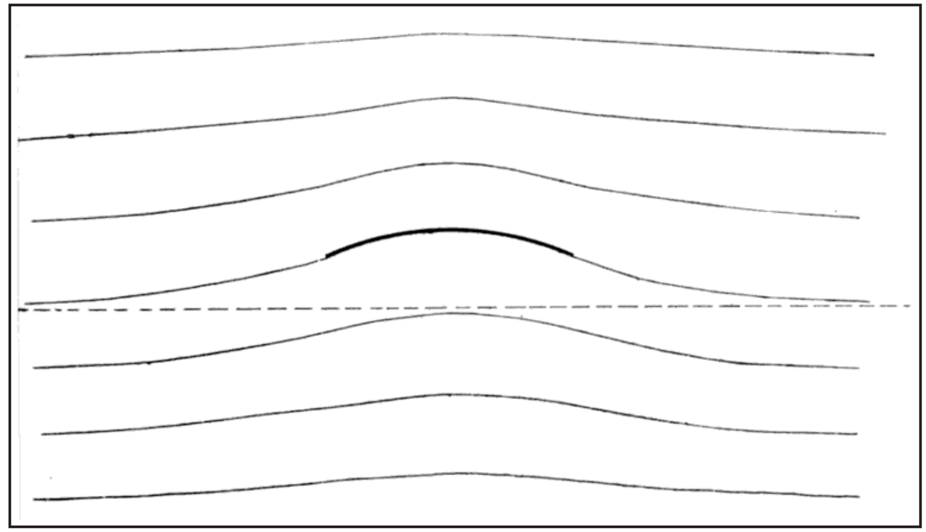


Figure 1: Lanchester's ;supporting wave' diagram, used in his 1894 presentation. He only applied such symmetry and perfect lift to infinitly long wings in inviscid (frictionless), incompressible fluids. The airfoil was curved to match the path of air, to avoid 'discontinuities' at leading and trailing edges, a requirement later known as the 'Kutta condition.' Flows over a subsonic wing in lift always show waveform, with upwash ahead rising to a crest, and downwash behind. © 2011 Philip Randolph

1 Your author found Lanchester, and a short reference to his wave theory, in Olivier Darrigol's superb, *Worlds of Flow, A history of hydrodynamics from Bernoulli to Prandtl*, and immediately ordered his two aerodynamics volumes on interlibrary loan. Since they have been digitized by Google.

that would become fundamental to aerodynamics, including 'upwash' and the trailing vortex system. It also contains nearly his last mention of his wave idea. 'Wave' isn't even a heading in his index.

His first two chapters also contain some of his earlier work, and discussions of streamlined forms and their pressure and energy recoveries, viscosity, boundary layers, all areas where he made at least partial contributions. His first chapter also contains a brief but monumental achievement, the correct analysis of the lift on a spinning ball. This would form the conceptual basis of modern circulation lift theory. And then things changed:

After the rejection of his paper, Lanchester studied Horace Lamb's *Hydrodynamics,* in attempt to rewrite his theory along "more orthodox hydrodynamic lines."

> In the present chapter [IV], on wing form and the motion of the fluid in its vicinity, the main argument and demonstration are taken without substantial alteration from the rejected paper, the subsequent work being a revision of the theory on more orthodox hydrodynamic lines.[5] – Lanchester, 1907

"More orthodox" meant abandoning his wave approach in favor of more counterintuitive concepts of 'circulation,' and 'vortex,' via a deeply flawed, 'circulation' theory of the lift of cannonballs spinning on an axis crosswise to travel, first published by Gustav Magnus, in 1852. (We'll make this difficult 'circulation' concept intelligible.) From what was incorrect for the veer of spinning round shot, Lanchester built the conceptual side of the valid modern theory of 'circulation' lift for wings. (The mathematics of circulation lift was derived independently by Lord Rayleigh in 1877, by Wilhelm Kutta in 1902, and by Nikolai Joukowski in 1906.)

It's a hard transition to watch, a theorist giving up on his own way of thinking in favor of a status quo he mistakenly thought was superior. In 1908 Lanchester met in Germany with the founding fathers of twentieth century mathematical aerodynamics, Ludwig Prandtl and his gifted student, Theodore von Kármán. Von Kármán later wrote, of Lanchester's 1897 paper:

> …these learned societies had turned down a major work. This surprising blunder occurred because Lanchester did not have… formal training in… mathematical form… and hence his colleagues found him difficult to understand. He also had a tendency to make up scientific terms. He called the vortex motion "peripteral motion," and vortices "forced waves."[6] - von Kármán, *The Wind And Beyond*, 1960

> Considered in the light of wave motion, the peripteroid system must be regarded as a forced wave, the aerofoil supplying a force acting from without – Lanchester, 1907[7]

What von Kármán missed, as we'll see via the 1802 wave theory of Franz Josef von Gerstner, is that waveform and 'vortex motion' (circulation) are inseparable. With its upwash ahead rising to a crest and downwash behind, the flows past a wing are in waveform, the sum of vortex 'circulation' plus linear velocity.

That these European aerodynamicists failed to understand Lanchester's wave approach was perhaps the result of one of those odd, geographic splits of scientific consciousness. After 1825, wave theory had become mainly English turf.[8] Toward the end of the century, continental theorists focused on the vortex theory of Hermann von Helmholtz. We'll visit the 1834 English origins of forced wave theory, of which the wing wave is an example. Yet in his native England, Lanchester's work was politely received but mostly ignored. It didn't help that he was a wordy, often unclear writer.

> As Prandtl later put it, 'Lanchester's treatment is difficult to follow, since it makes a very great demand on the

> reader's intuitive perceptions.' Only a reader who would have known the results to be essentially correct [John D. Ackroyd, Oliver Darrigol, and your author] would have bothered penetrating the carmaker's odd reasoning.[9] – Olivier Darrigol, *Worlds of Flow*

Yet despite his prolyx, 'peripteral,' Lanchester's initial focus on the actual flow motions around wings, rather than his later forced conformity to idealized vortex and 'circulation' patterns, was highly productive. Mathematically, Lanchester was not on a par with his colleagues. Conceptually, he was the eight-hundred pound gorilla. But he didn't know it, and allowed himself to be pushed around, and discouraged, by his fellow semi-sapient simian primates. Semi-sapient, as we all are, in the mix of knowledge and ignorance that is progress.

After Prandtl and von Kármán's incomprehension, Lanchester would never again even weakly champion his wave theory.

A century in which wing wave theory quietly sleeps

And herein is the odd split: Throughout the twentieth century, Lanchester's wave theory has been read, occasionally elucidated, even quietly verified, but never particularly valued. It has been as a retrograde zombie, waiting till someone might give it bite, and thus bring it to life.

Lanchester's early and later aerodynamics were always moderately well known and studied, especially in Germany and France, after the translations of *Aerodynamics* in 1909 and 1914, respectively. Credit for much of his thinking came late. It is now recognized that he was indeed the conceptual founder of modern aerodynamics.

We who dig through old ideas are in a way possessed by the authors who speak through us. It is as if the ghost of Lanchester, speaking through his various biographers and aerodynamic historians, rather than belatedly shouting his truth from the rooftops, remained of consistent character, not quite convinced of the importance of his wave theory.

It wasn't that Lanchester's wave theory was unknown. It was more that no one figured out what to do with it. Prandtl, during WWI, had built Lanchester's bound vortex/circulation and trailing vortex system into his 'lifting line' model, the first method of predicting the lift and drag of a proposed wing. See Figure 15. He published in 1918 - 1919. Prandtl got great credit, Lanchester little recognition, till later. But no one converted Lanchester's wave theory into the mathematics of either applied engineering or theoretical aerodynamics. The two authors who did discuss Lanchester's wave theory mentioned it more as a by-product of the early thinking that produced his recognized contributions.

The most extensive examination of Lanchester's aerodynamics was by John Ackroyd, first in a 1992 "Journal Aeronautics" article, that then forms the basis of the first of two chapters in *The Lanchester Legacy, Volume Three*, 1996. The book is rare. For my five bucks, Seattle Public Library's Interlibrary Loans had to have it shipped all the way from Great Britain! Ackroyd validates Lanchester's early thinking and, somewhat in passing, his wave theory, roughly on the centennial of its birth.[10]

John D. Anderson, Jr., in, *A History of Aerodynamics*[11] and in *Fundamentals of Aerodynamics*[12] describes Lanchester's early and later aerodynamics, sans wave. As does Olivier Darrigol, who does briefly mention Lanchester's conclusion of a supporting wave, in his 1995, *Worlds of flow, A History of Hydrodynamics from the Bernoullis to Prandtl.*[13] I found Lanchester through Darrigol in 2008. I'd been writing about wave lift for a few years. The words 'supporting wave' caught me. I ordered Lancheser's two volumes on interlibrary loan, and then found them on Google Books.

All the above authors are excellent. None dragged Lanchester's wave theory into public consciousness.

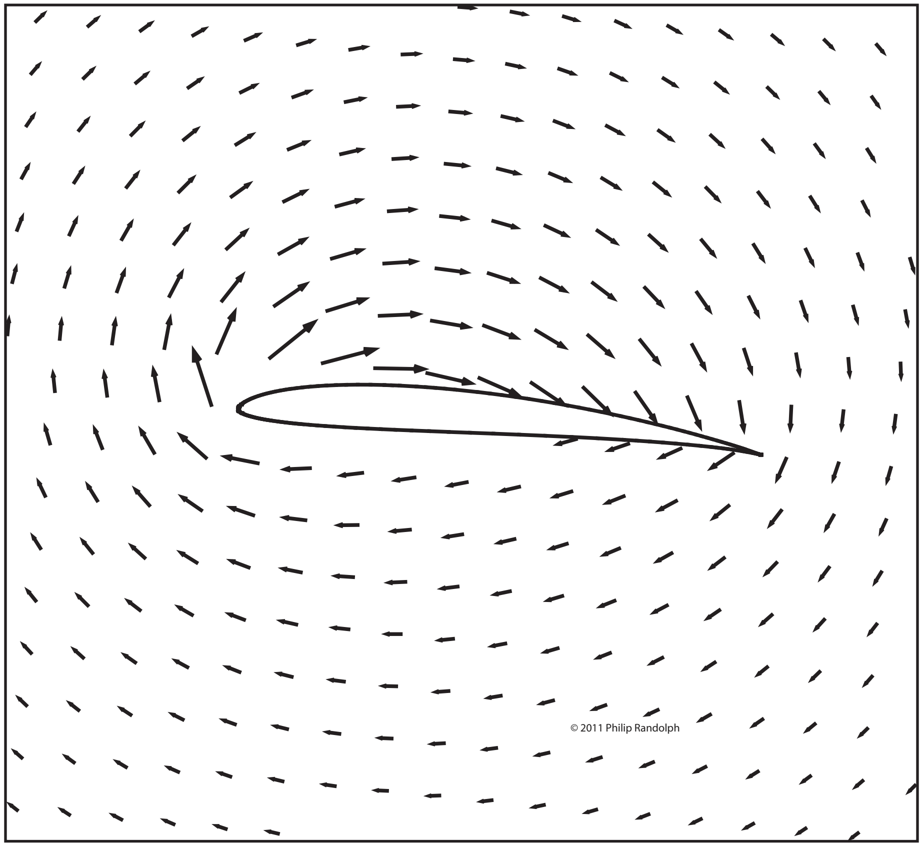


Figure 2: Asymmetrical 'circulation' disturbances of previously still air by a passing wing. This is the pattern a flashbulb would capture, after dark, just as a wing was passing, if the air were filled with cottonwood tufts. © 2011 Philip Randolph

If Lanchester had been someone to doggedly shout his truth, perhaps his fellow gentlemen scientists, Lords Kelvin or Rayleigh, might have suggested that he look at John Scott Russell's 1839 theory of wave lift, for canal boats, or *Franz Josef von Gerstner's 1802 deep ocean wave studies. With those, this article could have been written over a hundred years ago, and the course of aerodynamics changed. If.*

Before looking at Lanchester's wave theory, we'll cover some 'circulation' basics — the convoluted history of the concept, and Gerstner's 1802 theory of the inseparability of 'circulation' and wave. It's a theory that could have integrated Lanchester's wave theory of lift with the surviving concept of 'circulation lift.' Lanchester both failed to widen wing aerodynamics into wave theory, and narrowed it into the mysteries of 'circulation-lift' theory. 'Circulation' worked mathematically. Combined with the academician's attraction to unintelligibility, circulation has gone beyond paradigm to a century of aerodynamic tunnel vision. A sidebar should make wing 'circulation' intelligible. How 'circulation' relates to lift, mathematically or by centrifuging, is another question.

Circulation

'Circulation' was such a mysterious concept that its mathematical relation to lift was correctly established before correct physical concept, either for 'curve balls' or for wings. Here we'll give a correct visualization.

'Circulation' is an instantaneous pattern of 'bound vortex' asymmetrical velocities that sticks with the wing even as its component molecules are left behind.

Watching as air flows in wave-shaped streamlines past a wing is the wind tunnel perspective, and here, the wave perspective. We can also watch air, to see how it is disturbed as a wing passes through it. From this 'previously-still-air,' 'passing-wing,' perspective, we can 'see' the asymmetric velocities of circulation. See Figure 2.[14]

Picture still air full of cottonwood tufts. It's night. We affix a camera to a tall tripod with a motion sensor. The flash goes off just as a long, lightly loaded wing passes. The cottonwood tufts make short streaks, in a pattern of motion around the wing, moving back above (in relation to their previous stillness), down behind, weakly forward below, up ahead. This 'bound-vortex circulation' pattern of motion sticks with the wing, even as its component molecules are left behind. If we photographed again just after the wing passed, the same tufts would be doing something else — going down. New tufts, around the wing, would take over the 'circulation.'

Since circulation is an instantaneous pattern, with no air molecules actually orbiting the wing, there is no requirement for 'bound vortex' symmetry.

As we'll see, upper flows can be separated from lower flows, as if by a steel membrane, without change to either. Then 'circulation' is just another way to say that velocities of curving flows over a wing are strongly but temporarily increased, while flows below are slowed. We'll see how this increases 'centrifuging' of low pressures atop the wing. The difference between these low pressures above and slightly raised pressures below is lift.

Lanchester's main requirement for flow symmetry was that as much air must go up, somewhere, as is thrown down.[15] Air that curls up around wingtips doesn't help lift and isn't part of circulation. Wave upwash air, ahead of the wing, is part of circulation, and increases the centrifuging of the low pressure above the wing. (See the 'Centrifugal' topic.) The difference between low pressures above and higher pressures below makes lift.

Franz Josef von Gerstner, 1802, and the inseparability of wave and circulation

The observation that might have saved Lanchester's theory was not by an aerodynamicist. In 1802 the German

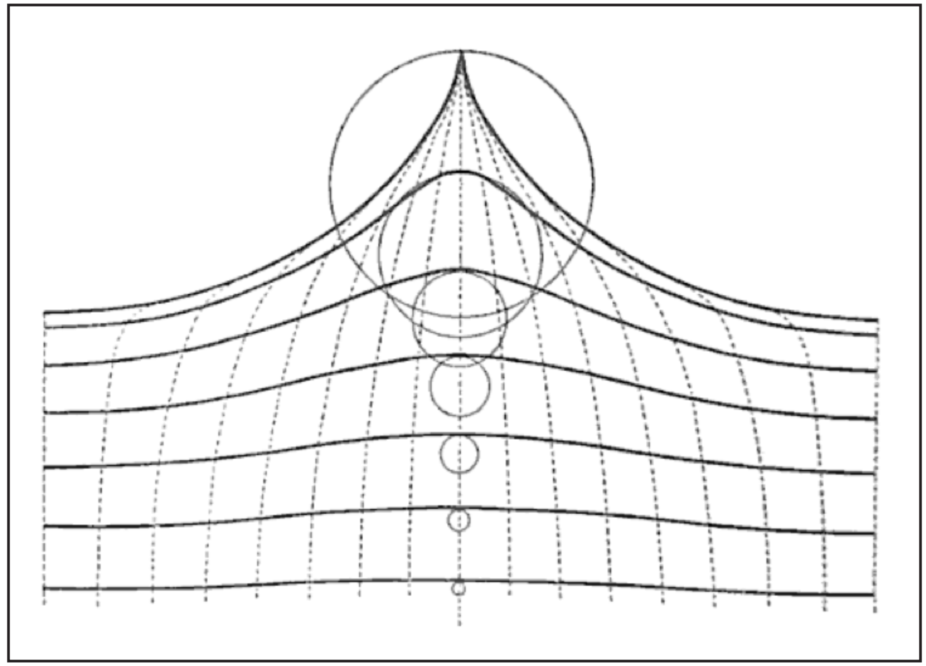


Figure 3: Horace Lamb's 1895 interpretation of von Gerstner's 1802 deep-water wave-circulation diagram As a wave passes, the water that makes it up moves in complete circles, that diminish with depth.

knight-professor Franz Josef von Gerstner published diagrams of the circular motions within repetitive, deep-ocean surface waves. See Figure 3.[16] Loci of water would move forward in the top half of a wave, as they rose to be overtaken by crest, and then fell. In the bottom half of the wave, they'd continue down, moving back, as the trough passed and they again started to rise, completing their circular path. The circular motion diminished with depth.[17] Those who have floated in ocean waves have experienced this. Please see the animation of water waves, courtesy of Dr. Dan Russell, Grad. Prog. Acoustics, Penn State, at <http://www.kettering.edu/physics/drussell/Demos/waves/wavemotion.html>.[18]

Von Gerstner's wave theory remained well known. Papers followed, by gentlemen scientists — John Scott Russell, William Rankine,[19] [2] Lords Kelvin, and Horace Lamb.[3] Sir Gabriel Stokes and Lord Rayleigh proved a slow, forward displacement of particles in such waves, rather than complete circles.[20] (We'll see such horseshoe-shaped 'displacement' paths in how a passing wing disturbs bits of air.)

But 19th century published science tilted toward elaborate calculus, often inadequately balanced by clear statement of concept. A simple, verbal generalization of von Gerstner's wave observation might have changed aerodynamic history: All traveling waveforms contain and are defined by elliptical or partial elliptical motions of the mediums through which they pass. That is, wave and 'circulation' are inseparable.[4]

Further, though without saying 'wave,' most introductory aerodynamics texts include an illustration of how subtracting the 'freestream' velocity of flows (flow velocity far from disturbance by a wing) from the wave-shaped flow over a wing yields the 'circulation' component of motion.

A proof that the math of circulation lift is the math of wave lift

The common 'circulation' applied aerodynamics equations of lift and drag work identically for the wave perspective. Proof: The difference between the two perspectives is a linear velocity, whether viewed as flow velocity or wing velocity. Since it is a constant (unaccelerated, force free), perspective makes no difference in force equations of lift and drag. The equations and all methods of predicting lift and drag are a 'bottom line' for either. The transformation from 'lifting line' or 'Lanchester-Prandtl wing theory' (based on bound-vortex circulation) is merely the addition of a constant velocity (change of perspective), which makes no difference in the output.

For those who took calculus 101: This can also be demonstrated by the most basic of calculus, in which forces are the first derivative of mass times velocity. Recall that in the first derivative, constant velocities disappear. See Figure 4.[21]

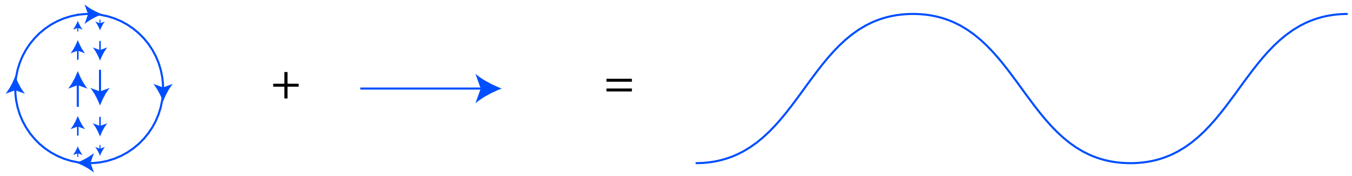
Current supercomputer-crunched, computational fluid dynamics (CFD) often derives the whole velocity field around a wing, in two or three dimensions, and performs mathematical operations on it. The changes of velocity in the field, times density, yield the forces of the pressure gradient around the

2 Rankine's independent equivalent analysis is noted by Lamb, 412.

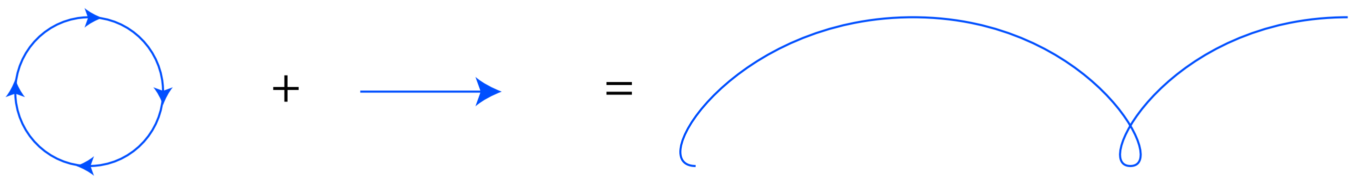
3 Lamb's *Hydrodynamics* illustration of Gerstner's wave circles is on page 412.

4 Waves are classified as 'longtitudinal,' 'transverse,' and mixed, or two-dimensional. Longtitudinal waves have motions and restorative forces parallel to their propogation, e.g., sound waves, typically depicted on the x-axis. Transverse wave motions and restorative forces are at right angles to propagation — e.g., the standing waves on a guitar string, typically depicted on the x-axis. Wing waves and surface waves have a mix of motions and forces, in two dimensions, or more. In longitudinal waves, the y component of the elliptical motion is reduced to zero.

The inseparability of traveling waveform and circulatory velocities



The oscillating, vertical component of a circular motion is a ‘simple harmonic motion.’ Adding horizontal velocity makes a sine wave.

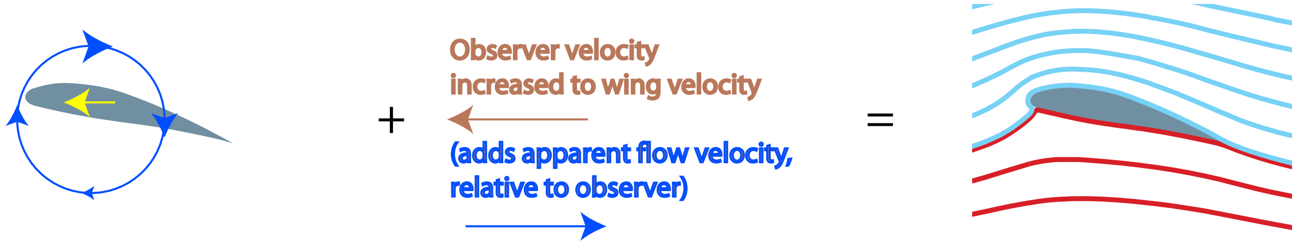


Adding a linear velocity to a circular motion makes a more complex waveform. Lanchester graphed a non-repeating form of this ‘superposition’ of symmetrical circulatory and linear motions, to develop the concept of wing-circulation lift. Actual wing circulation is not symmetrical. The math of circulation lift was independently derived by Rayleigh, Kutta, and Joukowski.

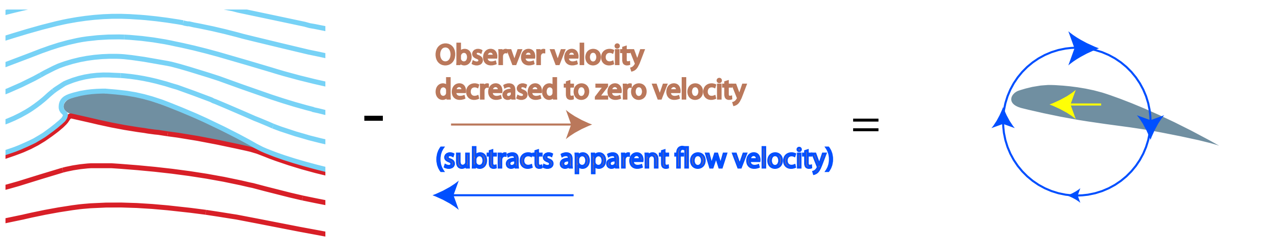
Figure 4A: The inseparability of waveform and circulatory velocities. © 2011 Philip Randolph

Circulation Perspective

Wave/Wind Tunnel/Flow Perspective



'Adding' a linear flow velocity to asymmetrical 'circulation' velocities makes an even more complex waveform, the wing wave. But flow and circulation velocities are insepa-rable. What we really change is the velocity of the observer.



Wave/Wind Tunnel/Flow Perspective
Observer at velocity of wing, watching air pass

Circulation Perspective
Observer at velocity of air, watching wing pass

Conversely, 'subtracting' the 'freestream' velocity from the streaming velocity field around a wing reveals asymmetric 'circulation,' an instantaneous view of how a wing disturbs air as it passes. A linear velocity is always present, whether viewed as flow ve-locity or wing velocity, and since it is constant (unaccelerated, force free), perspective makes no difference in force equations of lift and drag. Thus common 'circulation' ap-plied aerodynamics equations of lift and drag work identically for the wave perspective.

Figure 4B: The inseparability of waveform and circulatory velocities. © 2011 Philip Randolph wing, from which pressures at the wings surface can be derived and resolved into lift and drag. Whether the starting point is the velocity field from the flow perspective (the wave perspective) or from the circulation perspective (the instantaneous velocities of previously still air disturbed by the passing wing) makes no difference.

Circulation theory, from Newton to Lanchester, and then Prandtl

> I had often seen a tennis-ball, struck with an oblique racket, describe such a curve line. For, a circular as well as a progressive motion being communicated to it by that stroke, its parts, on that side where the motions conspire, must press and beat the contiguous air more violently than on the other; and there excite a reluctancy and re-action of the air proportionably greater.[22 23] – Isaac Newton, 1671

Translation: On the side of the ball where its forward motion 'conspires' with the forward motion of its spin, friction drags air forward into previously still air, and pressure builds. This is a very rough form of the Bernoulli equation of the next century, or of a raised-pressure, standing wave, and the best explanation till Lanchester's diagram of unequal flow attachment and centrifuging, which we'll see.

Newton had actually been trying to explain the properties of prismatic diffraction, initially suspecting,

> …if the Rays of light should possibly be globular bodies, and by their oblique passage out of one medium into another acquire a circulating motion, they ought to feel the greater resistance from the ambient æther, on that side, where the motions conspire, and thence be continually bowed to the other.[24] – Isaac Newton, 1671

He quickly determined that light, in the Newtonian world of his darkened room, with a quarter-inch hole in the blind, through which sunlight streamed at his prism, does not curve.

The English artillerist and brilliant experimentalist, Benjamin Robins, included Newton's quote in his 1742, *New Principles of Gunnery.* Robins' study of the 'resistance' and 'veer' of cannonballs were the first quantitative studies of aerodynamic drag and lift, and changed European warfare. Robins observed that a sphere spinning on an axis crosswise to flow would veer (lift) away from the side advancing into flow. He bent a musket barrel to the left, so its ball would gain a clockwise spin, laid it in a 'socket,' and watched as shots curved through successive paper targets. They started to the left, but impacted a wall some 300 feet distant well to the right of where a straight-barreled musket, in the socket, had aimed.[25]

In 1852, Gustav Magnus attempted to explain Robins' results.[26] He asserted that the spin of the ball drags a 'rotatory' flow around it, which, as the ball travels, or as a flow is added, he imagined to persist (true). He was mistaken about the cause of circulation — such viscosity-created circular flows are immediately swept away by linear flows — but he was right about the fact of circulation.

Magnus used Bernoulli's law, uncredited, as a (weak) explanation of spinning ball lift.[27] Bernoulli's law asserts that there will often be an exchange between pressure and velocity. Circulatory flows on the advancing side of the ball slowed linear flows, to which Bernoulli says to expect raised pressures. On the receding side of the ball, circulatory flows added to linear flow velocities, for lowered pressures. The difference in pressures made the ball lift away from its advancing side.

Bernoulli's law seldom provides complete understanding. It's a bottom line of other analyses. It predicts what must be, rather than explaining how that takes place. Lord Rayleigh astutely questioned the application of Bernoulli's law as explanation. Nevertheless, Magnus' causally flawed analysis

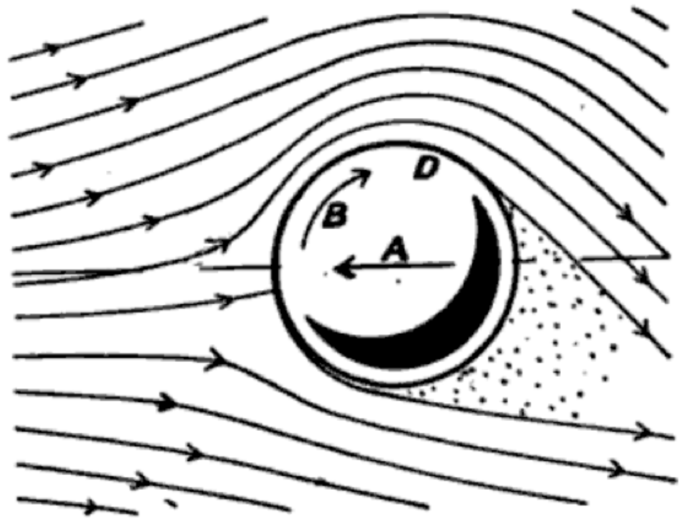


Figure 5: Lanchester's diagram of how a spinning ball lifts, showing both upwash ahead and longer attachment of flows above. He attributed the lift to unequal centrifuging of pressures. Observe strongly centrifuged low pressures atop, weakly centrifugally raised pressures below. Centrifuging is stronger with a tighter, upper radius of flow curves, and upwash ahead and longer attachment aft create a longer, deeper pressure gradient, for a greater cumulative drop in 'upper' pressure.

provided the basis for Rayleigh's 1877, correct mathematics of circulation lift. [28] Rayleigh's formula was essentially the same as Kutta's 1902 equation, and as Joukowski's 1906, better-known, elegantly and deceptively simple equation for circulation lift. Rayleigh applied his lift formula to tennis balls, but not to wings.[29]

Lanchester probably diagrammed his correction of Magnus, who he doesn't mention, in the early 1890s, but published in 1907. His wording needs translation. He wrote,

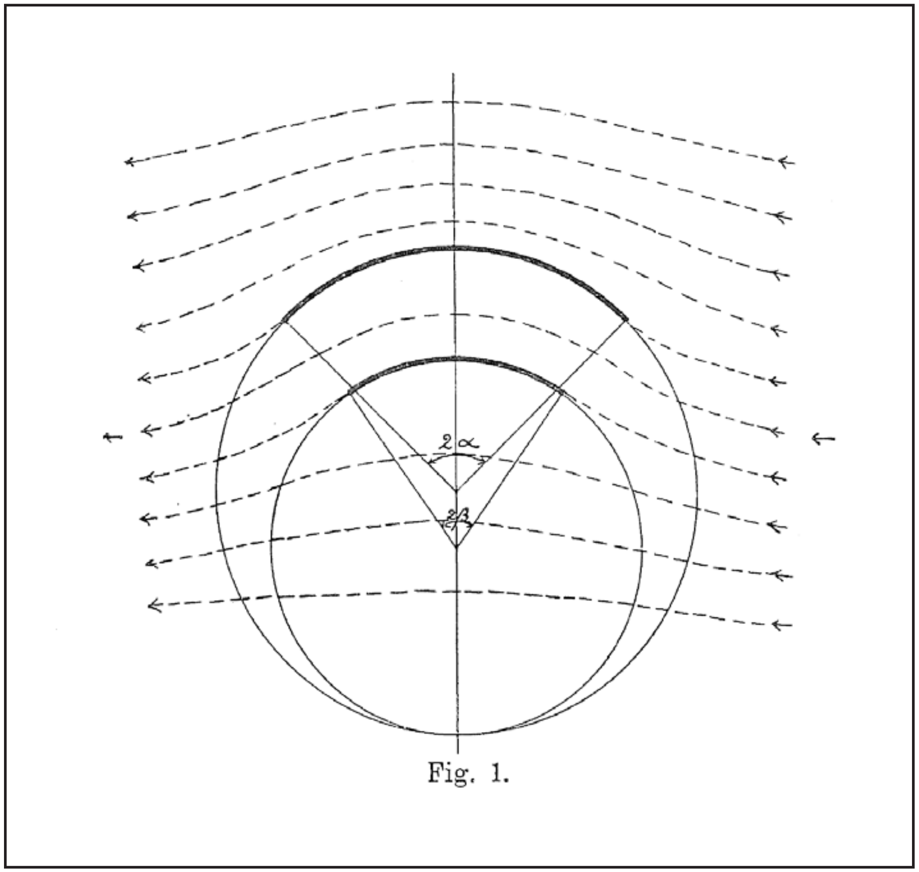
> Now, where the direction of motion of the surface of the ball is the same as the relative motion of the fluid, … the surface will assist the stream in ejecting the dead water…

He diagrammed how flows remain attached longer on the side of the ball where spin and flow align, resulting in a deflection of flows opposite to lift. The unequal attachment makes a longer, tighter curve of flows on that receding side. Lanchester correctly asserted that centrifuging by these curving flows lowered the pressures there, and raised pressures on the side advancing into flow. See Figure 5.

We may (Fig. 22) regard this reaction as the centrifugal effect of the air passing over the ball preponderating greatly over that of the fluid passing underneath…[30] — Lanchester, 1907

Probably independently, Lanchester's diagram also shows a principle stated by Sir Gabriel Stokes in 1845, that if there is a force on an object, there will be an opposite force on the fluid around it.[31] Stokes had made explicit Newton's cryptic, "re-action of the air." Upward lift (of spinning balls or wings) bends air down, a fact not perceived by Magnus and other post-Newton predecessors to Lanchester.

The forces on the lifted objects and on the air are from pressure differences, and a usually minor bit of friction. Within air, pressure differences are pressure gradients.



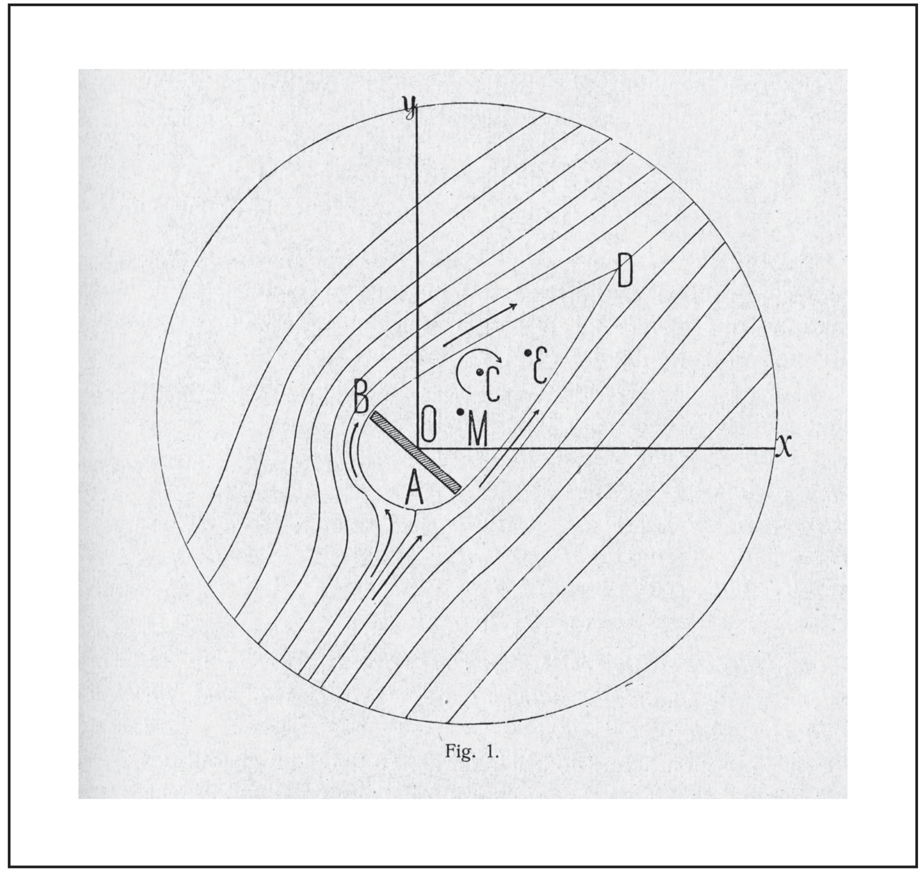


Figure 6: Wilhelm Kutta's 1902 diagram of the lift of a thin, arc wing. With mathematics divorced from concept, he neither recognized waveform nor circulation around a wing, and yet applied a 'circulation' factor to define his flows

Figure 7: Nikolai Joukowski's diagram of the lift of a spinning vane device.

Three theorists independently developed the math of circulation lift. The first, as mentioned, was Lord Rayleigh, for curving tennis balls. In 1902, Wilhelm Kutta developed the math of lift for a thin, arc-shaped wing, a simplified model of the wings of the German glider pioneer, Otto Lilienthal, who had fatally crashed in 1896 after about a thousand brief flights in beautiful, spindly, bat-winged hang gliders. Kutta's math used a 'circulation' term to map out the flow over his 'wing.' Kutta's math, with minimal translation to physical reality, was equally suited to describe waveform or that mystery, circulation 'around' a wing, though he had neither concept![32] [33] In 1906, Nikolai Joukowski independently derived the similar, immaculate and simple formula for circulation lift, but for a flying paddlewheel device.[34] Figures 6[35] and 7.[36]

Jouikowski's elegant and deceptively simple form of the circulation-lift mathematics would become the basis of applied aerodynamics. Joukowski's equation:

$L = \rho\Gamma V$

Where L = lift

ρ = density (rho)

Γ = circulation, a complex term

V = freestream velocity, or velocity of the flying device through air

Like the Bernoulli equation, Jowkowski's equation says what must be, without explaining why, or the particular forces involved. Those forces are pressure times wing surface area, and (Newton and Stokes) opposite pressure gradient forces on air.

In 1910 Kutta acknowledged that the concept of wing circulation was from Lanchester.[37]

Starting in 1911, published in 1918 - 1919, Ludwig Prandtl, using Herman von Helmholtz's vortex theory, built his theoretical mathematical wing theory. It stood on the shoulders of the intuitions of Lanchester, somewhat poorly acknowledged and not always technically correct, and the math of Kutta and Joukowski.[38] See Figure 14.

Oddly, Lanchester must have read von Gerstner's wave-circulation analysis in Lamb,[39] and yet did not use it to integrate his own wave and circulation conceptual theories.

Centrifuging of pressures? An early idea that fell by the wayside

When air rises past a wing's leading edge, its inertia would keep it going straight. It would break away, leaving a vacuum below it. That low-pressure area, in nineteenth century parlance, was called, 'dead water.' This doesn't happen, except in a stall. Air has internal pressure, a force that causes it to expand down toward the wing's upper surface. That expansion is both a bending of the flow and a drop in pressure. It is entirely the internal pressure of air that forces it down toward the surface, making 'attachment' of flows. This downward, pressure-gradient force is in a curving pattern, and so is a 'centripetal' force. The equal and opposite force is an inertial force in a curving pattern, centrifugal force.

> This curvilinear motion of the air particles gives rise to a definite centrifugal force with which the particles below the surface press against the latter, whilst those above exert a suction effect so that both produce a lifting effect.[40] — Otto Lilienthal, *Birdflight as the Basis of Aviation*, 1889

In 1889, Otto Lilienthal drew a sketch of a wing, without that mystery, upwash, and attributed its lift to 'centrifuging.' As we've seen, Lanchester used the concept, at least before he read Lamb. Figure 8.[41]

If you stir your coffee, so it develops a whirlpool, the fluid will pile up against your cup's rim, just as air piles up against the underside of a wing in its curve from upwash to downwash. Your coffee centrifuges away from the center of the curve,

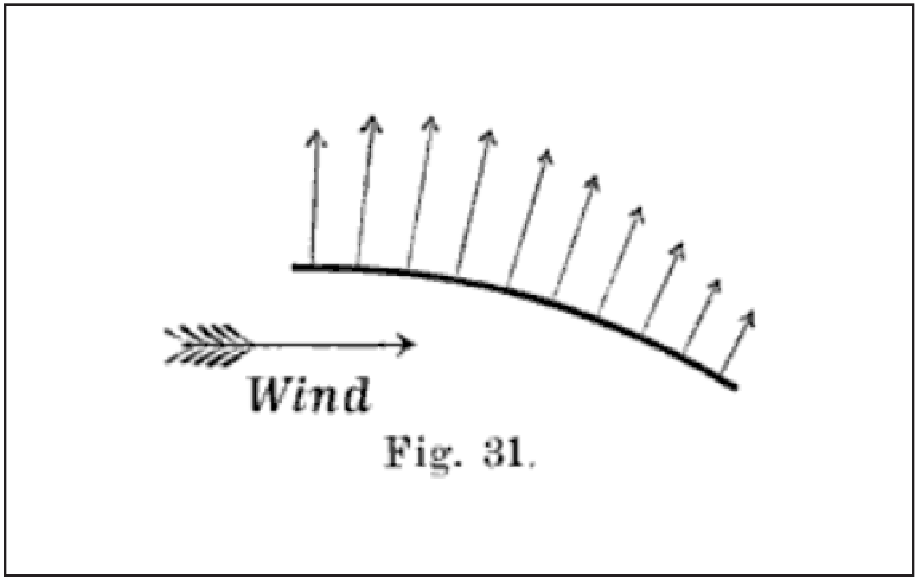


Figure 8: Lilienthal's 1889 diagram of centrifugal lift

lowering pressures there, as above a wing. The profile of the whirlpool is a fairly good map of the pressures of a circulatory flow. Wings are merely gas centrifuges.

The centrifuging of low pressures has not been a central idea in modern aerodynamics. Some physicists even call centrifugal force 'the fictitious force,' or, 'colloquial.' But centrifugal force is the inertial force, the resistance of mass to acceleration, in a curving pattern, by a centripetal force. Inertia is a moderately well established property of matter, called mass. Mass, in the physics of motion, is inertia, the resistance to acceleration by an external force. M = F/a

Following is a form of Newton's second and third laws, that force equals mass times acceleration; the minus sign indicating the equal and opposite force.)

$F_{external} = ma = -F_{inertial}$

$\text{Centripetal Force}_{(external)} = ma = -\text{Centrifugal Force}_{(inertial)}$

Centrifuging of pressure differences is often the best causal, conceptual explanation for what happens around a wing. So why hasn't it been a predominant concept in aerodynamics? It was historically computationally too complex for easy engineering. Only by integrating the whole velocity field around a wing can pressures from centrifuging be calculated. That could be done now, with modern computer models, but other approaches have taken precedence.

Conversely, Bernoulli's equation, with its predictive simplicity, dominated applied aerodynamics. Again, Bernoulli's equation just says that along a streamline, usually there is an exchange of pressure energy for velocity (kinetic) energy.

However: In a 1999, online paper, "The Physics of Flight - Revisited" two physicists, Weltner and Ingelman-Sudberg, derived Bernoulli's equation for curving flows.[42] Centrifuging is thus a valid underlying explanation for the Bernoulli prediction of the low-pressure atop Lanchester's spinning sphere or atop a wing.

Trap: Bernoulli is a result, a bottom line, not a cause or explanation of anything. The explanations are within its derivations, of which there are three: Conservation of momentum, conservation of energy, and centripetal forces, or centrifuging.

Lanchester's 1894 wave theory

To read Lanchester's *Aerodynamics* is like looking into a giant kaleidoscope. Gems are hidden within voluminous prolixity and innovative approaches, even in the following synopsis. Hang on.

Lanchester, in 1892 or so, drew a sketch of the flows upward around the edges of a vertically sinking, flat plate. He called the flows a 'vortex fringe.'[43] His diagram is functionally identical to an 1867 diagram by William Thomson, Lord Kelvin, that we'll call a 'sinking vortex.' See Figure 9.[44]

Figure 9: Kelvin's diagram (in black) of a traveling vortex (sinking, here), illustrating Lanchester's vortex sink flows. It is functionally similar to the previous sketch by Lanchester. Picture a smoke ring travelling downwards. The middle sinks, forced down by the weight of the passing plane. The great mass of slow, downward-moving air in the center is balanced by more rapid, upward motion around wingtips, and slower, upward motion further out, so air doesn't 'accumulate' (Lanchester's word) below. All subsonic airplanes fly in sinking air. Thus all airplanes sink. All airplanes angle upwards to maintain level flight.

Paradox: A wing always encounters rising air, the upwash of the wave, so where's the sink? The wave itself sinks, surrounded by the upwash of Kelvin-Lanchester sinking vortex.

If you drop a stone, it forms this sort of vortex, and sinks rapidly. An airplane would sink like a rock if it weren't zipping forward. A small plane's wing passes an air molecule in a few hundredths of a second — not enough time for vortex sink to gain much velocity. Thus airplanes sink slowly.

Forward speed means a plane accelerates a tremendous volume of air per second, slowly, in the sinking vortex pattern, to create the pressures of lift. Energy use is inversely proportional to velocity squared, so accelerating this large mass of air slowy is much more efficient than swirling a small amount of air rapidly.

Lanchester drew pictures of the symmetrical 'acceleration fields' that make such upward flows.'[45] In modern terms, Lanchester's 'acceleration fields' are the forces on air by pressure gradients. See Figure 10.

He then considered wings of infinite span — both infinitesimally loaded, flat plate, 'aeroplanes,' and lightly loaded, under-curved 'aerofoils' — sinking in an incompressible, frictionless (inviscid) fluid. He reasoned that, at velocities less than the speed of sound, as such wings also moved forward, this symmetrical acceleration field would persist. (That is basically true. Compare his 'acceleration fields' with the pressure gradient forces in Figure 11.)

As the aeroplane approached a lower, stationary particle of air, the air particle would be accelerated up and forward, below the wing. Since the acceleration field was symmetrical, its velocities would be precisely reversed as the aeroplane passed. The air particle would be left in its 'initial state,' at rest, keeping no motion energy. The energy of motions created by the acceleration field would stick with the wing.

Lanchester left it up to the reader to figure a similar pattern of upwash, backward acceleration, and symmetrical reversal of accelerations above the wing, though that is where exchanges in the forms of energy, as pressure gradients and velocities, and as energy recoveries, are most concentrated. Figure 12.[46]

He wrote:

> …the motion imparted to the fluid is eventually given up by the fluid both in respect of its vertical and horizontal components, and consequently there is no continual transmission of energy to the fluid, and no work requires to be done to maintain the motion or to support the plane.[47]
>
> The system of flow…may be classified as a conservative system, the energy of the fluid motion being carried along and conserved just as is the case in wave motion. The motion round about the plane may thus be considered as a supporting wave.[48]

It is this assertion of wave (motion) energy conservation that makes Lanchester's theory invaluable. It explains part of how subsonic wings can be so incredibly efficient.

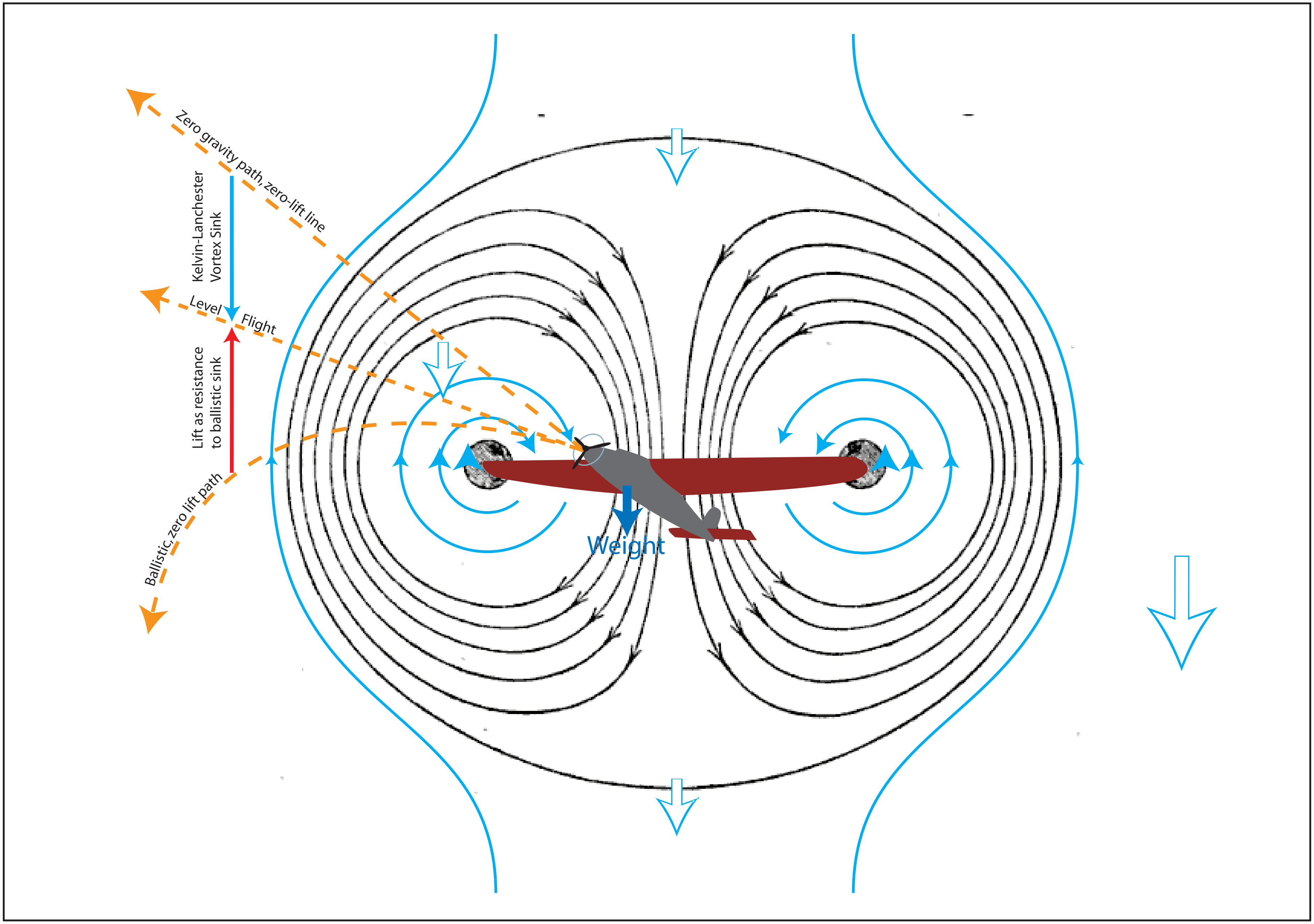
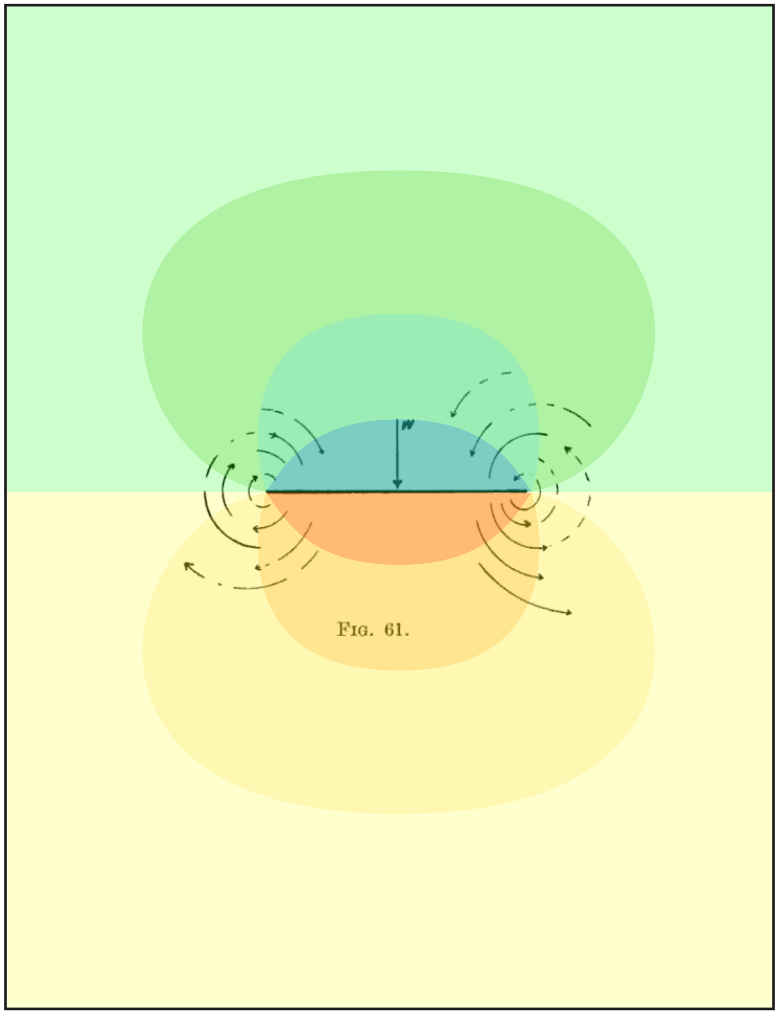


Figure 9: Kelvin's diagram (in black) of a traveling vortex (sinking, here), illustrating Lanchester's vortex sink flows. © 2011 Philip Randolph



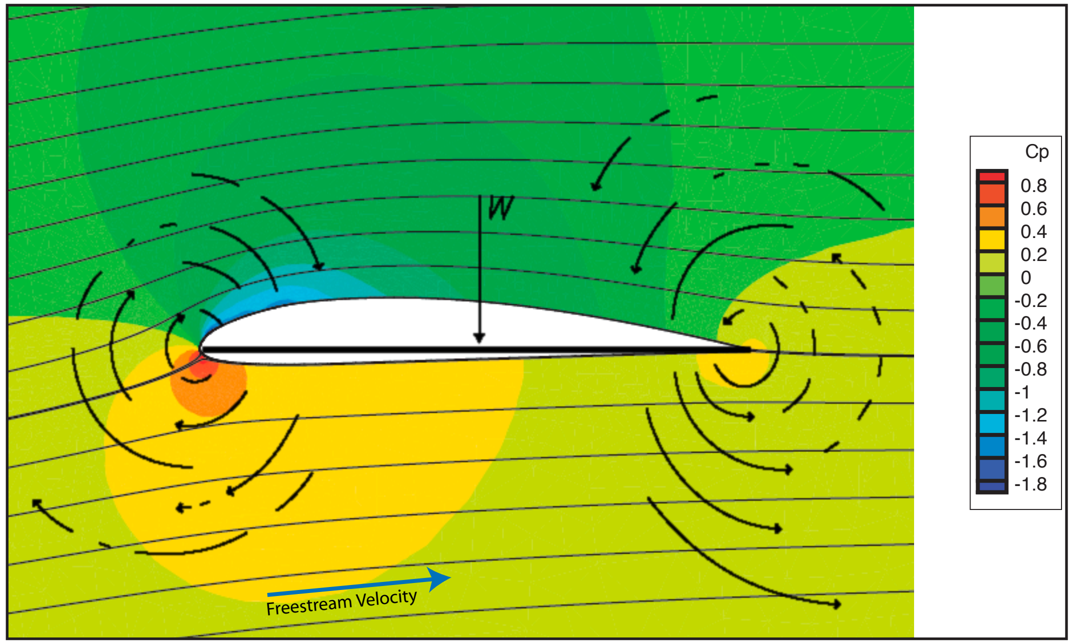


Figure 11: Lanchester figured his ‘acceleration fields’ would persist even as his flat plate ‘flew’ forward and down, approximately true. A reproduction of Lanchester’s early diagram of a gliding, flat plate and ‘acceleration fields (black) is superimposed on a pressure ‘isoline’ plot around a modern airfoil. Lowest pressures are in cool colors, highest pressures in warm colors. Pressure gradient forces are at right angles to pressure ‘isolines,’ lines of constant pressure. Lanchester’s diagram is qualitatively accurate. It also shows the forces that create upwash ahead and slow downwash aft.

Figure 10: The equivalence of Lanchester’s ‘acceleration fields’ and pressue gradient forces. Lanchester’s early diagram (in black) of a vertically sinking, flat plate. Superimposed are pressures (not to scale). Lanchester’s ‘acceleration field’ arrows show the pressure gradient forces from highest pressures below (red) to lowest pressures above (blue), that slow the plate’s sink.
Lanchester asserted that the acceleration fields would persist, even if the flat plate ‘wing’ were flying, or gliding — in this picture, moving to the left, as well as sinking. The symmetry was, of course, an idealization. But Lanchester’s idea was correct. Compare this figure with the following pressure plot around a modern airfoil.

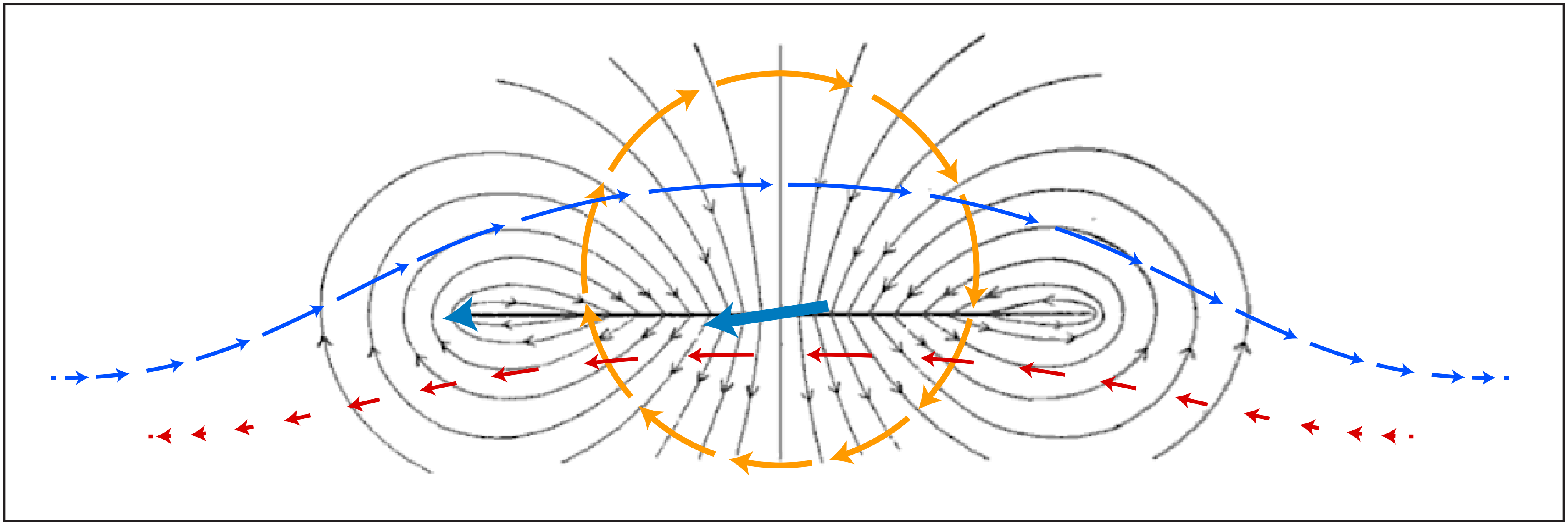


Figure 12: The path of a particle over a wing, through symmetrical 'acceleration fields,' showing wave 'motion energy' conservation. © 2011 Philip Randolph

Lanchester's third diagram (in black) of the symmetrical acceleration fields around a sinking, infinitely long, flat-plate wing. (His first such sketches, probably from around 1892, are similar but less aesthetic.)

In modern terms, these 'acceleration fields' represent the direction of pressure gradients resulting from the vertical sink of the flat plate. The acceleration fields persist as the wing also moves to the left. We are watching how air is disturbed as the wing approaches and passes.

Lanchester asserted that a particle of air (red) that the wing will pass above is first pushed forward and up by the acceleration field, and then is pushed down and slowed, till it again has zero velocity. Air (blue) that the wing will pass below is sucked up and backwards, and then pushed down and slowed, till it again has zero velocity. No motion energy is left behind. Thus Lanchester showed "the energy of the fluid motion being carried along and conserved just as is the case in wave motion."

The path of air through Lanchester's 'acceleration fields' also explains why there is upwash ahead of wings. Paths shown are for illustration, and are not realistic for a flat-plate wing. Since actual paths would be distorted by turbulence at leading and trailing edges, Lanchester then required an arc shaped wing, to conform to the curve of air.

In our modern understanding, lower air is displaced forward less than upper air is displaced back, so circulation velocities (orange) are lower beneath the wing. Lanchester's concept of circulation came later, published in1907, but with the circulatory component inaccurately described as symmetrical.

Lanchester used the same diagrams (in which the observer must imagine the wing travelling away, into the page) to show how the acceleration fields resulting from 'sink' create wingtip vortices.

What Lanchester left out, or only implied, was that pressures (or acceleration fields) also largely recover near the trailing edge. We'll see that Lanchester's argument is equivalent to the more standard, centuries old concept of 'pressure energy recovery' around streamlined objects. The more complete reality is energy form recovery, where pressure and momentum energies vary and restore inversely, till near the trailing edge of a wing each is approximately restored.

As we'll see, the wing doesn't carry much total energy along with it. Above the wing, which is where most of the action is, there is a pressure gradient from ambient pressures ahead to centrifugally lowered pressures above to ambient pressures aft. The pressure gradient temporarily speeds flows along streamlines, increasing motion energy. Pressure energy gets used up temporarily increasing 'motion energy' till collisions with slower air aft again restore pressure and slow flows. The total energy of any bit of air stays roughly constant as it whips along an upper streamline. So energy isn't carried along by the wing, mostly. See Figure 13.

What is actually carried along is a pattern of exchanges between pressure energy and motion energy, in which low pressure energy and high velocity energy above the wing, and slightly raised pressures below, make the pressure imbalance between the wing's upper and lower surfaces — lift.

Lanchester had started his forward-moving-and-sinking (gliding) wing argument with a flat plate wing of infinitesimal weight, as a greater weight would make a greater acceleration field and greater curvature of flows. The curving flows would make 'surfaces of discontinuity' as they broke over the edges of the flat plate. He therefore suggested that with small but finite weight, the plate would need to be curved, to match the curve of flows, with greater curve needed to support greater weight. Hence his 'supporting wave' diagram. See Figure 1. He asserted that there is a balance between velocity, weight, and wing curvature (camber) that would avoid such 'discontinuities,' and thus allow perfect, symmetrical lift. His requirement of avoiding discontinuities was qualitatively equivalent to Wilhelm Kutta's 1902 requirement of tangential flows at leading and trailing edges, now called the 'Kutta condition.' Lanchester suggested that the flexibility of bird feathers achieves this in nature.[49]

Then Lanchester considered finite wings. As they moved forward while slowly sinking (a glide), he asserted that the same, surrounding, upward acceleration field (pressure gradient) that makes a wave-shaped flow over a wing also makes flows up around wingtips, creating his now familiar wingtip and trailing vortices. Only energy lost to wingtip vortices need be replaced. See Figure 14.[50]

> Thus in the case of a loaded aerofoil of finite lateral extent, there is a continual loss of energy occurring, and a source of power is consequently necessary to maintain the aerofoil in horizontal flight.

For Lanchester, 'upwash' ahead of a wing was both fact and enigma. He summarized an earlier argument, that lift is both from slowing upwash momentums and then from accelerating that air downwards.

> The immediate function performed by the sectional form of the aerofoil is to receive a current of air in upward motion and impart to it a downward velocity…[51]

The benefits of 'high aspect ratio' wings were originally recognized by Francis Wenheim, inventor of the first (1871) wind tunnel. They were later quantitatively studied by by the Smithsonian's Professor Langley, and later yet tried by Horatio Phillips in his 'venetian blind' flying machine attempt. Lanchester referenced Langley in his assertion that longer wings of "great lateral extent" have lower losses (essentially, to wingtip vortices):

> … approaching more and more nearly to the ideal case in which the conservation is complete, and

Total energy along upper and lower streamlines

is best observed from the perspective of how a passing wing disturbs previously still air.

Energy remains constant along upper streamlines. Pressure is used up accelerating flows (backwards).

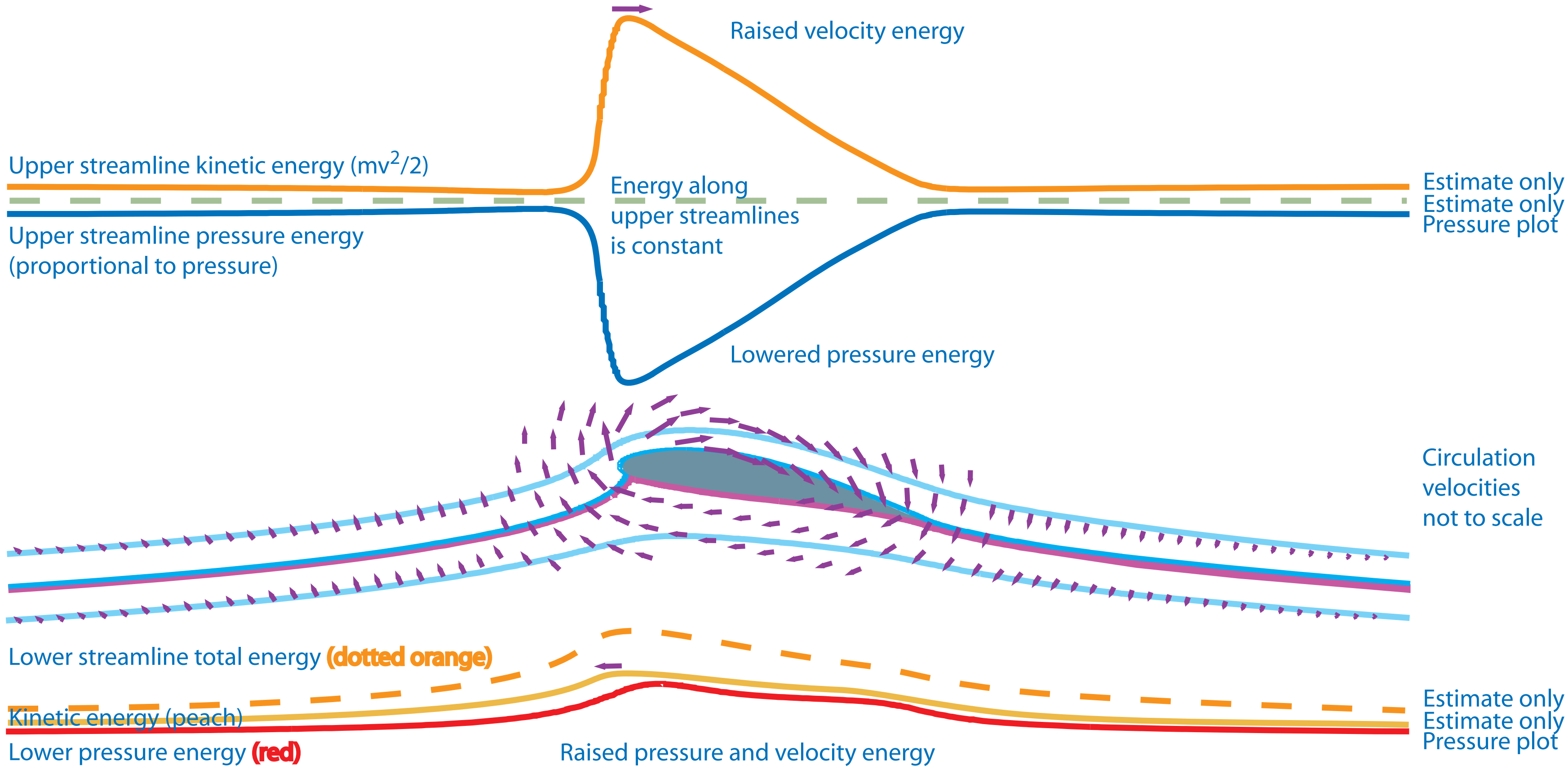


Figure 13: Total energy along upper streamlines is constant. Energy along lower streamlines is raised by a standing, raised pressure wave. Raised energy is carried along beneath the wing in the lower, pressure and momentum ridge wave. Along lower streamlines, pressure and velocity are simultaneously raised.

This is typical of raised-pressure waves, which, like tsunamis, carry raised total energy. © 2011 Philip Randolph, 10° e393 streamline and CP plots by S. Allmaras

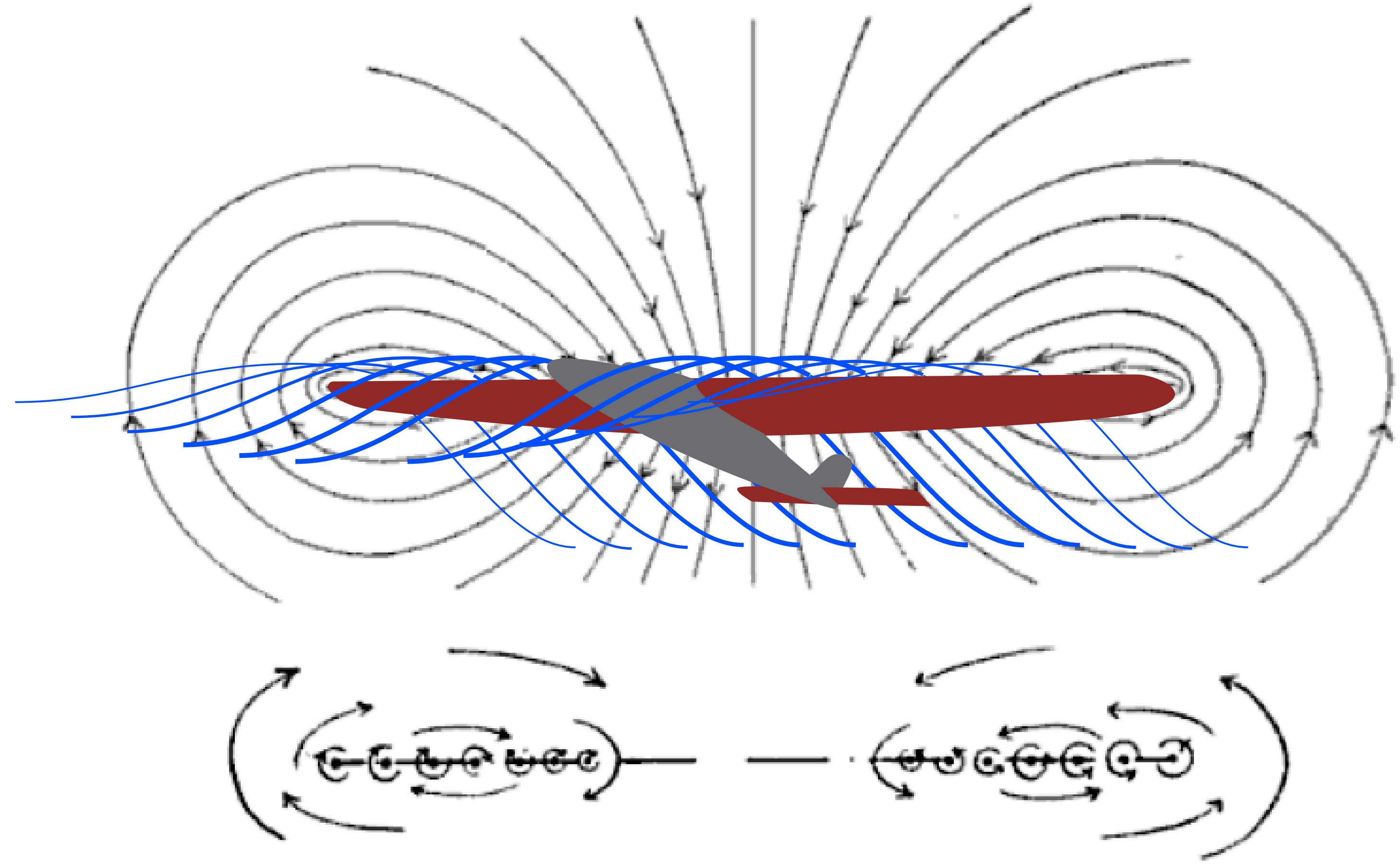


FIG. 83.

Figure 14: A wave in the direction of flight, a vortex in the dimension of sink. Near wingtips, the upper pressure gradient and downwash energy recycling are weakened, making less wave upwash ahead. Lanchester's acceleration field, the result of the plane's sink, is in gray, and makes the wingtip vortices. Lanchester's concept of wingtip vortices as the sum of 'vortex filaments' (lower half of his illustration)

Prandtl quite brilliantly mathematized this concept as his 'lifting line' theory, published in 1918 - 1919. In it, he adds the horseshoe shaped vortices of infinitesmal sections of wingspan to get the bound-vortex circulation of the entire wing, rendering the first method of predicting the lift and drag of a proposed wing. © 2011 Philip Randolph the plane reaps the benefit of the whole up-current generated.[52] – Lanchester, 1907

Thus Lanchester clearly implied the role of upwash as the vehicle of his wave energy 'conservation.' But he struggled to define the mechanism for what he knew to be true. We'll see the causes of upwash.

Even amidst the flurry of his own, mostly adequate answers, he still worried at an inexplicit, flawed question, paraphrased, 'What holds up "the wave on the crest of which the aerofoil rides?"' Lanchester speculated about elastic collisions with air reaching all the way to the earth, then bouncing back to impact the wing, perhaps via 'prismatic columns.' He failed at an analogy between a wing and "a loaded piston supported by gaseous pressure in a closed cylinder,"[53] a pneumatic concept which can be made to work, although that's another story.

Somehow, perhaps lost in verbal haze, he missed his own answer: The wave isn't held up. It sinks, in his and Kelvin's sinking vortex pattern. But it sinks slowly, for, exactly as he asserted, it loses only limited energy to trailing vortices. Even a powered plane is always sinking, slightly 'down' the vector sum of thrust and gravity (again, Lanchester's concept).[54]To achieve level flight, it angles up, compensating for the sinking mush downwards that produces the upward flows of wingtip vortices. See Figures 10 and 17.

So, Lanchester: He was like an artist unsuccessful at selling realism, so then pursuing vogue. Throughout, he threw concepts around like Jackson Pollack with paint, assembled them into something only slightly more coherent than a staircase descending a nude, but trailed bits of string, that he or we might find our way through his minotaur labyrinth. Rather than completing a coherent, convincing picture, he got lost in his own tangles, of magnificent contributions.

A wing doesn't carry much total energy. It carries a pattern of exchange between energy forms, that makes lift

Sometimes to be technically correct makes for difficult language. Lanchester stated that "the energy of the fluid motion [is] carried along and conserved." That's true, but it's half of the total energy picture. The energy of pressure gradients is also carried along with the wing. But pressure energy drops by increasing kinetic (motion) energy, so a wing mostly just changes the form of energy within surrounding airflows, from pressure to velocity, and back. A wing (with exceptions) mostly doesn't add to the energy of the air that flows over it. See Figure 14.

In fact, a wing carries very little total energy — almost none above, where we find the most powerful pressure gradients and changes in flow velocity, plus a minor amount below (in a raised-pressure, standing wave, discussed later). This can be shown with a bicycle example, by Bernoulli's equation, or by a pressure analysis.

• The bicyclist: A bit of air rising in upwash, passing over a wing, and exiting downward, is much like a bicyclist coasting through a tight turn. The energy the cyclist carries into the turn is all there is. He exits with the energy he started with, minus a tiny loss to friction. We'll extend our analogy by putting a dip in the curve. As our cyclist loses altitude during the first part of the curve, he gains speed. His energy remains constant, a Bernoulli exchange of his elevation loss times his weight, for a momentum energy gain ($mg\Delta h + m\Delta V^2/2 = 0$). In the upslope of the curve, the form of energy recovers, to nearly his original elevation and velocity. Just so, over a wing, pressure drops as velocity increases, and then pressure increases as velocity drops. The energy of the flow over the wing stays constant, but the form changes temporarily. (This was a written statement of the Bernoulli equation.)

• Bernoulli's equation, in its aero usage, simply says that along streamlines, often there is an exchange of pressure energy for kinetic (motion) energy. One of its forms, for flows around wings, is: $\rho V^2/2 + p = \text{constant}$. The first term is momentum in terms of density, ρ, rho. The p is pressure. Again, it just says that when pressure goes up, velocity goes down. The units of the 'constant' are energy per volume. Thus it asserts that when pressure energy goes up, velocity energy goes down. Caution: Bernoulli's equation is often misapplied.

• Pressures: Since pressures forces on wing surfaces are normal (at right angles) to the surfaces, they exert no tangential forces on the wing. Hence there are no equal and opposite pressure forces by the wing on flows tangential to wing surfaces. The wing, ignoring skin friction, doesn't directly speed or slow flows along streamlines. The wing adds no energy to streamline flows.

How pressure gradients along streamlines do develop: The curve of flows over a wing, from upwash to downwash, centrifuges the lowest pressures approximately above the thickest part of the wing. That creates a double pressure gradient, from ambient ahead to lowered pressures above, to roughly ambient near the wing's trailing edge. The pressure gradient first accelerates and then slows flows. (This is Lanchester's somewhat symmetrical, 'acceleration field.') The added velocity over the wing increases centrifuging, for even lower pressures and higher velocities.

One excellent author has asserted that the rotational momentum energy of 'circulation' is carried along with the wing. That's true enough, though associated with those awkward 'circulation' visualizations, but again, he's only talking about half the energy picture. Even the raised kinetic energy of 'bound vortex,' 'circulation' is balanced by the lowered pressure energy of its low-pressure core, that sits atop the wing. The wing, with a minor exception or two, doesn't carry energy. It carries a pattern of exchanges between energy forms. That these energy forms include lowered pressure energy above the wing and slightly raised pressures below is the benefit: lift.

Pressure energy recovery of streamlined objects at lifting angle of attack

All wings are distortions of minimum drag profiles, teardrop shapes, which exhibit pressure energy recovery. The fact of pressure energy recovery around wings is observed: Away from wingtips, near the trailing edge of a wing, both upper and lower flows return, as Lanchester theorized, to nearly their original states (pressures and velocities), plus a relatively small downward and foreward velocity.

The concept of pressure energy recovery in flows around streamlined objects dates to the Benjamin Robins. In 1742, Robins theorized that air displaced by a subsonic cannonball 'circulates to the hindermost,' preventing a vacuum from forming there. The discovery of minimum drag, tear-drop shapes came later — Lanchester observed the low drag shape of trout, and in 1907 diagrammed a wing with such a profile, a decade before the Fokker D.7 biplanes showed the superiority of thick wings over thin.[55] John D. Anderson, Jr., in *A History of Aerodynamics*, explains that in 1912 - 1913 Prandtl's wind tunnel tests of Lanchester's airfoil designs showed a lift/drag ratio of 17, 10% better than other airfoils previously tested.[56] (If a reader knows the influence on German WWI airfoils, please respond.)

Around minimum-drag objects aligned with flow (for example, symmetrical wings moving at zero angle-of-attack), pressures are slightly raised at the leading edge, lowered to the sides, and increase to roughly ambient by the trailing edge. Pressures aft nearly balance those pushing back on forward surfaces, making very low drag.

We can describe the low pressures to the sides of such objects as centrifuged, low-pressure, trough waves. In relation to the object, they are 'standing waves.' As a bit of air passes along a streamline, from high pressures ahead to low pressures, pressure is used up increasing its speed. Passing the thick point, it plows into slower moving air aft, again raising pressures that slow it. The low-pressure, high-velocity, upper wave stays with the wing.

Wings, however, are minimum-drag shapes distorted by camber, with an upper and a lower surface, and usually fly at a positive angle of attack. Lanchester astutely divided his wave analysis into upper and lower flows. If he had talked about both forms of energy recovery, 'motion' energy and 'acceleration field' (pressure gradient) recovery, his analysis would show that the raised pressure, standing wave below a wing also exhibits wave energy-form recovery — as a wing approaches and passes a previously still bit of air, the air is accelerated forward and up as it increases in pressue, and then is slowed and pushed down as its internal pressure decreases.

When a streamlined object is not aligned with flows, as long as the flows remain attached, the resulting waves around it, whether low-pressure, trough waves or raised-pressure waves (or a mix), show pressure-motion energy-form recovery.[5]

Waves add, and interact. The strong backwards acceleration above a lifting wing combined with the weak acceleration of air below make the pattern we know as 'circulation.' The interaction of the upper and lower waves makes the whole wing wave.

An exception, incomplete pressure and motion energy recovery

Since real wings lose energy to wingtip vortices, they sink in relation to their 'zero-lift' angle of attack. They are always 'mushing' downwards from perfection. To stay level, they operate at a positive angle of attack. This has implications — they create 'net downwash,' and drag air forward. If we visualize a flat-plate wing operating at a positive angle of attack, pressure forces, always normal to its surfaces, are tilted slightly, so below (pushing) and above the wing ('sucking') there is a component of pressure force forward. The same, on average, is true for actual wings. This is the drag, on wing and air, in standard lift/drag vector diagrams. It contributes to wingtip vortex drag. It also pushes air and pressures forward under the wing, the source of added energy there.

5 For those familiar with lift/drag polar diagrams, the 'minimum drag buckets' represent angles of attack where there is good attachment. Drag increases rapidly with bubble formation, till stall.

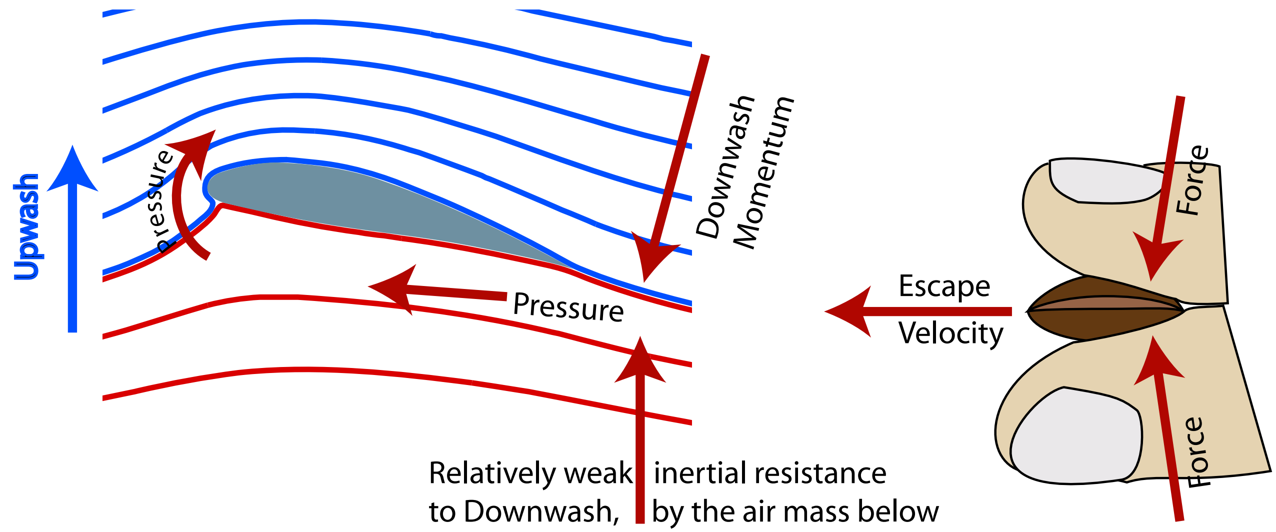
Two sources of upwash. Energy form recovery, and recycling of energy below the wing

Pressure and motion recoveries happen above and below the back part of a wing. A minor recycling of energy from downwash aft into upwash ahead happens below the wing.

A false notion was actually published a few years ago, an assertion that the wing pulls upwash up (false), which must pull the wing down (false), so upwash must not add to lift (false again). The wing itself does not pull upwash up. Simple proof: There is no upward pressure gradient between a wing and upwash that would pull upwash up. Just the opposite — all pressures on a wing push or pull it up, and air down. As Ergo the Greek wrestler said, Ergo sumo clouto. Upwash has other causes.

The strongest force creating upwash is the pressure gradient from ambient ahead up toward the low pressure above a wing. (See Figure 12.) In conjunction with usually somewhat raised pressures below a wing, a broad pressure gradient forms up around its leading edge, Lanchester's 'acceleration field.' The same difference in pressures that lifts a wing also lifts upwash ahead, and creates wingtip vortex flows.

As with lift, the strongest wing-wave pressure and motion energy recoveries are above the wing, though starting

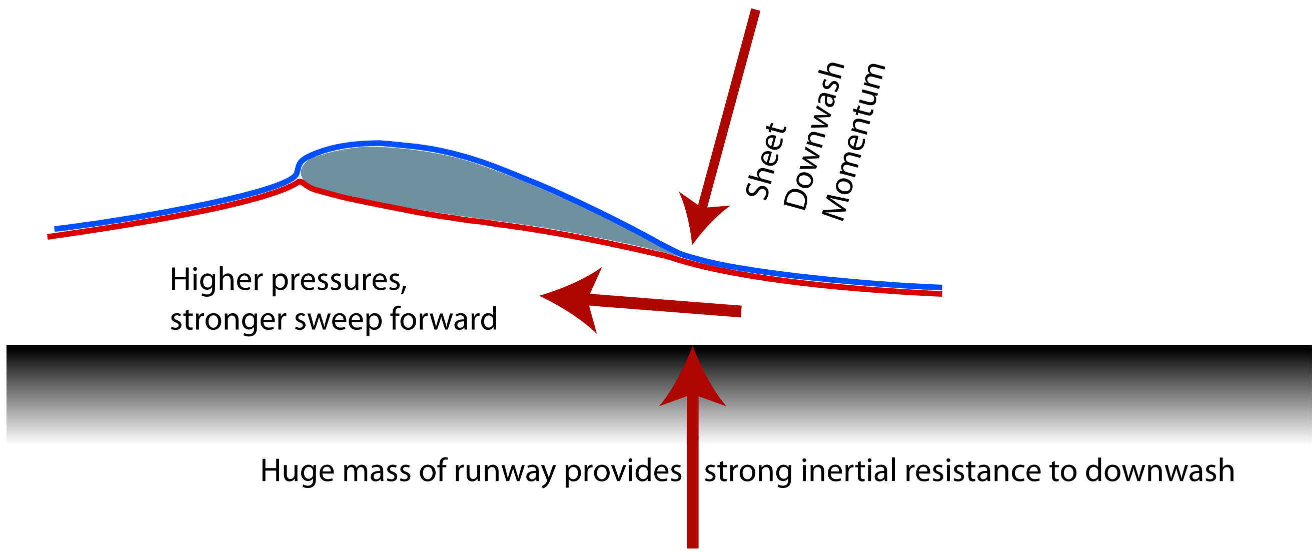


The strong force on upwash: The centrifuged, low-pressure wave above the wing has a stronger effect on upwash than pressures below. Upwash is pushed up by the pressure gradient around the front of the wing, from somewhat elevated pressures below toward significantly lowered pressures above. The wing slices into rising air, putting the forward 'stagnation point' below the leading edge. The pressure gradient drags air forward, up and around the leading edge.

Downwash energy recovery: The lower surface of the wing and sheet downwash 'sweep' pressures forward below the wing, to escape as upwash. Downwash is slowed, its energy partly recoverd as the pressures forcing a small part of upwash.

The minor, lower squeeze: Pressures are 'squeezed' forward between sheet downwash and the air mass below, much like a cherry pit squirts forward when squeezed between thumb and forefinger. At altitude the squeeze is weak,. The forces on upwash are mostly from centrifuged low pressures above the wing. In ground effect, the squeeze of pressures and air forward, between sheet downwash and runway, is strong.

Figure 15A: Upwash, ground effect, lower energy recycling. © 2011 Philip Randolph



In ground effect, sheet downwash and air pushed down by the lower surface of the wing is rapidly decelerated by the huge mass of the runway, resulting in elevated pressures. Equivalently, between sheet downwash, the wing, and the runway, air is more strongly squeezed forward than at altitude, and escapes as stronger upwash, making greater velocities above the wing, for stronger centrifuging of low pressures there. The wing seems to 'float.'

Figure 15B: Upwash, ground effect, lower energy recycling. © 2011 Philip Randolph

roughly aft of its thickest point. Just aft of where ambient pressures are most strongly lowered and ambient velocities are most strongly increased is where we find the reverse, the strongest energy-form recoveries.

A lesser part of wing-wave energy recycling, that Lanchester didn't explain, is the salvage of part of the energy of 'net downwash' into part of upwash. If a wing's trailing edge scrapes along the ground, air beneath it is squeezed forward at the speed of the plane. Close to the ground, air under a wing is strongly 'swept' forward, relative to surrounding air. The increased upwash allows lift at a lower angle of attack, for lower drag. That's ground effect. At quite low angles of attack, at elevation, air below a wing may be displaced weakly backwards. At altitude, at significant angles of attack, downwash behind the wing hits air below, which has a lower density than runways, but the sweeping collision still results in pressures being squeezed forward. See Figure 15.[57] These pressures strengthen the pressure gradient up around the leading edge, adding to upwash, and recycling the energy of sheet downwash, which otherwise might be lost.

One author briefly asserted that energy from downwash bounces off air below, making upwash. That's true, if vague, but it's the small potatoes of the story. When you think of how air is accelerated up, ahead of a wing, think mainly of a pressure gradient from mildly raised below, up and around the leading edge, to strongly lowered pressures above.

One other possible source of energy recovery is beyond the scope of this article, but: Behind long, lightly loaded wings, sheet downwash may turn back up, or even oscillate, forming an additional crest or two. (Otto Lilienthal diagramed this in 1889![58]) Some of this motion ends up as turbulence and ultimately heat, or turbulence at the molecular level. But there is also a well-studied phenomenon, wave-group interaction, by which energy from trailing oscillations transfers forwards, leaving relative calm. You can watch this phenomenon in a boat wake. Perhaps.

To the extent that pressure and motion energies are recovered or recycled, they reduce energy loss and increase flight efficiency. Some pressures and motions are always lost. The cost of flight is pressure and motion energy that is not salvaged, mostly in wingtip vortices and skin friction, that a plane leaves as its wake.

The Lifting vortex

A wing stays up by putting downward pressure forces on air — as Lanchester said, reversing upwash ahead to somewhat greater downwash aft. The difference is 'net downwash.'

A wing doesn't stay up merely by throwing 'net downwash' air down, like a rocket. That common notion ignores the pressures that result from air pushed down pushing other air up. It is these pressures that help create the weaker, lower part of the wing wave, and it is within the wave's pressures and flows that a wing flies. To ignore these pressures is to recapitulate Newton's generally false theory of flight, in which molecules hitting the underside of a wing don't interact to make pressure. Newton's typical, 'if this were the unlikely case' hypothesizing turns out to be accurate for supersonic flight, or flight in rarified atmosphere, where molecules seldom collide, as on Mars.

Lanchester's diagrams show that for a subsonic plane to stay up, it has to move his whole acceleration field, in a double vortex pattern. Again see Figure 14. The pressures a wing creates to move air in this vortex are also the pressures that lift a wing. The equal and opposite reaction of creating the sinking vortex is lift. Thus the sinking vortex is also a lifting vortex. Basically, air something for the wing to push on, which, via inertia, pushes back.

Viewed from ahead, the upward displacement outboard of wingtips becomes energy lost to the trailing vortex system. The magic is that even though some displaced air pushes up around wingtips, air ahead of the wing also gets pulled and displaced up, as upwash, while the reverse pressure gradients aft slow and calm sheet downwash.

The result is Lanchester's wing wave, with its curve of upwash ahead to downwash aft.

Oddly, Lanchester didn't repeat his argument, from his analysis of the lift of spinning spheres, that this curving flow centrifuges the pressure differences around the wing that make lift. Note that this same centrifuging creates the pressure gradient above the wing that bends air over the wing down, in modern terms keeping it 'attached,' at angles of attack less than stall.

Energy efficiency. How the wing wave lowers drag. All flight is within sink.

An airplane is more efficient to the extent that it has less energy losses per some performance target — miles covered, cargo hauled, lift/drag or speed sink ratios at specific speeds, absolute sink rate. Wing wave energy recovery and energy recycling reduce energy losses and so increase efficiency. Ignoring skin friction, there are several ways that long wings are more efficient than shorter wings, bearing the same weight.

It's basic physics that lift from accelerating a large mass of air gently uses less energy than achieving the same lift from accelerating a smaller air mass rapidly. A wing makes pressures that move Lanchester's whole acceleration field, a cross-section of air with greater span than the wing, and great depth. The longer the wing, the greater the span of the acceleration field. Longer, faster wings affect a greater volume of air per second more gently than shorter, slower wings, for more efficient flight (ignoring skin friction, and with planes of equal weight).

But that's a third of the story. Second: To the extent that the wing wave recovers and recycles its two energy forms, rather than leaking their energy into wingtip vortices, efficiency is increased. Recovery and recycling mean less energy ends up in the plane's wake. Another way to say this is that the 'up-currents generated' ahead of the wing make lift, while 'up-currents' around wingtips are losses. As Lanchester explained, long, lightly span-loaded wings have better recovery and recycling of energy, more beneficial upwash, and less losses to wingtip vortices, than short, stubby wings.

The third energy efficiency is from wing-wave, vortex drag reduction. Vortex drag is from the low-pressure cores of the trailing vortices pulling trailing air forward, and also 'sucking' back on wingtips — the opposite of pressure energy recovery. For the same weight of airplane, a longer wing has less losses to wingtip vortices, and lower vortex drag, than a stubby wing.

Vortex drag reduction detail: For a given load, longer wings have better wave energy recovery than shorter wings. Comparatively, air leaks up more strongly around our shorter wing's tips. Less gets 'sucked' and squeezed forward into the upwash ahead that creates part of lift. So our short wing must operate at a higher angle of attack, and must create its lift with stronger net downwash. That strong downwash aft adds oomph to the rotational velocity of wingtip vortices. The sheer between the faster downwash and upflows outboard of a stubby wing's tips centrifuges stronger low-pressure center of the trailing vortices. That low-pressure center 'sucks' air forward from further back, and pulls back on the wingtip, for very strong vortex drag.

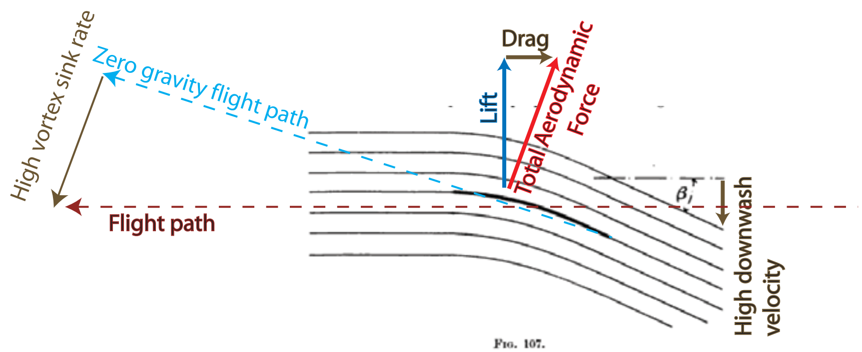
Vortex drag is proportional to span-loading — not to aspect ratio or wing area.

A wing always flies in sinking air of its own creation. As with lift and energy recovery, the main cause is the low pressures above the wing. While ahead of a wing, pressures force upwash, above a wing the forces on air are downwards. Even ahead of a wing, upwash doesn't go up forever, but is overcome by the pressure gradient down toward the low pressures above the wing. The average motion of air above a finite wing is downward — a statement equivalent to the fact of net downwash. Below a wing, slightly raised pressures also push air downwards. That is the vortex sink (sinking air), inboard of wingtips, in which a plane always flies.

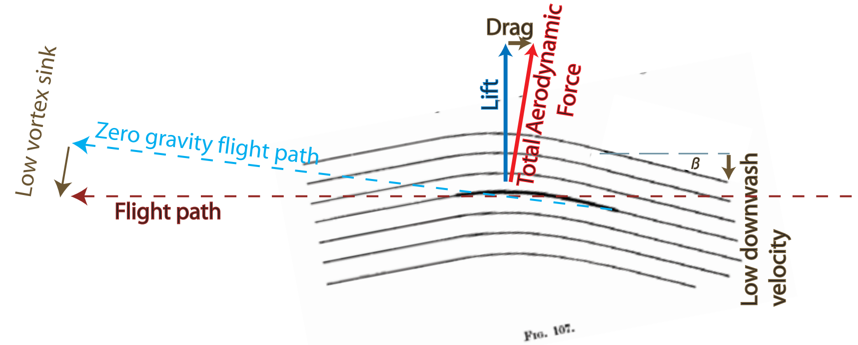
To overcome the sink of air in which it flies, a wing angles up, from its 'zero-lift angle of attack,' the path it would take if gravity disappeared. Figure 16[59] shows how that important part of the wing wave, upwash, reduces losses to downwash and increases flight efficiency. Upwash is stronger away from wingtips, where the wing wave suffers.

The rest of this article is mainly to support the fact of the wing wave, with five wave analyses, and a few hints at the mechanisms of wing-wave energy recovery.

How upwash increases flight efficiency



Lanchester's diagram (black) of the then prevailing fiction, that a wing hits a horizontal airflow. He showed such fictitious, 'wave-upwash-free' wings would have about half the lift of real wings. Force vectors show that for similar lift, they'd fly at a higher angle of attack, angling their total aerodynamic force backwards, for high drag. The high velocity downwash aft is wasted energy, and resolves into violent trailing vortices, making high wingtip vortex drag. The dotted blue line is the path the wing would take in zero gravity, it's 'zero-lift line.' Gravity makes it sink from that path to level flight, strongly displacing air up around wingtips, in a violent sinking vortex pattern. No real subsonic wing has zero wave-energy recovery, but because of losses up around wingtips, short, heavily span-loaded wings have weak upwash and poor wave-energy recovery.



Lanchester's diagram rotated to represent strong upwash and wave energy recovery. (Lanchester did make a similar diagram.) Rotating his diagram keeps the curve of flows the same, so the total aerodynamc force is the same, but angled more vertically, showing the lower drag. Lower downwash velocity means less energy lost to trailing vortices. Downwash energy aft not recovered is waste. The greater downwash velocities sheer with up-currents outboard of wingtips, making stronger rotation of trailing vortices, and stronger centrifuging of their low-pressure cores, which drag back on wingtips.

Upwash, vesus the fictitious lack of upwash, creates similar lift is at a lower angle of attack. The vortex sink rate is lower. Vortex sink is from spill of air up around wingtips. Long, lightly span-loaded wings always have efficiencies both from good wave energy recovery and from influencing a larger (wider) volume of air per second than short wings.

Figure 16: How wave energy recovery increases flight efficiency. © 2011 Philip Randolph

The wing wave as similar to other waves, including earthquake waves(!) and more

The wing wave can be understood, and validated, through a few comparisons — with surface water waves, earthquake wave crests, the waves five-ton 'flyboats' once rode on Scottish canals, standing waves, as over submerged rocks and depressions in creeks, and linear pressure waves. Lanchester's 'wave, motion-energy conservation' is equivalent to the modern term, 'pressure-energy recovery.' Comparisons with surface waves are supported by an 1886 discovery, of surface waves within air, and by the conceptual side of the mathematical aerodynamics term, 'similitude,' or 'flow-similarity.'

Your author's first exposure to serious aerodynamics was on a trip to Eastern Washington, in March of 2001, to fly a four-foot flying wing in a slope combat. On the trip from Seattle, Adam Weston, who has a degree in aerodynamics, attempted to explain Reynolds numbers, basically a numeric ratio of inertial to viscous forces. (Speed times fluid density times chord length, divided by viscosity.) I didn't quite get it, so he told me to go read a book. The Reynolds number is the 'flow similarity,' or 'similitude' number, for similar shapes. For example, if a model wing, 'flown' at slow speeds in water (with a density much greater than air) has a Reynolds number similar to that of its similarly shaped, full scale wing, their flows will be similar in pattern, attachment, bubble formation, turbulence, and coefficients of lift and drag. The Reynolds number is thus the computational basis for comparing models in wind tunnels to full-scale flight. But that's a hint at the math side of aerodynamics, which doesn't always get well balanced by simple statements of concept.

Watching waves in front of the beach cabin I rent, in 2004, I realized I didn't quite get water waves, other than the standard measures of frequency, velocity, and amplitude. But I'd been thinking about flows and forces around wings for a few years. I saw gravity reversing the upwash in front of a wave to downwash aft, and figured that the force that drives a wave forward is the push down on its aft half. I saw that push forward is a bit like squeezing a cherry pit between thumb and forefinger, till it fires. That's only part of the reality, but I immediately pictured the similar pattern of downward pressure-gradient forces on air above a wing. I saw the wing wave as very much like a water surface wave. Again, that's not entirely accurate, but it allowed a very basic, qualitative form of the conditions of flow similarity, or in aero vernacular, 'similitude: ' Similar patterns of dissimilar forces result in similar flows. This allowed comparisons between the wing wave and other waves — earthquake crests (!), standing waves over rocks in creeks, a pair of pressure waves, and a solitary wave that carried canal boats in the 1830s. Each reaffirms the fact of the wing wave.

Wing waves as similar to water and earthquake surface waves. Surface waves within air?

The downward 'restorative force' of the crest of a water surface wave is weight, which reverses upward cresting to down-rush aft. A similarly-downward 'restorative force' operates above a wing. It's the downward pressure gradient that bends air down around a wing's curved upper surface, reversing upwash ahead to downwash aft. It's not a perfect comparison. The motion in a water-wave crest is forwards, while air above a passing wing is accelerated backwards. Figure 17.[60]

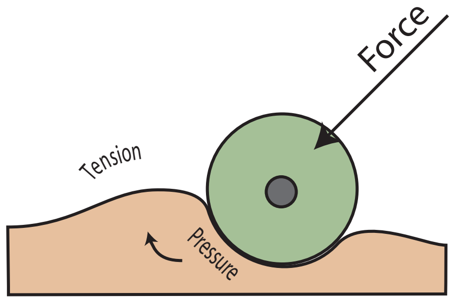
But surprisingly, there is a surface wave crest with forces and motions in a remarkably similar pattern to those of the wing wave — the crest of 'Rayleigh solid surface waves,' typical of earthquakes, or the waves across a sheet of Jell-O when you tap it with a spoon. Each has a forward moving crest, in which particles move backwards. Just as an earthquake 'P' wave passes, rock and dirt in its crest move in the opposite direction of its travel, while the earth further below moves weakly forward.[6] Similarly, as a wing passes, previously undisturbed air above is accelerated backwards, while air below is usually displaced weakly forward. Neither air nor dirt does tension, but they fake it, in the same way that differences in pressures will 'suck' soda up a straw. It's another case of similar force patterns making similar flows. The sum of forces above a wing and in the crest of a solid surface wave act like tension, pulling particles backward in a pattern that sticks with the forward moving crest.

That air and rock could make similar wave crests is counterintuitive. Air can swirl and shear, while rock merely distorts. But away from wingtips, airflows over and under a long wing don't swirl — they mostly deform, like a solid. A major difference is that distorted solids, up to a point, have restorative

6 A good animation of Rayleigh solid surface waves, and a few other waves, is at: <http://paws.kettering.edu/~drussell/Demos/waves/wavemotion.html>

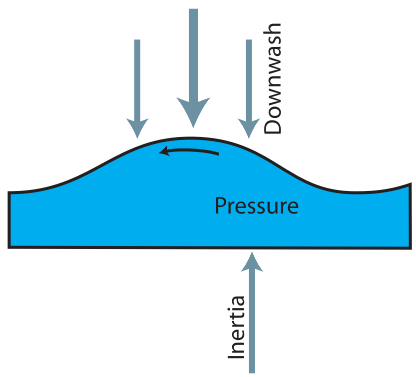
Flow Similarity: Similar patterns of dissimilar forces make similar flows

Dough and a rolling pin. Downward force squeezes pressures forward, making 'upwash.' Similarly, a wing's angled underside and sheet downwash 'sweep' pressures forward to increase upwash.



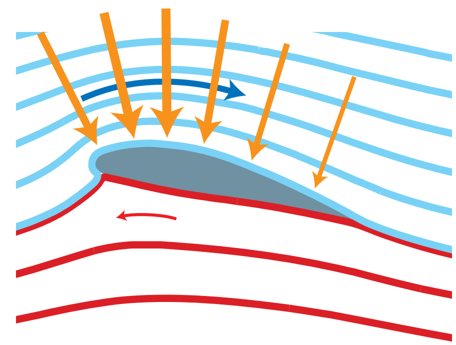
The weight of water in the backside of a wave exerts a similar pressure to the rolling pin. Downwash slams into the inertia of the water below, making pressures that accelerate water ahead, where it piles up, moving the crest forward.

Weight slows and reverses the upward cresting

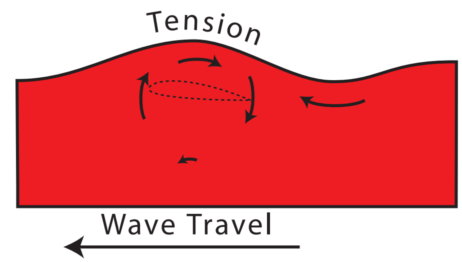


The pressure gradient from ambient well above a wing to low pressure at its upper surface is in a similar pattern to the weight of water in a crest. Air is displaced more strongly backwards above a wing than forward below.

Pressures reverse upwash to downwash



Earthquake (or Jell-O) wave crests and wing wave crests have similar internal patterns of motion. The sum of forces in a wing wave make the air above it act like it is under tension. Unlike solids in an earthquake or Jell-O wave, wing wave air is permanently displaced.



In 'positive' forced solitary waves, water is permanently displaced forward. That is similar to the wave action below a wing.

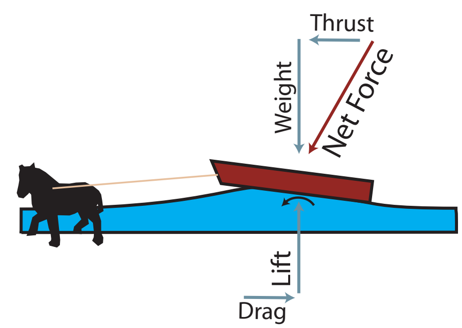


Figure 17: Flow similarity: Dissimilar forces in similar patterns make similar wave motions. © 2011 Philip Randolph

forces that return them to their original shapes, while air is free to remain displaced, with forces mainly from plowing into other air. So away from their crests, the force patterns on air and rock are very different. Air is also very much more compressible than rock, which transmits pressure waves mainly by distortion. But in their wave crests, they act very similar!

Please surf again to Dr. Dan Russell's site. Note the similarity of motion in his Rayleigh, solid surface wave animation, to the motions within the wing wave. And see Figure 18.

Lanchester's wing-wave theory, and comparisons of surface waves to the wing wave, imply waves within air! But how can there be surface waves around a wing within air?

In 1886, the great German vortex and wave theorist, Herman Von Helmholtz, while hiking in the Alps, observed huge waves on the surface of a cloud layer. By 1889 he had related waves between sheering layers of atmosphere to waves between wind and sea.[61] Kelvin had also derived equations for waves resulting from the sheer of wind over water.[62] Lord Rayleigh reconciled the theories.[63] A web search under the reversed eponym, 'Kelvin-Helmholtz instabilities,' will get you many images. One such photo is Figure 19.[64] So yes, surface waves within air. However:

As standing waves. A Bernoulli resolution: The tsunami energy of the lower wave

It's slightly more accurate to describe the wing wave as the sum of upper and lower standing waves, typical of flows over bumps and depressions in a solid surface, as in a creek bed. See Figure 20.[65]

These are pressure-inertia waves, as they perpetuate through exchange of pressure and momentum energies. Such waves show pressure and motion energy recovery.

And! It is entirely within generally accepted aerodynamic principles to picture the upper and lower waves as separated by a solid surface, such as our streambeds.

> Because, by definition, a fluid element will not cross over a streamline, then any streamline can be selected and interpreted as a solid boundary without this in any way changing the picture of the flow.[66] – David Bloor, *The Enigma of the Aerofoil*

The flow over a wing forms a standing wave a bit unlike what one might find over a rock in a shallow creek bed. Note that in such waves, if smooth, the velocity, pressure, and elevation of flows change and then revert, to approximately their original state.

Our upper wing wave is more like the flow over a deeply submerged rock. It's a forced, lowered-pressure, raised-aftward-momentum, standing wave. Within it, pressure energy is used up accelerating flows, becoming motion energy, and then is recovered as flows pile into higher pressures aft and are slowed. A standard interpretation of the Bernoulli exchange of pressure for velocity thus holds: In pressure trough waves, pressure drops as velocity rises.

A dual, standing-wave approach also resolves an old Bernoulli quandary: From a wind tunnel perspective, the Bernoulli exchange appears to hold beneath a wing, since as pressures initially increase, flows are temporarily slowed. But the wind tunnel perspective hides the actuality. As the lower wave passes over a previously still bit of air, it first accelerates it forward and then slows it (as Lanchester asserted), while pressures rise and then drop. By the trailing edge, original pressure and calmness, (plus minor downward momentum) are approximately restored. That its velocity and pressure increase simultaneously (and then decrease simultaneously) indicates that the lower wave carries raised total energy — forward motion plus raised pressure. That's typical of raised-pressure waves.

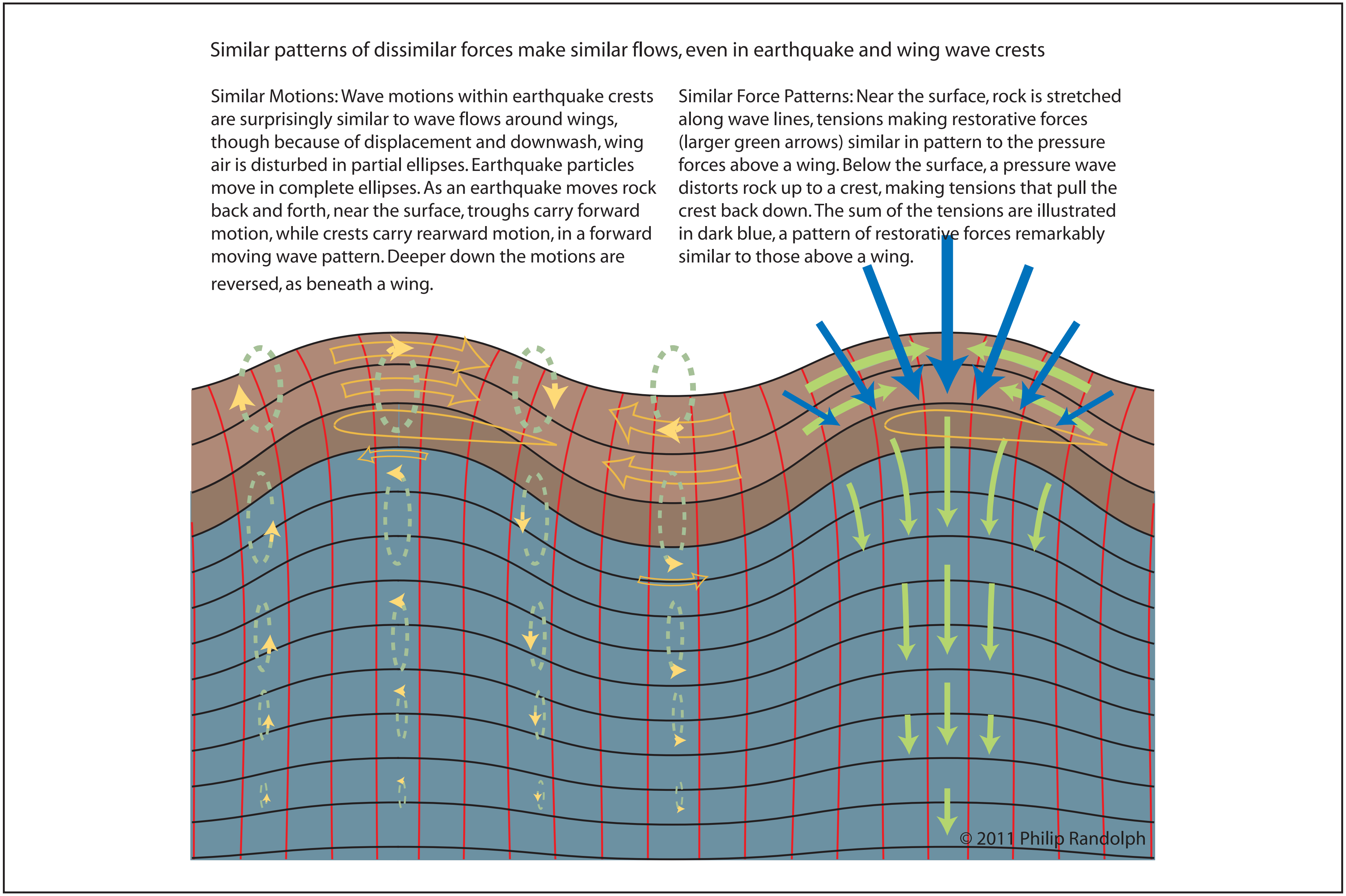


Figure 18: Similar patterns of dissimilar forces make similar flows, even in earthquake and wing wave crests. © 2011 Philip Randolph

Figure 19: Kelvin-Helmholtz instability wave formation on a cloud surface, from shear between two layers of air. Photo by Cesca.

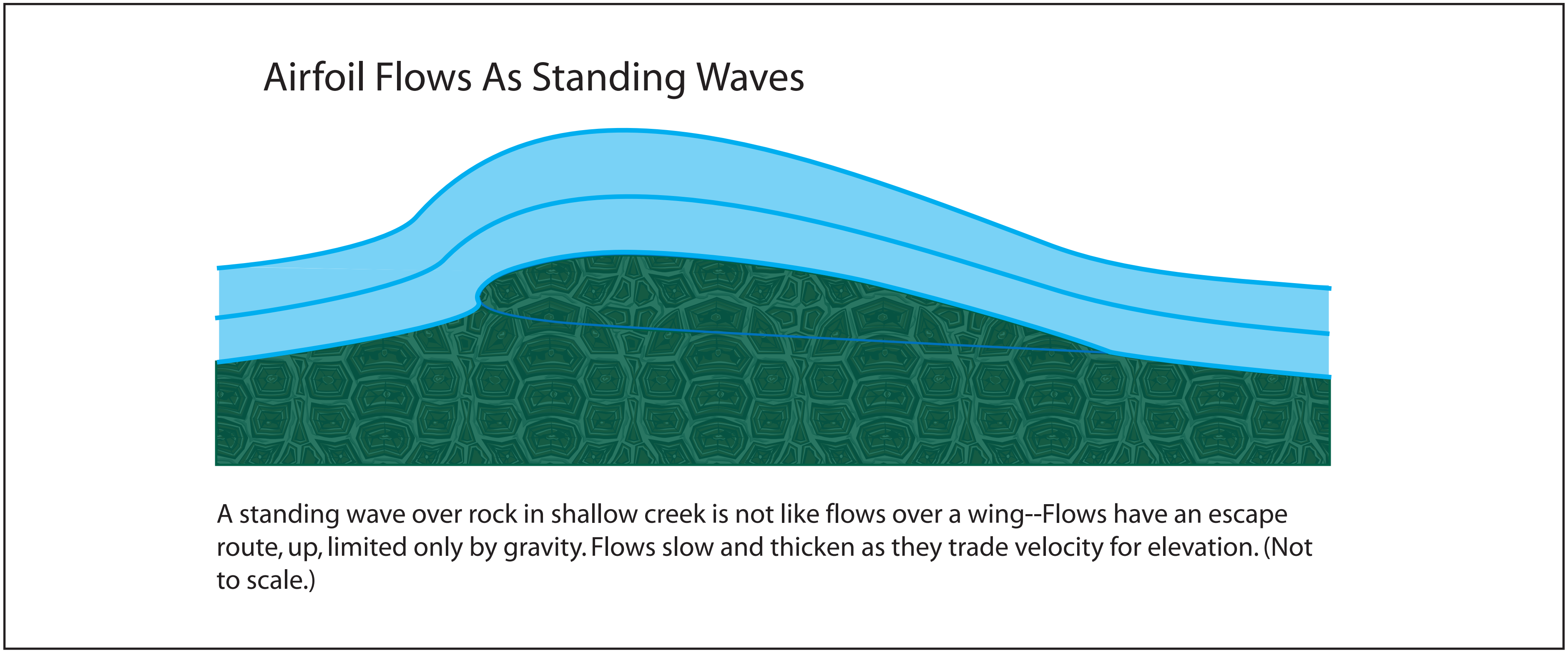


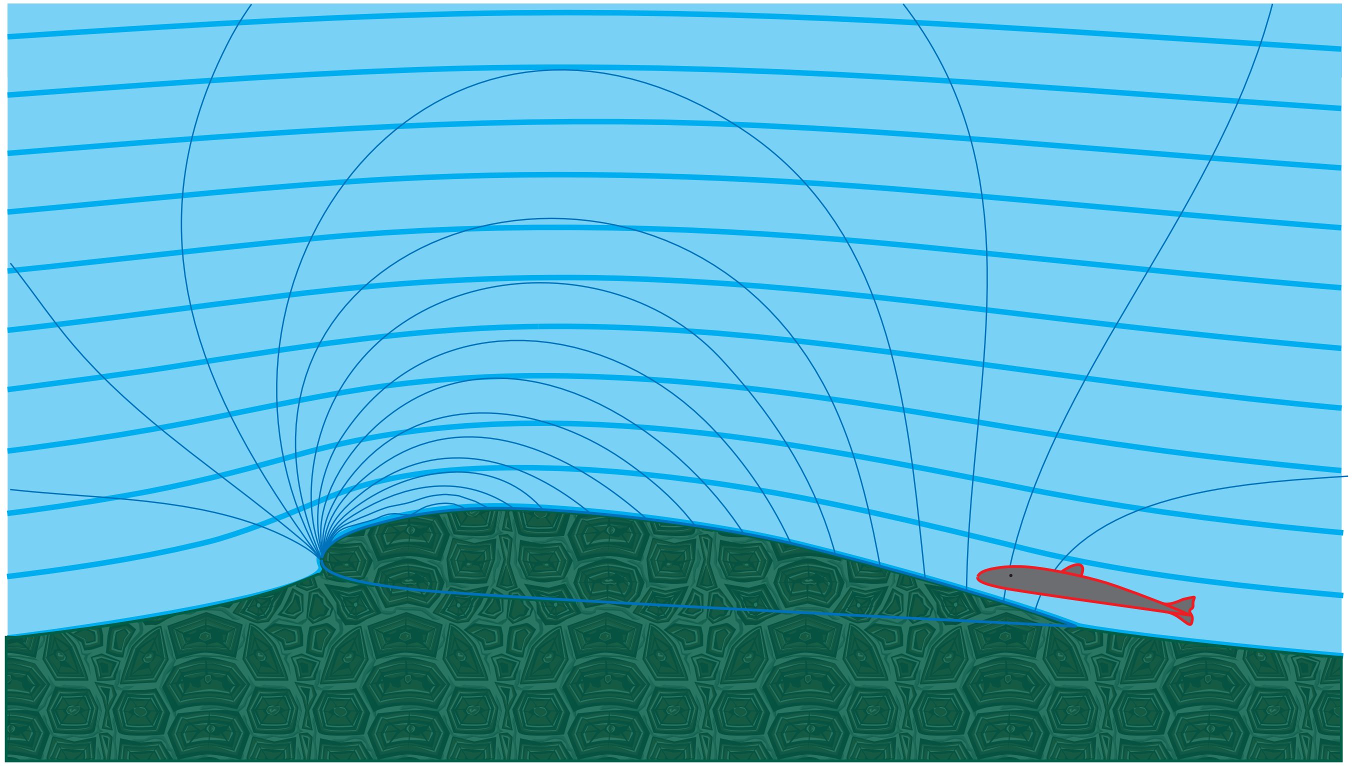
Figure 20A: Standing waves over airfoil shapes in a streambed. © 2011 Philip Randolph

The Bernoulli exchanges below the wing, for those who worry about such things, is still between the forward velocities of the lower wave, which drop as they create the pressures that then impart velocity to air ahead. Thus the lower wave perpetuates forward. However, it all takes place within a pile-up of air that is raised pressure and a forward shove on previously still air. The process is reversed in the aft half of a wave, where air's forward speed is slowed as pressures drop. See Figure 12.

An example may help show that some waves do indeed carry raised total energy, rather than just an exchange of energy forms. The lower wing wave, carrying raised pressures and velocities, is very similar to raised, solitary water waves, such as tsunamis, which carry energy as simultaneously raised elevation and velocities. Tsunamis convincingly carry energy. *Erg sum transportus.*

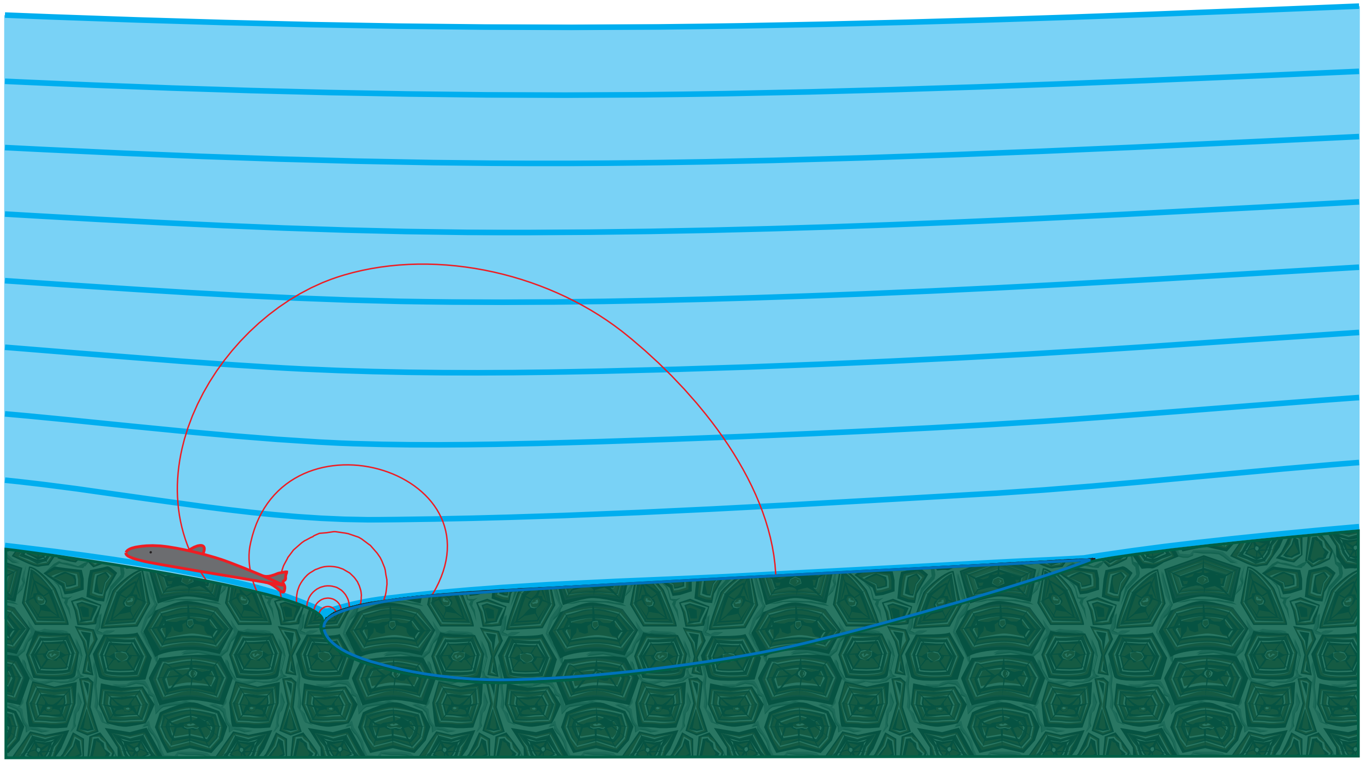
Waves add. The two standing waves sum to the entire wing wave. Since the upper wave temporarily speeds air back, and since the lower wave weakly speeds air forward, the sum is the instantaneous pattern of motion called circulation.

The Gerstner principle, the inseparability of circulation and waves with motion in two dimensions, even applies to upper and lower flows, taken separately. See the displacement patterns in Figure 21. But the upper and lower wing waves, taken separately, can also be looked at as linear (one



A standing wave over airfoil-shaped rock in deep creek (or over a hill) is like the flow of air over a wing--The mass of fluid above blocks the trade of velocity for elevation above the distant surface. Flows centrifuge upper, low pressures (inner pressure isolines), that briefly accelerate and narrow flows--a trade of pressure for velocity aft. Original pressures and velocities are restored near the trailing edge. It makes no difference to flows that upwash and downwash 'zero' streamlines are the boundary between rock and water, rather than within air or water. Aerofoil Fish has his nose in lower pressure than his tail, reducing pressure drag, perhaps even gaining thrust. Trout probably fight as much over such energy saving locations as for food. Salmon probably take advantage of pressure graidents to migrate upstream. Lanchester studied the low-drag profiles of trout.

Figure 20B: Standing waves over airfoil shapes in a streambed. © 2011 Philip Randolph



The flow of air under a wing is like a standing wave in a creek-bed dip shaped like the underside of an inverted airfoil, with its upwash (ahead) and downwash (behind). Flows centrifuge slightly higher pressures, especially under the leading edge. Where flows apprach higher pressures, they thicken and slow. On the aft side of the higher pressures, the pressure gradient accelerates flows backwards, till pressure and velocity are restored. Flip the picture for flight orientation.
Aerofoil fish deux has her tail in higher pressures than her head, and may be taking advantage of lowered boundary-layer flow velocities close to the streambed surface.
(Pressure isolines and flow plot, Clark Y airfoil, 5° aoa, by S. Almaras)

Figure 20C: Standing waves over airfoil shapes in a streambed. © 2011 Philip Randolph dimensional) pressure waves along streamlines. Separately, they're almost like pressure waves travelling through pipes — streamlines are sometimes called streamtubes.

As a pair of linear pressure waves

We've discussed how the upper and lower waves are centrifugally forced, and 'standing' in relation to the wing. Here we can forget causes, and compare the upper and lower waves to linear, or 'longtitudinal,' pressure waves, operating along streamlines. This is a reinterpretation of Lanchester's wave theory, in which, for his 'acceleration, field of force,' we substitute pressure waves.

The lower wing wave can be described as a fairly linear, raised-pressure wave, operating along streamlines. It's like a line of pool balls spaced slightly apart. When the aftmost is hit, a wave of collisions travels forward. As the wave passes, it leaves the balls in its wake relatively still. It carries positive total energy — raised pressures of collision and increased velocities.

The upper wing wave is a pressure trough wave. It's similar to the sound wave emanating when a speaker magnet pulls its paper cone backward — a forward travelling, backward displacement of air molecules, which pulls your eardrum outwards. It is much like pulling suddenly on one end of stretched Slinky®, making a forward moving pattern of backward displacements. The pattern of energy exchanges stays with the wave. The backward momentum of a bit of the Slinky® spring creates a tension ahead of it that then slows it. The tension gets spring further ahead moving back, continuously transferring the tension further ahead. See Figure 21. The forces in a pressure-trough wave are similar. The pressure gradient along streamlines, from ambient pressures ahead toward the low pressure above the wing, speeds air. Low pressures in the back half of the wave pull forward on aft-rushing air within the wave, slowing it, leaving relative calm behind. See Figure 22.[67]

Both raised and lowered pressure waves display wave energy-form recovery — they travel great distances leaking little to net-downwash velocities aft. Near wingtips, such recovery fails, with resulting loss, as Lanchester described, to wingtip vortices.

John Scott Russell's forced solitary waves, and 1830's 'flyboats'

> Considered in the light of wave motion, the peripteroid system must be regarded as a forced wave, the aerofoil supplying a force acting from without — Lanchester[68] [7]

Roughly equivalent to standing waves over deeply submerged rocks or depressions are the forced versions of two solitary waveforms discovered by an English Engineer, John Scott Russell, in the 1830s. Standing waves are a wind-tunnel perspective, while Russell watched as waves forced by boats passed him. To Russell's credit are the first descriptions of wave lift, which he applied to boats, but unfortunately not to wings.

Russell first investigated what Lord Kelvin much later would call, "the discovery… by a horse."[69] Around 1830, the equine experimenter invented the modern planing (significant pun) hull, and created an industry. The horse, while pulling a usually slow canal boat owned by a Mr. Houston, panicked and bolted. Russell wrote:

> …it was then observed, to Mr. Houston's astonishment, that the foaming stern surge which used to devastate the banks had ceased, and the vessel was carried on through water comparatively smooth with a resistance very greatly diminished.[70]

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7 Lanchester likely read of Russell's solitary waves in Lamb, 418 - 421, and perhaps from other sources.

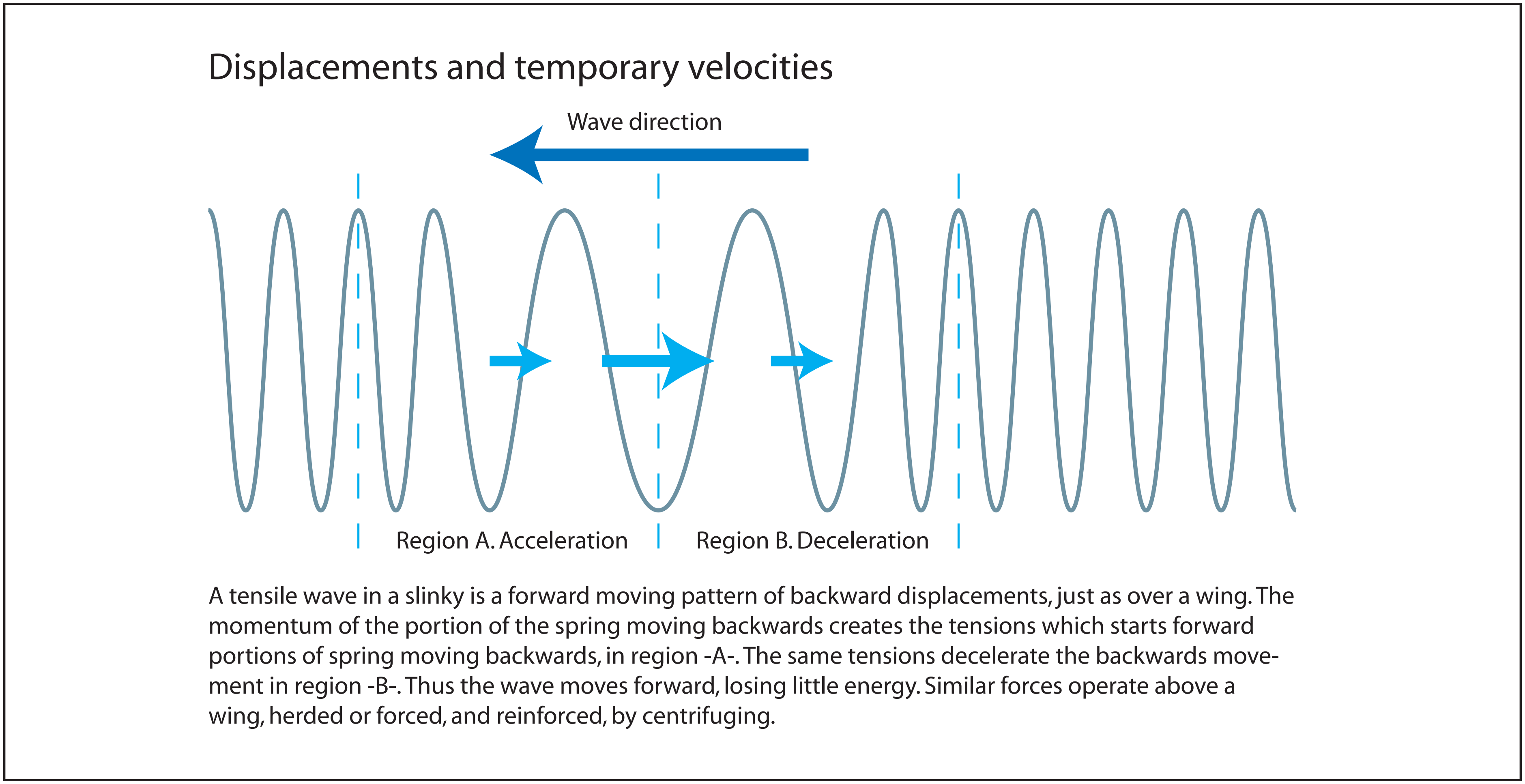
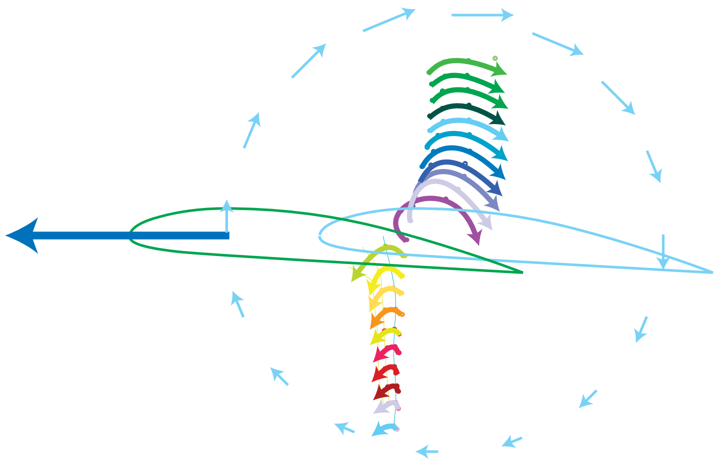
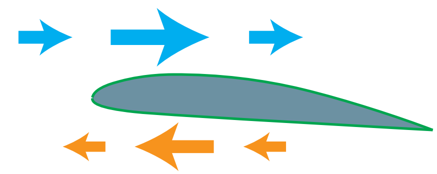


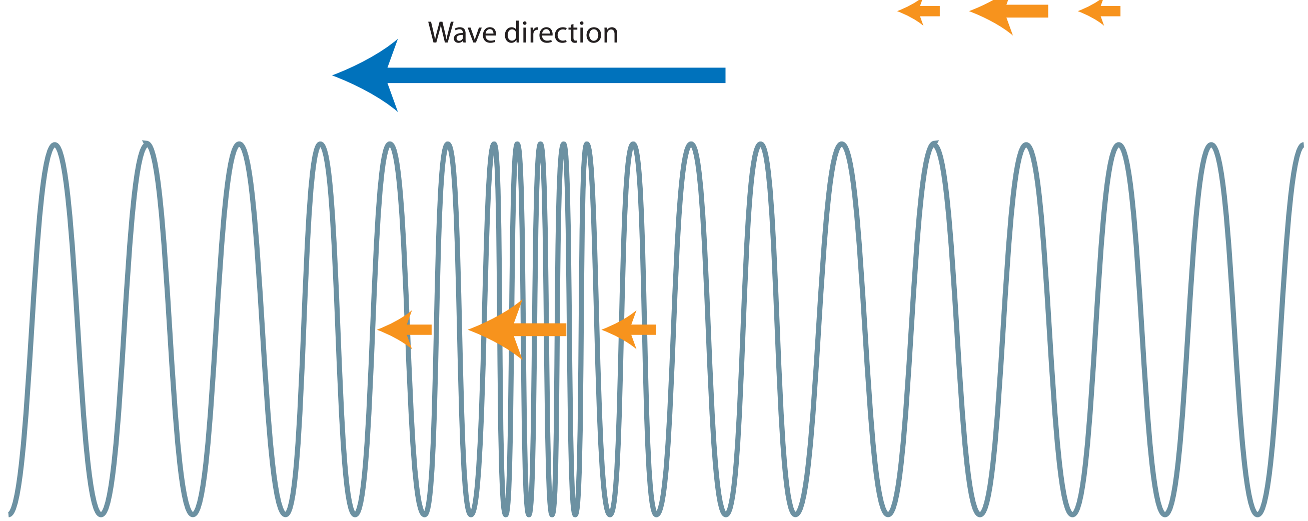
Figure 21A (above) and 21B (opposite page): A 'Slinky®' shows how a tension wave moves forwards with backwards displacements, as does air above a wing.

A compression wave moves forwards with forward displacement, of Slinky coils or air beneath a wing.
© 2011 Philip Randolph



Within streamlines, as a wing passess, particles of air are permanently displaced in partial horseshoe shapes, backwards above, forward below. Compare with the previous, 'Slinky' displacements. The temporary velocities of air particles so disturbed and displaced are 'circulation.'





A compression wave in a slinky is a forward moving pattern of forward displacements, just as under a wing. Both upper, pressure-trough waves and lower, compression waves show pressure energy recovery.

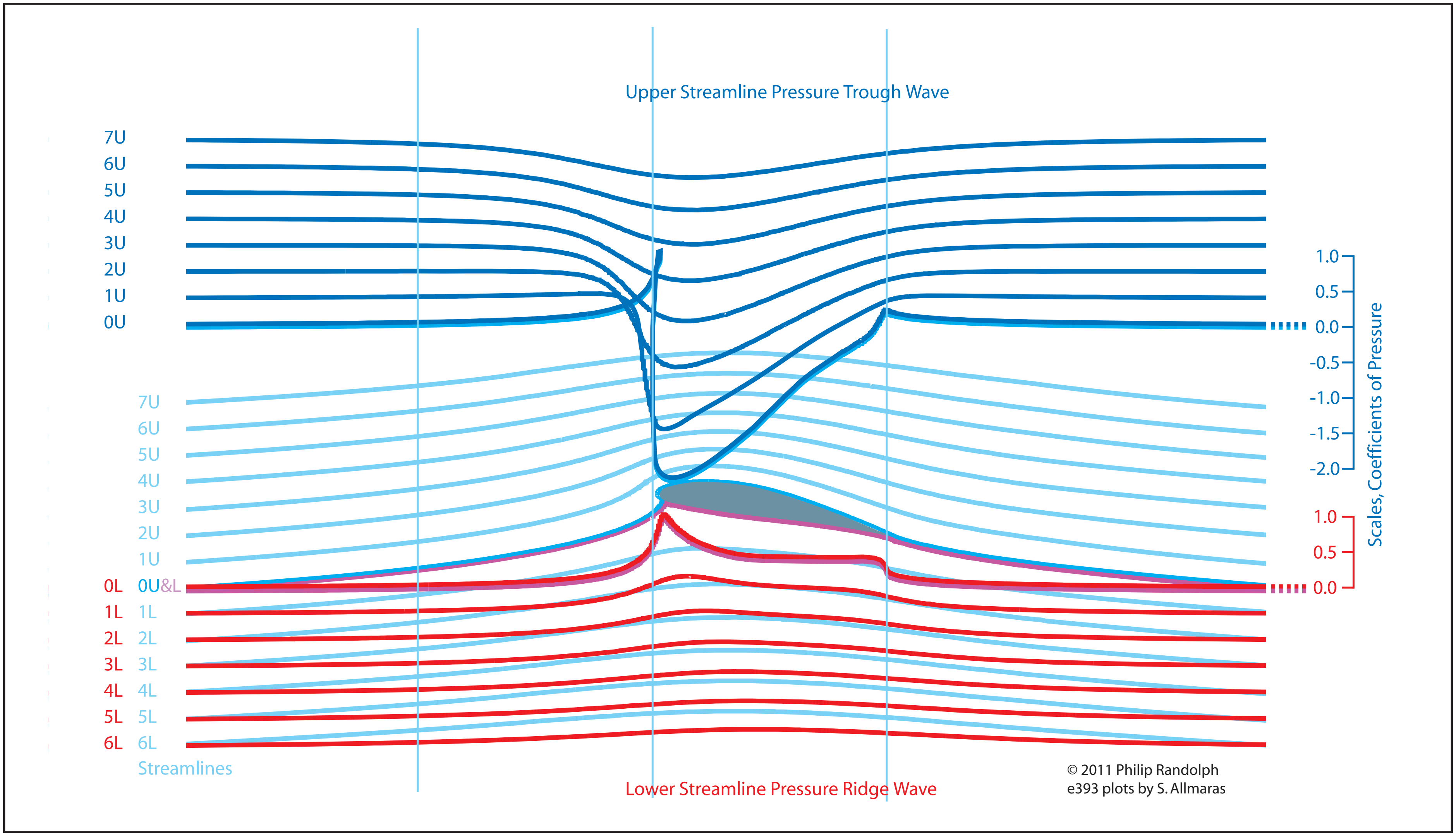


Figure 22: Upper and lower pressure waves along streamlines. Energy in springs is stored either by compression or stretch. Waves along a spring are an exchange of momentum for tension or compression. It's the same for pressure gradients — raised or lowered, they store energy, that around a wing is temporarily exchanged for velocity of air, kinetic energy. Such energy patterns are 'carried along' in constant relation to the wing, though leaking a little to wingtip vortices. The pressure gradient down toward the low pressures above the wing bends flows down, and keeps flows 'attached' to the wing. The equal and opposite force, the difference between low-pressures above the wing and slightly raised pressures below, is lift.
© 2011 Philip Randolph, e393 plot by S. Allmaras

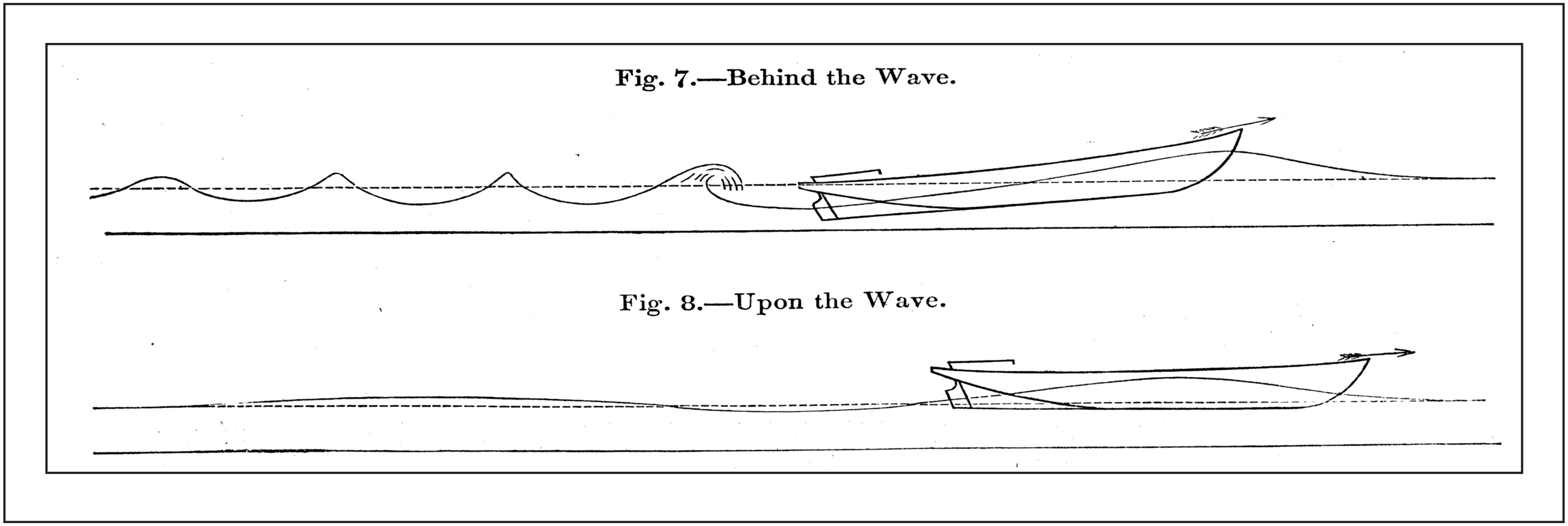


Figure 23: Russell's 1839 sketches of a canal boat towed at speeds less than and greater than the speed of its solitary wave.

Through the 1830s, till railroads took over, sixty-foot, five-ton, horse-drawn 'flyboats' operated on a couple Scottish canals, at dazzling speeds of eight to thirteen miles per hour.

In 1834[71], Russell was puzzling over the 'diminished resistance' of such a horse-towed canal boat, when it suddenly stopped, presumably grounded. (And this could be considered as the second demonstration by a horse.) A 'great, solitary wave' continued. Russell followed it on horseback for more than a mile, during which it diminished little. He later discovered that such waves may be 'positive' (raised) or 'negative' (trough) waves. Russell's solitary waveforms are now called, 'solitons,' and provide a theoretical basis for lasers, some acoustics, tidal and tsunami analysis, and here, for Lanchester's wing-wave.

Russell applied his 'solitary wave' observations to flyboats. When the boat equaled or exceeded the speed of the solitary wave it forced, it would rise up, lifted by its wave, and bow and stern waves would diminish. See Figure 23.[72]

The wing equivalent of the flyboats' diminished wake and lowered 'resistance' (lowered drag) is the smooth sheet-downwash behind wings (away from wingtips), and the surprisingly low energy use of many airplanes. For boats or wings, it's all indication of wave energy recovery, or, in Lanchester's terms, a 'conservative system.'

Russell also called his solitary waves, 'waves of translation.' By 'translation,' Russell meant that water in the wave was permanently displaced, forward in his 'positive' wave, and backwards in his 'negative' (trough) wave. Russell was contrasting his solitary wave displacement with the complete circular motions within von Gerstner's repetitive waves.

The 'flyboats' *lifted and rode on 'forced,' 'positive waves of translation.'*[73] They rode on a pressure ridge, a forward moving pattern of forward displacements. That's very similar to what happens below a wing, at significant angles of attack.

The wave above a wing is Russell's 'negative wave of translation.' It's also a forced, low-pressure-trough wave. As in our earlier Slinky® analogy, it's a forward moving pattern of backward displacements. Its forced form, on water, is illustrated by how a buoy in a current, or a displacement hull, will be sucked downward, by centrifuged low pressures around their curved undersides. The flows above a wing are in precisely such a forward-moving wave pattern, with backward displacements of previously still air, though upside down from our buoy. See Figure 24.

The backward displacement of previously still air above a passing wing, combined with the forward displacement below, makes a pattern of movement that sticks with the wing, even as its component molecules are left behind, dubbed 'circulation.'

Russell quantified how 'resistance' was lower at shallower canal depths. Kelvin, speaking in 1891, said, "and the horse certainly found this…"[74] Such Russell or horse analysis should establish 'ground effect' (lowered drag of wings close to the ground) as a forced, solitary wave phenomenon.

Unfortunately, unlike floatplanes, Russell's concept of wave lift failed to make the difficult

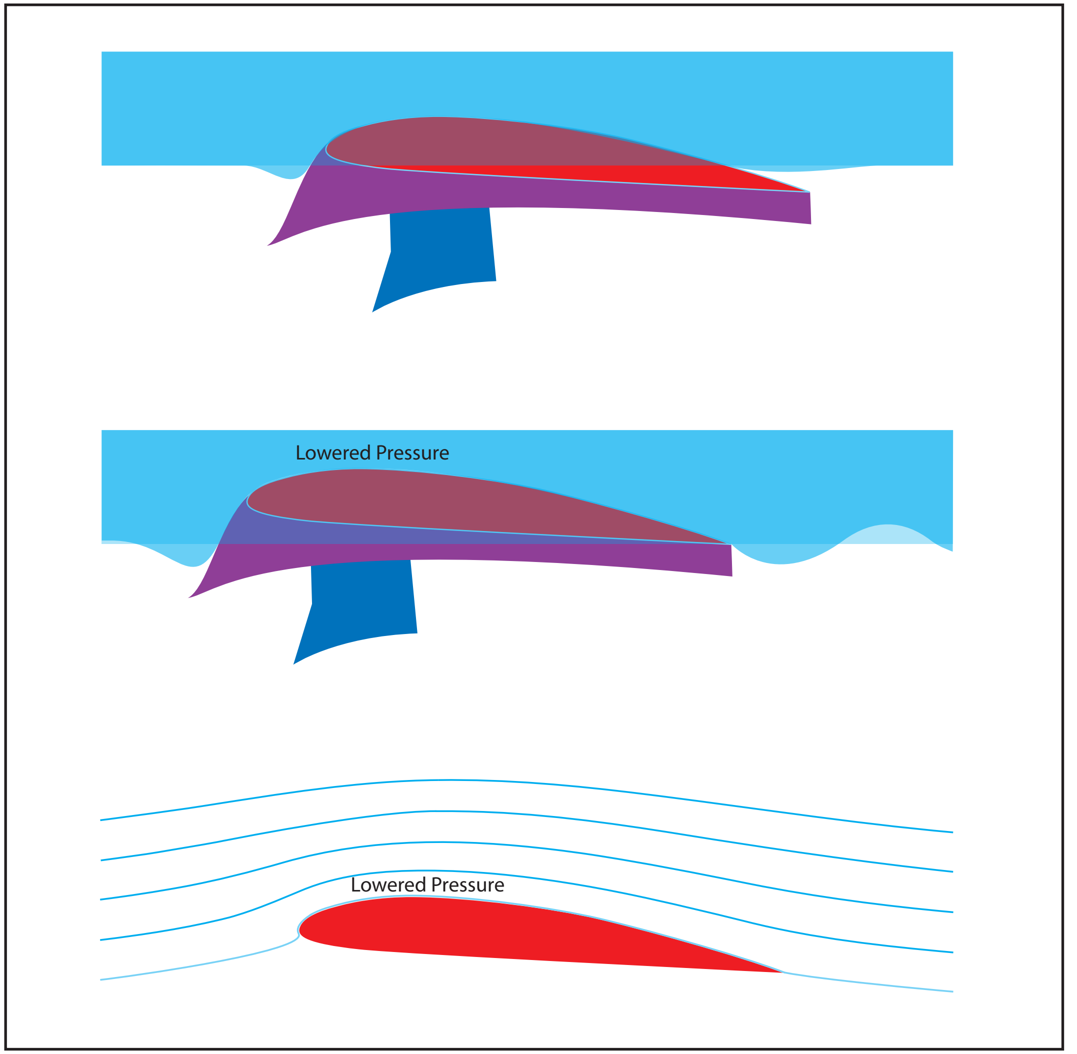


Figure 24: Airfoil boat. Displacement hulls and buoys lift downwards in the same way Russell's 'negative solitary wave' lowers pressure on a wing's upper surface. As a displacement boat hull picks up speed, it centrifuges a lowered pressure beneath it and 'lifts' down into water in the same way a wing centrifuges a lowered pressure above it, and lifts, up. The negative lift on a hull (lowered pressures) is in balance with buoyancy and weight. The lift on a wing is the difference between lowered pressures above and less-changed pressures below. © 2011 Philip Randolph

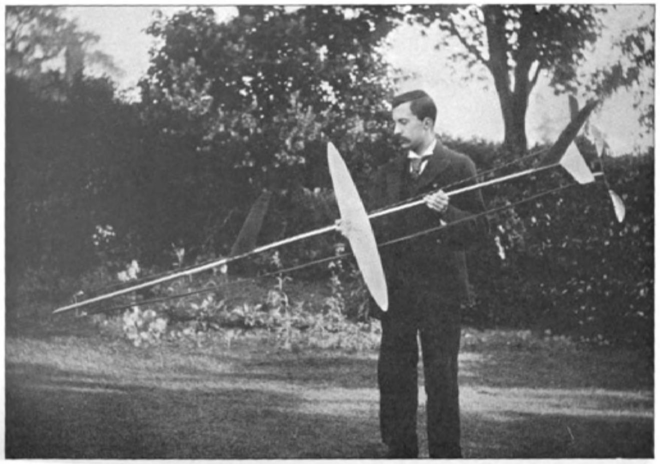


Fig. 163.

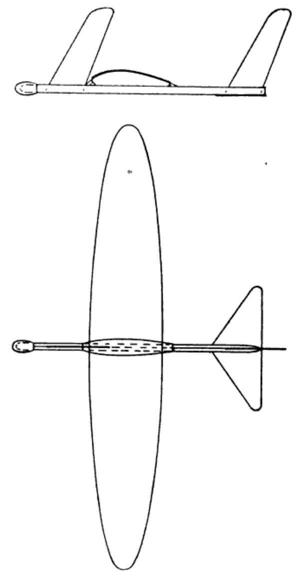


Fig. 151.

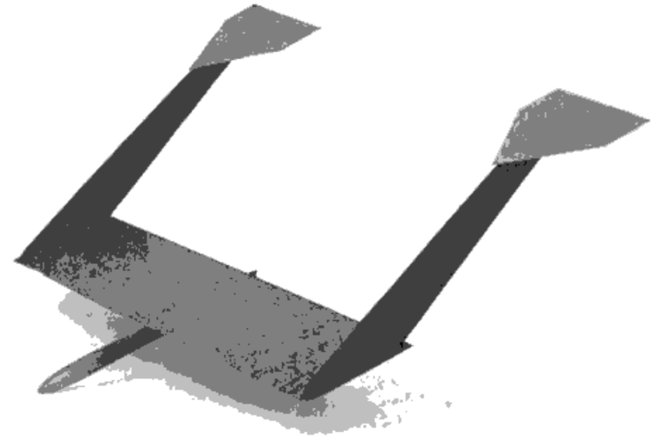


Fig. 152.

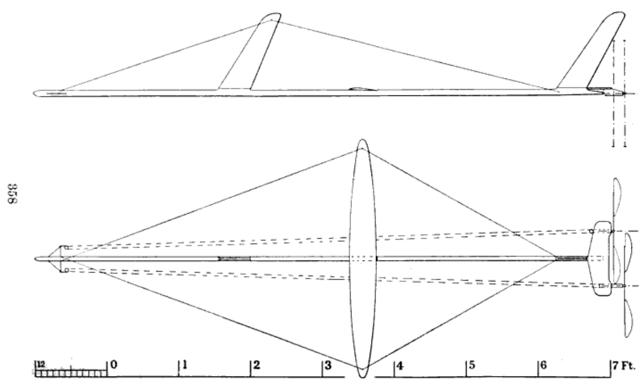
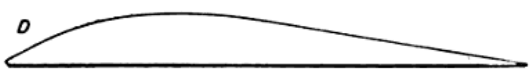


Fig. 164.



Above left: Frederick William Lanchester with his 1894 'aerodrome,' plans at left. Over 7' long with a 40" elliptical span, it had twin, self-feathering, aluminum propellers powered by India rubber 'elastics' and a catapult launch. It flew 133 yards in 4.5 seconds, ending in an elm tree.

Wing sections, as shown below left, were about 10% thick, flat-bottomed with a sharp leading edge, and the thickest point about a third back from the leading edge.

After 1905, Lanchester used lamina of mica, sometimes less than 1/1000", for airfoil surface in flight-test models weighing between 1 grain (0.06 grams!) and 12 grams. He called these later models 'aerodones,' a term which did not stick, but gave a name to his second book, largely devoted to stability issues, "Aerodonetics."

The mica model 'Fig. 151,' above, weighed 0.24 grams.

The cedar model 'Fig 152,' above right, weighed 46.3 grams. Each had about a 1/3 glide ratio.

transition from water to air. That transition, into air, must be difficult, because here it is, well over a century after Lanchester's initial, 1894 presentation of his theory of wing-wave lift, which I hope will now fly.

Ergo sum

These multiple wave analyses should convincingly establish the fact of the wing wave, most of the mechanisms of its energy recovery, and how the wing wave contributes to subsonic flight efficiency. But the fact of the wing wave is not so much a conclusion as a starting point. What else does it do for understanding flight? And how? Some of the answers are through Lanchester's analysis that all airplanes are technically gliders, knowing nothing of horizons or where forces come from, but happily coasting 'down' the vector sum of thrust and gravity.[75] More answers are via Lanchester's second, great, partially missed contribution, that airplanes fly within the sinking vortex pattern of flows. That's another article.

In memorium

'If the flow over a wing looks and acts somewhat like a water surface wave or earthquake wave crest, if it has a pattern of restorative forces and motions similar to those of surface waves, if it has the elliptical or partial elliptical internal motions and circulation velocities typical of surface waves, if it looks like the standing wave over a rock in a creek, and if it also obeys the rules of pressure waves, if it localizes and recovers energy forms in standard wave exchanges of potential and kinetic energy (pressures and motions, and for some waves, crest elevation), so that it perpetuates and travels in the efficient manner of waves, if it moves faster than its medium, as do all traveling waves, if, like many surface waves, it creates upwash that then reverses to downwash, and if it focuses additional recovered energy into that upwash, toward a crest that a wing rides in a similar manner to how 1830's 'flyboats' once rode waves…'

— Frederick William Lanchester, 1868 - 1946.

Endnotes:

1 Frederick William Lanchester, Aerodynamics: Constituting the First Volume of a Complete Work on Aerial Flight, vol. 1 (A. Constable & co., ltd., 1907), 142, <http://books.google.com/books?id=yLc3AAAAMAAJ&lr=>.

[This diagram is from 1894, as Lanchester explains: — PR.]

"The author gave a resume of his theory in a paper read at the annual meeting of the Birmingham Natural History and Philosophical Society on June 19th, 1894, a wall diagram of which Fig. 68 is a reproduction being exhibited." [Lanchester's 1894 'supporting wave' as a wall diagram from his 1894 talk, 142] <http://books.google.com/books?id=yLc3AAAAMAAJ&printsec=frontcover#v=onepage&q&f=false>

2 Olivier Darrigol, Worlds of Flow: A History of Hydrodynamics from the Bernoullis to Prandtl (Oxford University Press, USA, 2005), 305 – 308.

3 Lanchester, Aerodynamics, 1: viii – ix, 142, 160 – 162.

"Chapter IV. Consists in most part of an investigation on peripteral motion,[2] dating from the year 1894 - 5 and offered to the Physical Society of London in the year 1897, but rejected." [Lanchester, on his paper's rejection. 1907, viii] <http://books.google.com/books?id=yLc3AAAAMAAJ&printsec=frontcover#v=onepage&q&f=false> [Lanchester, 1907, 142] <http://books.google.com/books?id=yLc3AAAAMAAJ&pg=PA142#v=onepage&q&f=false>

["The hydrodynamic interpretation…added subsequently…" sections of Chapter IV start by pages 160 or 162. — PR.]

4 Frederick Winsor and Marian Parry (illustrator), The Space Child's Mother Goose, 1st ed. (Purple House Press, 2001).

5 “This is the Erudite Verbal Haze/Cloaking Constant K/That saved the Summary/Based on the Mummery/Hiding the Flaw/ That lay in the Theory that Jack built.”

Lanchester, Aerodynamics, 1: 142.

6 Theodore von Kármán and Lee Edson, The Wind and Beyond: Theodore Von Karman, Pioneer in Aviation and Pathfinder in Space, First ed. (Little, Brown and Company, 1967), 60.

7 Lanchester, Aerodynamics, 1: 156.

8 Darrigol, Worlds of Flow, 32.

9 Ibid., 308.

10 J. A. D. Ackroyd, “Lanchester's Aerodynamics,” in Lanchester Legacy: A Celebration of Genius: A Trilogy of Lanchester Works, ed. John Fletcher (Coventry University, 1996), 61 – 98.

11 John D. Anderson Jr., A History of Aerodynamics: And Its Impact on Flying Machines (Cambridge University Press, 1999), 244 – 247.

12 John David Anderson, Fundamentals of Aerodynamics (McGraw-Hill, 1991), 366 – 368.

13 Darrigol, Worlds of Flow, 308.

14 Allmaras, S. (Plot), Asymmetric Circulation. E64 Airfoil Velocity Field Less Freestream Velocities, 2009.

15 Lanchester, Aerodynamics, 1: 157.

> …the portion of the fluid transversing [the wing] will be ultimately left with some residual downward momentum, which must be equal to the total upward momentum received by the regions [surrounding such downwash], for otherwise there would be a continual accumulation, or else attenuation, of the field in the lower strata of the atmosphere, which is impossible. Lanchester, Aerodynamics, 1: 157.

16 Sir Horace Lamb, Hydrodynamics, 2nd ed. (University press, 1895), 414, <http://books.google.com/books?id=d_AoAAAAYAAJ&printsec=frontcover&dq=hydrodynamics,+lamb&ei=0qpuTcPGLobilATXusnnAQ&cd=1#v=onepage&q&f=false>.

[Gerstner's wave circle diagram as interpreted by Lamb, 1895, p. 414.] <http://books.google.com/books?id=d_AoAAAAYAAJ&dq=hydrodynamics%252C%20lamb&pg=PA414%23v=onepage&q=Gerstner&f=false#v=snippet&q=Gerstner&f=false>

> Gerstner's original diagram is in: Abhandlung über die Theorie der Wellen, reproduced Darrigol p.72, interpreted in Rouse-Ince, History of Hydraulics, 111.

17 Hunter Rouse and Simon Ince, History of Hydraulics (Iowa Institute of Hydraulic Research, State University of Iowa, 1957), 110 – 111.

18 Daniel A, Ph.D Russell, “Longitudinal and Transverse Wave Motion,” February 12, 2012, <http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html>.

[Dr. Russell's animations of water and earthquake waves] <http://www.acs.psu.edu/drussell/Demos/waves/wavemotion.html>

19 Lamb, Hydrodynamics, 412.

> It appears therefore that the motion of the individual particles, in these progressive waves of permanent type is not purely oscillatory, and that there is on the whole a slow but continued advance in the direction of wave propagation.*… * Stokes l.c. ante, p. 409. Another very simple proof of this statement has been given by Lord Kayleigh l.c. ante, p. 279.

> A system of exact equations, expressing a possible form of wave motion when the depth of the fluid is infinite, was given so long ago as 1802 by Gerstner†, and at a later period independently by Rankine. …† Professor of Mathematics at Prague, 1789 - 1823.

20 Ibid.

21 S. Allmaras, E393 10° Streamline Plot, 2009.

22 Isaac Newton, “A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; Containing His New Theory About Light and Colors: Sent by the Author to the Publisher from Cambridge, Febr. 6. 1671/72; In Order to Be

Communicated to the R. Society," Philosophical Transactions 6, no. 69 – 80 (January 1, 1671): 5, <http://rstl.royalsocietypublishing.org/content/6/69-80/3075.short>.

[Newton's letter on light, 1671] <http://rstl.royalsocietypublishing.org/content/6/69-80/3075.short>

23 Benjamin Robins, New Principles of Gunnery: Containing the Determination of the Force of Gun-powder, and an Investigation of the Difference in the Resisting Power of the Air to Swift and Slow Motions, with Several Other Tracts on the Improvement of Practical Gunnery (F. Wingrave, 1805), xxviii, <http://books.google.com/books?id=3j8FAAAAMAAJ&lr=>.

[Dr. Wilson, ed., quotes Robins quoting Newton. xxviii] <http://books.google.com/books?id=3j8FAAAAMAAJ&pg=PA213#v=twopage&q&f=false>

24 Newton, "A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; Containing His New Theory About Light and Colors: Sent by the Author to the Publisher from Cambridge, Febr. 6. 1671/72; In Order to Be Communicated to the R. Society."

25 Robins, New Principles of Gunnery, 213 – 214.

26 Gustav Magnus, "On the Deviation of Projectiles; and on a Remarkable Phenomenon of Rotating Bodies, [From the Memoirs of the Royal Academy, Berlin, 1852.]," in Scientific Memoirs, Selected from the Transactions of Foreign Academies of Science, and from Foreign Journals. Natural Philosophy, vol. 1 (Taylor and Francis., 1853), 210, <http://books.google.com/books?id=C1i4AAAAIAAJ&lr=>.

Robins, who first attempted, in his ' Principles of Gunnery,' to account for this deviation, thought that the deflecting force was generated by the rotation of the projectile; and at present this opinion is generally accepted. [Magnus cites Robins, 210]

27 Ibid., 218 – 219.

28 Baron John William Strutt Rayleigh, "On The Irregular Flight of a Tennis-Ball," in Scientific Papers: 1869 - 1881, 1877, 344 – 346, <http://books.google.com/books?id=Gs4EAAAAYAAJ&q=tennis+balls#v=onepage&q&f=false>.

29 David Bloor, The Enigma of the Aerofoil: Rival Theories in Aerodynamics, 1909 - 1930 (University of Chicago Press, 2011), 128 – 131.

30 Lanchester, Aerodynamics, 1: 42 – 43.

[Lanchester's spinning ball lift, 1907, 42 - 43] <http://books.google.com/books?id=yLc3AAAAMAAJ&pg=PA42#v=twopage&q&f=false>

31 George Gabriel Stokes, "On the Friction of Fluids in Motion and the Equilibrium and Motion of Elastic Solids [From the Transactions of the Cambridge Philosophical Society, Vol VIII, P. 287.] 1845," in Mathematical and Physical Papers, George Gabriel Stokes and Baron Rayleigh John William Strutt, vol. I (University Press, 1880), 76, <http://books.google.com/books?id=_YnvAAAAMAAJ>.

32 Darrigol, Worlds of Flow, 311.

"The remarkably simple formula $L = \rho\Gamma V$ is now called the Kutta-Joukowski theorem. However, Kutta did not explicitly identify Γ with the circulation of the air around the foil. Nor did he refer to Rayleigh›s tennis-ball problem as the origin of formula (7.31) for the irrotational flow around a circular cylinder…» - Darrigol

33 Anderson, A History of Aerodynamics, 248.

"Kutta's equation was derived without recourse to the concept of circulation; indeed, at that time, he was not aware of Lanchester's work. Kutta's image of the flow over an airfoil was that described in a more fundamental sense by the governing flow equations (the Euler equations), rather than the more abstract image of a synthesized flow combining uniform flow and circulatory flow…" - John D. Anderson

34 Ibid., 314.

"He [Joukowski] applied these notions to the rotating blade and to the vortex pair behind a plate immersed perpendicularly in a uniform stream. He did not consider the case of an airfoil or wing, in which he may not yet have understood that circulation-flow occurred." – Anderson

35 Wilhelm Kutta, "Auftriebskräfte in Strömenden Flüssigkeiten.," Illustrirte Aeronautische Mittheilungen 6 (1902): 133.

36 Nikolai Joukowski, "De La Chute Dans L'air De Corps Légers De Forme Allongée, Animés D'un Movement Rotatoire' (On the Fall Through Air of a Light Elongated Body Possessing Rotational Movement)," Bulletin De L'institut Aérodynamique De Koutchino 1 (1906).

37 Darrigol, Worlds of Flow, 311.

107...Kutta ([1910] p. 3) credited Lanchester for the concept of wing circulation. [Darrigol's footnote includes date in brackets - PR]

38 Anderson, A History of Aerodynamics, 282 – 287.

39 Lamb, Hydrodynamics, 412 – 418.

40 Otto Lilienthal, Birdflight as the Basis of Aviation: a Contribution Towards a System of Aviation, Compiled from the Results of Numerous Experiments Made by O. and G. Lilienthal (Markowski International Pub., 2001), 59.

41 Otto Lilienthal, Der Vogelflug Als Grundlage Der Fliegekunst: Ein Beitrag Zur Systematik Der Flugtechnik (R. Gaertner, 1889), 86, <http://books.google.com/books?id=GWsaAAAAYAAJ&lr=>. [Lilienthal's 1899 centrifugal diagram] <http://books.google.com/books?id=GWsaAAAAYAAJ&pg=PA86#v=onepage&q&f=false>

42 Klaus Weltner and Martin Ingelman-Sundberg, "Physics of Flight - Revisited," 2000, sec. 4, <http://user.uni-frankfurt>.de/~weltner/Flight/PHYSIC4.htm>. [Physics of Flight Reviewed] <http://www.uni-frankfurt.de/service/404.html>

43 Darrigol, Worlds of Flow, 306.

44 William Thomson Kelvin, "Lord Kelvin | On Vortex Atoms," 1867, <http://zapatopi.net/kelvin/papers/on_vortex_atoms.html>. [On Vortex Atoms, Kelvin] <http://zapatopi.net/kelvin/papers/on_vortex_atoms.html>

45 Lanchester, Aerodynamics, 1: 145, 152, 157, 176.

[Lanchester's 'vortex fringe' and diagram, 1907, 145] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA145#v=onepage&q&f=false>

[Lanchester's diagram of upward momentum outboard of wingtips, 1907, 157] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA157#v=onepage&q&f=false>

Lanchester's acceleration fields up around a sinking flat plate, here for wingtip vortices, but similar to his wave acceleration field, 1907, 176] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA176#v=onepage&q&f=false>

46 Ibid., 1: 176.

47 Ibid., 1: 155.

48 Lanchester, Aerodynamics, 1: 155 – 156. [Lanchester on his wave conclusion] <http://books.google.com/books?id=yLc3AAAAMAAJ&pg=PA155#v=onepage&q&f=false>

49 Ibid.

50 Ibid., 1: 176. [Lanchester's diagram of his 'acceleration field,' and of wingtip vortices as the sum of vortex filaments, later mathematized by Prandtl] <http://books.google.com/books?id=yLc3AAAAMAAJ&pg=PA176#v=onepage&q&f=false>

51 Ibid., 1: 158 – 159.

[Lanchester on lift from upwash reversed to downwash, 1907, 158 - 159] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA158#v=twopage&q&f=false>

52 Ibid., 1: 160.

[Lanchester on aspect ratio and conservation, 1907, 160] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA160#v=onepage&q&f=false>

53 Ibid., 1: 146 – 149.

When we consider part of the support of a body as derived from an up-current, it is necessary to examine the origin of the up-current, for it is evident that the generation of such a current must give rise to a downward reaction, and everything depends upon whether such reaction is borne by the body itself or by the deeper layers of the air, and eventually by the earth's surface. [146]

…Such a case is exemplified in the dynamical theory of heat when a loaded piston is supported by gaseous pressure in a closed cylinder. We could also suppose it to be effected by imbuing the supported body with sufficient intelligence and skill so to direct the particles that they would always rebound within its reach. [147]

54 Ibid., 1: 146.

It is evident that the problem as above presented [a sinking glider or aeroplane] is in effect identical with that of an inclined plane moving horizontally — that is to say, the relative direction of the horizon is not of importance. The force of gravity in the one case [of a gliding plane] can be substituted by the resultant of the force of gravity and an applied force of propulsion in the other [a powered plane]. [PR brackets]

55 Ibid., 1: 170.

[Lanchester's 1907 thick wing, 170] <http://books.google.com/books?id=yLc3AAAAMAAJ&pg=PA170#v=onepage&q&f=false>

56 Anderson, A History of Aerodynamics, 246 – 247.

57 Randolph, Philip (graphics), S. Allmaras (e393 airfoil 10° flow plot), Lower Air "Squeezed" Forward, 2009.

58 Lilienthal, Birdflight as the Basis of Aviation, 56.

59 Lanchester, Aerodynamics, 1: 227, 230.

[Lanchester's 'no-upwash' diagram, 1907, 237] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA227#v=onepage&q&f=false> [Lanchester's 'upwash' diagram, 1907, 230] <http://books.google.com/books?id=yLc3AAAAMAAJ&vq=magnus&lr&pg=PA230#v=onepage&q&f=false>

60 Randolph, Philip (graphics), S. Allmaras (pressure plot, e64 airfoil, 5°), Flow Similarity, 2011.

61 Darrigol, Worlds of Flow, 172 – 173, 178 – 179.

62 Ibid.

63 Ibid., 190.

64 Fran Cesca Oliva, Kelvin-Helmholtz, "Sunrise Waves" Photo, Photo, n.d.

[10/25/2011 Permission for use by the photographer, Fraces Oliva, to be credited to 'Cesca' — PR]

65 Randolph, Philip (graphics), S. Allmaras (pressure plot, e64 airfoil, 5°), Flow Similarity.

66 Bloor, The Enigma of the Aerofoil, 50.

67 S. Allmaras, E393 10° Streamline and Pressure Plots, 2009.

68 Randolph, Philip (graphics), S. Allmaras (pressure plot, e64 airfoil, 5°), Flow Similarity.

69 Baron William Thomson Kelvin, "On Ship Waves. [Lecture Delivered at the Conversazione of the Institution of Mechanical Engineers in the Science and Art Museum, Edinburgh, on Wednesday Evening, 3re August, 1887.]," in Popular Lectures and Addresses, Volume 3 (Macmillan and Co., 1891), 470 – 472, <http://books.google.com/books?id=SUMKAAAAIAAJ&lr=>.

I say his [Russell's] discovery, but in reality the discovery was made by a horse… ["I say his [Russell's] discovery, but in reality the discovery was made by a horse..." - Kelvin, 1887, 470] <http://books.google.com/books?id=SUMKAAAAIAAJ&pg=PA470#v=onepage&q&f=false>
[Kelvin in 1887, quoting Russell 1837 & 1840, 472] <http://books.google.com/books?id=SUMKAAAAIAAJ&pg=PA472#v=twopage&q&f=false>

70 Ibid., 471 – 472.

These experimental researches led to the Scottish system of fly-boats carrying passengers on the Glasgow and Ardrossan Canal, and between Edinburgh and Glasgow on the Forth and Clyde Canal, at speeds of from eight to thirteen miles an hour, each boat drawn by a horse or pair of horses galloping along the bank. The method originated from the accident of a spirited horse, whose duty it was to drag the boat along at a slow walking speed, taking fright and running off, drawing the boat after him 'and it was discovered that, when the speed exceeded the velocity acquired by a body falling through a height equal to half the depth of the canal (and the horse certainly found this), the resistance was less than at lower speeds.' [Kelvin, 1887, 471] <http://books.google.com/books?id=SUMKAAAAIAAJ&dq=Kelvin&lr=&pg=PA470#v=onepage&q&f=false>

71 Darrigol, Worlds of Flow, 48 – 49.

72 John Scott Russell, "Experimental Researches into the Laws of Certain Hydrodynamical Phenomena That Accompany the Motion of Floating Bodies, and Have Not Previously Been Reduced into Conformity with the Known Laws of the Resistance of Fluids," Transactions of the Royal Society of Edinburgh 14 (1839): 66 – 67.

73 Darrigol, Worlds of Flow, 54 – 55.

[PR Note: Darrigol reproduces Russel's chart, "System of Water Waves," including a "Positive" and "Negative," "Wave of translation," both "Free" and "Forced."]

(i) Waves of translation. They involve mass transfer. Positive waves of this kind can be solitary. Negative ones are always accompanied by an undulating series of secondary waves (see Fig. 2.13). – Darrigol

74 Kelvin, "On Ship Waves. [Lecture Delivered at the Conversazione of the Institution of Mechanical Engineers in the Science and Art Museum, Edinburgh, on Wednesday Evening, 3re August, 1887.]," 471.

See previous endnote quote.

75 Lanchester, Aerodynamics, 1: 146.

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DEUTSCHER AERO CLUB E.V.

Mitglied der Fédération Aéronautique Internationale und des Deutschen Olympischen Sportbundes

BUNDESKOMMISSION MODELLFLUG – SA SEGELFLUG

www.modellflug-im-daec.de

FAI World Championship for Soaring Model Aircraft F3F 2012
Kap Arkona / Germany

October 6th – October 13th

Bulletin 1

Bulletin 0 for the FAI World Championship F3F 2012
German Aero Club

Impressions from the Viking Race 2004 Kap Arkona

Type of Event:	**World Championship**
Event Classification:	**1st Category Event**
Title of Event:	**1st FAI World Championship for Slope Soaring Model Aircraft F3F 2012**
Date of Event:	October 6th – 13th 2012
Location:	**Kap Arkona / Isle of Rügen / Baltic Sea**
Organizer:	**German Aero Club (DAeC)** Bundeskommission Modellflug (Aeromodelling Commission) Sub-committee Soaring classes
Official homepage:	www.f3f.de

Invitation
The German Aero Club (DAeC) invites all Active or Associated Members of FAI (as defined by FAI SC Gen Sec 3.5.4.3) to participate with a team in the 1st FAI World Championship for Slope Soaring Model Aircraft F3F.

Junior World Championships
The World Championships will include a junior classification, according to SC4 Vol ABR B.3.4. and B.3.5. NACs may enter a junior competitor by adding him/her to the senior team or even as their only representative. The title of a Junior World Champion will be awarded if competitors participate from at least four different nations. Regardless of the number of competitors, the organizer will honour the achievement of junior competitors at the official award ceremony. **Entry fee for juniors 165 € only!**

Participation
The NACs respective Associated Members may enter a Team consisting of one Team Manager, three senior pilots, one junior pilot and helpers. Supporters from all participating countries are welcome.

Event- and Organization Director on behalf of the Aeromodelling Commission of the DAeC:
Franz Demmler, Merbitzer Straße 16, D-01157 Dresden, phone +49-351-2036650
mobil +49-1520-1736109, e-mail franz.demmler@f3f.de

Contest Director, on behalf of the Aeromodelling Commission of the DAeC:
Armin Hortzitz, Joseph-Schwarz-Weg 31, 81479 Munich, armin.hortzitz@arcor.de

Flight-Line-Management
Uwe Schönlebe, Jochen Kirsten, Robert Matthes

The Office to turn to is run by Executive Secretary Michael Thoma, DAeC, Hermann-Blenk-Str. 28, 38108 Braunschweig, e-mail m.thoma@daec.de, phone +49-531-23540-56 fax +49-531-23540-11

Entry Fees

Competitors	€ 330,00	This covers participation to the World Championships, access to the flight line area, entry to Opening Ceremony/Party and reception, souvenirs and gifts and includes the Banquet Fee.
Team Managers	€ 330,00	This covers participation to the World Championships, access to the flight line area, entry to Opening Ceremony/Party and reception, souvenirs and gifts and includes the Banquet Fee.
Helpers	€ 66,00	This covers participation to Worlds Championships, access to the flight line, entry to Opening Ceremony/Party and reception, souvenirs and gifts.
Supporters	€ 50,00	This covers access to the World Championship, entry to Opening Ceremony/Party and reception, souvenirs and gifts.
Banquet Fee	€ 30,00	**Not nessecary for 1 - 2**

Terms of Payment
Entry Fees to be transferred no later than August 10th, 2012

Recipient	Address of Bank	Intern. Money Transfer
Deutscher Aero Club Attn. Michael Thoma Hermann-Blenk-Strasse 28 D-38108 Braunschweig	Deutsche Bank PGK AG Branch Bank Querum Bevenroder Straße 123 D-31108 Braunschweig Germany	BIC: DEUTDEDB270 IBAN: DE92270700240344499904 Title: F3F WCh 2012, Country

FAI-Jury:
Tomás Bartovský (CZE, S/C F3 Soaring Chairman, President)
Gerhard Wöbbeking (GER, CIAM 1st Vice-President)
Franz Prasch (AUT)
Emil Giezendanner (SUI, S/C F5 Chairman, Reserve)

Competition Rules
The event will be run according to the FAI Sporting Code, Section 4, Vol F3 Radio control Soaring Model Aircraft 2012 edition

Frequencies
2.4 GHz transmitters have to fulfil European Standard EN 300328. The maximum equivalent emission power EIRP is 100 mW peak. The transmitter must be CE marked and bear the declaration of conformity. Other transmitters for model aircraft must use the legal frequencies approved by the German "Federal Network Agency" (Bundesnetzagentur) in the 35 MHz-Band. See the list of frequencies on the websites; frequencies within the 27 MHz- and the 40 MHz-Band are not recommended.

Protest
Team Managers are entitled to file a complaint or to lodge a protest. Protest fee as stated SC4 Vol ABR B.18.1. Euro 35. If the protest is upheld the deposit is to be returned.

Anti-doping
In case a competitor has to take any of the substances listed on the 2012 WADA Prohibited List for medical treatment he/she must bear a Therapeutic Use Exemption from the FAI, applied for no later than 21 days before the event. All participants of the F3F event shall assure their acceptance of the FAI Anti-Doping Rules with their signature on the "Acknowledgement and Agreement" form (see Bulletin 2).

Documents to be presented at registration:
- Entry form signed and stamped by the National Aero Club / National Federation
- FAI Licenses of competitors and Team Managers
- Proof of payment of entry fee
- Model certificates to be presented during model processing

Certificates + FAI Licences will be returned to the Team Managers after the Closing Ceremony. Please note: Flags and anthems are provided by the organizer and need not be brought by the national teams.

Awards
FAI medals and Cups will be awarded to the first three individual places for senior and for junior pilots. FAI medals will also be awarded to the first three teams (competitors and their Team Managers). FAI diplomas for the first three individuals and teams, all other competitors will receive diplomas of the inviting NAC.

Official Language
Official Languages are English and German.

Timetable

Saturday October 6th
Arrival
09:00 – 18:00 Processing and registration in the headquarter
09:00 – 18:00 **FAI-World-Cup "German Open F3F" 1st day**

Sunday October 7th
09:00 – 15:00 Processing and registration in the headquarter
09:00 – 17:00 **FAI-World-Cup "German Open F3F" 2nd day**

18:00 **Team manager meeting** in the Headquarter

20:00 **Opening ceremony** with reception of all teams and public concert with the ***Philharmonic Brass Orchestra*** of the Semper-Opera Dresden

Monday October 8th
09:00 – 18:00 Rounds

Thuesday October 9th
09:00 – 18:00 Rounds

Wednesday October 10th
09:00 – 18:00 Rounds

Thursday October 11th
09:00 – 18:00 Rounds

Friday October 12th
09:00 – 18:00 Rounds

Saturday October 13th Reserve day
18:00 Prize Giving Ceremony in the Rügenhof
19:30 Dinner-Bankett

Foods and Beverages
Because of the different venues it's up the participants to buy foods and beverages for lunch at the slopes. A big Supermarket in Altenkirchen, 6 km away from Putgarten, meets all needs. In the evenings it is good practice to gather in the restaurants and pubs in Putgarten. With self catering mainly one may count 15 € per person and day for foods and beverages.

Banquets
will take place Sunday October 7th, from 19:00 hours at the opening ceremony and Saturday October 13th after the Prize giving Ceremony. Both banquets are free for registered Competitors and Team Managers, drinks not included. Additional tickets for Saturday € 30 per person, drinks not included. Additional tickets to be ordered during registration. The banquets will be hosted at the barn in the Rügenhof Putgarten.

International Airports
Airport Berlin-Schönefeld (370 km)
Airport Hamburg (370 km)

Figure 1 and 2: Area **Kap Arkona**
54°40'20.90'' N
13°24'50.74'' E
www.kap-arkona.de

Venue

The area at Kap Arkona on the Island of Rügen is one of the best known and most appreciated F3F areas worldwide. Slopes for all wind directions are available and the location has the highest probability for wind within Germany. Based on the experience of the organizer, the month of October has proven to be particularly well suited.

The slopes are exclusively cliff lines directly facing the Baltic Sea. Therefore relatively even lift conditions without significant thermal influence are guaranteed. The competition is supported by the local authorities and the hosting municipality of Putgarten, so - during the period of the World Championship - unrestricted flying at the otherwise closed ridges is permitted.

STATION : ARKONA (WST)
AUSWERTUNGSZEITRAUM: 1976 - 1995

Relative Häufigkeitsverteilung der Windgeschwindigkeit in den Windrichtungssektoren

OKTOBER
Angaben in Promille

Windgeschwindigkeit in m/s	Sektoren in Dekagrad 35-01	02-04	05-07	08-10	11-13	14-16	17-19	20-22	23-25	26-28	29-31	32-34	UML	SUMME
0,1 - 1,0	1	1	1	2	1	2	1	2	2	3	2	2	1	21
1,1 - 2,0	2	1	1	3	1	2	3	4	4	3	4	3	0	34
2,1 - 3,0	3	1	2	5	2	5	7	6	10	4	5	4	0	54
3,1 - 4,0	4	2	3	5	4	7	10	11	13	7	6	4		76
4,1 - 5,0	3	2	2	7	5	9	11	15	18	9	6	4		92
5,1 - 6,0	3	2	4	8	6	9	14	20	19	10	7	4		106
6,1 - 7,0	3	3	2	8	7	10	13	19	21	10	7	4		106
7,1 - 8,0	2	2	2	10	8	9	10	21	20	14	7	4		110
8,1 - 9,0	1	2	2	9	6	6	9	13	17	10	7	3		88
9,1 - 10,0	0	2	2	9	6	7	5	10	15	10	7	4		79
10,1 - 11,0	1	2	2	6	4	5	3	8	11	9	6	2		59
11,1 - 12,0	0	1	2	6	3	5	2	6	9	8	4	1		48
12,1 - 13,0	0	1	1	4	3	2	0	4	9	6	4	1		35
13,1 - 14,0	0	0	0	2	3	1	0	3	7	5	2	1		27
14,1 - 15,0		0	0	3	1	0	0	2	5	4	2			18
15,1 - 16,0		0	1	3	1		0	1	3	4	1	0		14
16,1 - 17,0			1	2	1			1	2	3	1			11
17,1 - 18,0	0	0	0	1	1			0	1	2	0			6
18,1 - 19,0			0	0	0			0	1	1	0	0		3
>= 19,1		0	1	0	0			0	1	1		0		4
SUMME	24	22	29	94	64	81	91	149	190	123	79	42	1	989

Anzahl der Windstillen 11

UML = umlaufend

* GF KB 03/01/0e

Figure 3: Probability density of wind speeds in wind direction sectors (deka-degrees) on Kap Arkona.

The German Aero Club (DAeC) hosts the International German Open at Rügen since 2001, with participants from all over the world. The Viking Race 2004 at the same location is still considered as one of the most successful events ever in the history of the former unofficial World championship of the former provisional FAI class F3F. Almost all potential pilots of the upcoming world championships have participated in competitions hosted here during the last years. Also the desire to promote the F3F class to an official one, with world championship status, roots back to the multi-national discussion rounds held at Kap Arkona. Furthermore, the team of organizers, officials and judges can refer to the successful hosting of six large international FAI competitions and the Viking Race 2004.

The Island of Rügen

The Island of Rügen is the largest German island and excels by nature and landscapes of great diversity. Main source of income is the tourism, which has a long tradition. Famous beach resorts with the characteristic seaside-resort architecture of the 19th century characterize the island. But also dreamy, almost lonesome fisher villages belong to the island's scenery. The

unique interplay of open sea and Bodden landscapes gives Rügen its unique appearance. It has special reputation as a recreational area. As it is furthermore one of the windiest regions of Germany it has developed to an El Dorado for sailors and surfers – and last but not least the model slope soaring community.

Accommodation

It's up to the teams to book their accommodation. Please see the list of hotels and apartments, all *** plus. Available are other hotels, pensions, cottages, holiday flats, private rooms. Information at tourist centre of Kap Arkona http://www.ruegencenter.de; http://www.ruegen-abc.de/ Apartments are usually equipped with two bedrooms and a modern kitchen; sometimes breakfast is offered for extra money. Because of tourist's demands, there are more apartments offered than hotel rooms.

Hotel „Zum Kap Arkona“ 0049-38391-4330
http://www.zum-kap-arkona.de/
Official WCh Hotel + Headquarters of the competition direction. Participants are offered a discount price of 33 € per person and day incl. breakfast (double room).

Hotel “Zur kleinen Meerjungfrau” 0049-38391-950 0
www.zur-kleinen-meerjungfrau.de 500 m away from the mostly used world famous „Turbulator“ (west slope)

Holiday flat resort „Rügenhof“ 0049-38391-4000
http://www.kap-arkona.de/
Roomy and affordable flats for 2-9 persons are available. Average price per night and person is 15 € (without breakfast). Located 100 m from the headquarters.

Holiday Residency „Kap Arkona“ 0049-421-30 60 220
http://www.urlaubserlebnis-ruegen.de/ferienwohnung-kap-arkona.html
Comfortable holiday flats for up to 4 persons. Ca.15 € per night and person. Located 200 m from the headquarters.

Holiday flat resort „Hof Kracht“ Tel. 0049-42 09 91 91 80 Fax 0049-42 0991 91 82
http://www.hof-kracht.de/ E-Mail: hof-kracht@t-online.de
Luxurious holiday flat resort, exposed at the ridge and directly adjacent to the competition slope for south wind. 4-person flat for about 18 € per person (without breakfast), 2 km from the headquarters.

Hof „Wollin“ Tel. 03 83 91 / 40 80
http://www.hof-wollin.de/
Comfortable resort with flats for 2-8 persons. Price per person from 12 to 30 €. 2 km from the headquarters.

Franz Demmler
Event- and Organization Director

Uwe Schönlebe
Bundeskommission Modellflug DAeC

2012 Cumberland Soar-For-Fun Spring Edition

Pete Carr WW3O, wb3bqo@yahoo.com

This was the third year for the spring Soar-for-Fun and the first time that I was able to attend. The event bracketed the weekend of March 24/25 but started on Thursday and ended on Monday. The e-mail I received from Jim Dolly was that maybe there would be some good weather flying days in there somewhere.

There were!

I selected Sunday and Monday to attend, so showed up about 10 AM at the gate which is about 1.5 miles up a very unimproved dirt track on the side of the mountain.

The gate was locked!

Yes, it was cloudy and there was some fog but the guys were normally at the meadow on the hilltop by 9:00. I waited only a few minutes and then a convoy of vehicles arrived to open the gate. It was obvious that the pre-flight chats had taken place over coffee and breakfast in town.

We drove up to the meadow and were greeted by fog so thick that vehicles 10 feet away disappeared. The grass was extremely slippery so even the 4-wheel drive SUVs were sliding around.

One of the guys had brought a Night Vapor electric plane and got it out. Who would bring a Night Vapor to a slope event! Well, he did and proceeded to put in several very nice flights never exceeding eyebrow height. I had seen one of those fly at the Toledo Show last year in the big room and was impressed that it could take off and land by hand.

About an hour later, as the fog began to lift, another pilot flew a 36 inch hand launch sailplane that was controlled by the airborne unit from a Vapor. He did really well with the ship and

Opposite page: The building now has a set of solar panels on the roof. These charge a set of gel-cell batteries that supply power for charging radios and electric packs. The building was also good shelter from the cold winds on Monday.

The Vapor sits in the foam shipping tray. It has small LED lights along the leading edge of the wing. These were no help at all in the fog. Possibly the next version will have fog lights for days like this.

A Night Vapor electric three channel aircraft circles back to the pilot is heavy fog. It was high noon and without any wind on top of the 1600 foot Old Knobley Hill just south of Cumberland, Maryland.

A gas powered Senior Telemaster has just been assembled. This wood kit also makes an excellent electric tow tug. Jim Dolly used a length of yellow tow line from the hardware store and usually used for chalk lines.

The 3+ meter span Pilatus tow tug has the side door open to reveal the 80 ounce fuel tank. The tow point is just visible at the trailing edge of the orange stripe on the top of the fuselage. The sliding side doors required additional fasteners in flight because they bulged outward into the airstream.

A homebrew 36 inch span HLG was flown to check the fog ceiling. It has the radio from a Night Vapor and uses carbon pushrods. The front pod is soft styrofoam. Rotary launches resulted in the ship rolling inverted at max height but then it would roll out. This may be a whole new way of launching HLGs without a mixing type radio.

routinely got better than a minute in the still air of the meadow.

About 1:30 PM the sun came out and the temperature jumped 15 degrees in about 15 minutes. We had been standing around watching the fun in coats and gloves but shed them for t-shirts and sun glasses.

Most of the guys assembled their smaller slope ships while Jim Dolly put a 100 inch Telemaster together to tow. This was a gas version of the design that has been used with electric power to tow the 120 inch and smaller ships with ease. Jim said that the electric version could get about 15 tows per battery charge depending on the wind and the size of the sailplane.

We also discussed the position of the towline attached to the Telemaster. It was just aft of the wing at the top of the fuselage. Given the rather tall rudder I asked if the line would hang up and cause trouble.

He asked if I'd ever flown full scale sailplanes but I had only watched them launch at Ridge Soaring Glider Port near State College.

He mentioned that the big ships were towed from the tail of the tow plane and were instructed to remain at the same


PR-710

Above: Jim Dolly holds the Lunak fuselage as the elevator controls were checked out. It had two pushrods, one to each elevator half, joined to single ball link at the servo. Pushrod lengths were individually adjustable to set trim.

Opposite page: What a difference a day makes. A DAW KA-6 foam sailplane is set to launch. The hundred inch ship was not ballasted yet did very well in the gusty windy of Monday morning. The factory at the southern end of the valley is in the distance.

altitude as the tow ship while climbing out. That's fine if the pilot can judge his alignment but isn't possible with models.

For that reason the tow line is mounted high and the sailplane flies above the tow plane on climb out. The towline stays above the rudder so the tow pilot is free to make turns in either directions without worrying about the tail.

Later, Jim showed me his very large Pilatus tow plane. It had a balanced rudder and again, the tow line was mounted just behind the wing.

Jim said that he's never had the line hang up in the rudder hinge with that setup.

He did mention that the sliding side doors of the model would bulge out from the wind blast and he was afraid they would come off in flight. They are needed to access the inner workings of the model so are not just for looks.

Jim had used 4-40 blind nuts and screws to fasten the doors in place just before flight.

I didn't get to see the Pilatus fly but can guess that, with an 80 ounce fuel tank, it could tow all day!

The building has a new addition on its roof. Solar panels have been installed that charge some 12-volt gel-cell batteries. The purpose is to allow electric modelers to charge their planes and radios from the site battery supply.

There is a station available under the rigid canopy in front of the building for this purpose. That's a very nice touch since there is no electric service anywhere near to site.

Monday was very clear and cold with a 30 to 40 knot wind out of the north. That is basically across the hill.

We got to the meadow about 10 AM and spent some time watching the view from inside the building.

Finally some of the braver souls got out a few planes and used a bungy to launch. Because of the tree line at the edge of the meadow there is considerable turbulence on the way out over the valley. It is a good idea to have about 50 feet of altitude before venturing out over those trees or they will flip you over in a heartbeat!

First up was a DAW KA-6 foamy that performed amazingly well in the choppy conditions. It was not ballasted so had an extra exciting time on landing!

The rest of the slopers used the bungy and had no problems with their flights.

By noon the wind had increased so that I was not willing to get the two 12-foot sailplanes out of the truck to fly. I could just see them folding the wings on launch so decided to say goodbye and depart for home.

An Artimus 3-meter sailplane is recharged in the wind. This 10 year old ship looked as if it were new and performed extremely well in the choppy lift. It was launched from a medium size bungy so as to clear the trees and turbulence at the edge of the meadow.

The Spring event is much different than the one each fall because of the weather and the conditions.

I was so used to seeing the fall foliage and colors that the place looked far different to me.

Still, the guys were great and the air was wonderful.

Because of the hilltop location it's possible to fly for miles, literally.

It would take my fairly fast sailplane about ten minutes to fly from the south end of the valley, over the factory, north to the edge of visibility.

Much of the lift was from the farm fields down below while occasional slope lift could be found as the wind picked up. All told, it combines the fun of the thermal hunt with the aerobatics of slope lift.

Jim has a web site and the local soaring club has one, too. They are listed here so that pilots can check the dates for the next event.

Resources:

High Point model club
<http://www.highpoint-aviation.org>

Jim Dolly's e-mail address
jdolly@atlanticbb.net

Source for the DAW KA-6 sailplane
<http://www.skykingrcproducts.com>

A two meter 4-channel slope ship is ready to launch via the bungy. While the air was very clear it was coming across the slope so lift was spotty. That also made landings difficult in the turbulence but no planes were damaged.

Aeroclub Israel

F5J JUNIORS COMPETITION

Text by Rene Wallage, rene_wallage@yahoo.com
Photos by Ari Silbermintz

In order to breathe some new life into the Israeli F5J scene, 13 pilots, the Aeroclub Israel (the Israeli equivalent of the AMA) organized a competition for (electric) motorized gliders up to 2.15 meter wingspan. The date was set for Friday March 9th.

While we were getting closer to the date the weather turned worse, and worse, and worse…

Up till a week before the competition date we had an unusually cold and wet two months, complete with rain, snow, and high winds.

But the day of competition dawned, and we had sun and clear skies. The mud had dried up, apart from some small puddles. Those who decided to wear sandals paid the price…

Wind was forecasted as northerly at 6 to 8 knots, increasing after 10h00 to 10 to 12 knots. The right direction for our field, but a bit strong (but do-able) for the gliders.

As the competition was going to start at 09h00, around 08h00 saw the arrival of assorted competitors, friends, family, and shop teachers. Some were not very pleased with the waist high weed growth of the landing area. But these turned out to be a blessing in disguise. More on that later.

Most pilots came from the Kfar Saba and Ra'anana branches of the Aeroclub, where they have workshops for youths and the youthful alike. That was also why most pilots had a 2 meter Gentle Lady look alike. That, or a smaller version of the venerable Lady. All build from plans, and outfitted with two standard sized servos, Chinese motor/ESC/Lipo setups, and simple 4-channel radios.

The competition direction was in the capable hands of the same person who founded this new section for juniors, Mr. Israel Ofek. A familiar name amongst European F5J pilots, as he won the European F5J championship four times over the past six years.

At the briefing, Israel explained the (somewhat modified) rules:

- Each pilot will fly four flights
- Working time is 10 minutes,
- The appointed timer will start the stopwatch when the motor is switched off.
- If a pilot decides to restart his glider's motor, the timer will reset the stopwatch to zero, and start counting again when the motor is switched off.
- The landing pattern must be entered before the glider is at 5 meters altitude For this the adjacent tree line was a point of reference. Usually this is 3 meters, but taking into account the inexperienced pilots, 5 meters was deemed safer. If the glider is lower than that, it must be landed in the security zone to the windward side of the launch line, and no points are awarded for the flight.

2 meter gliders are just perfect for this kind of competition.

- A spot landing will give an extra 50 points. Less points for each meter away from the spot. 10 meters or more will give no landing points.
- No landing bonus after the 10 minutes are up. Although, considering the strong wind, that would not be very likely to happen.

Israel also stressed that the aim of today's competition was mostly to have fun.

And, as for all pilots this was their first ever competition, he had made sure that

at each launch spot – in addition to the timer - there was an experienced pilot at hand to mentor the pilots. For some inexplicable reason I was appointed mentor as well.

Nerves and jitters were high before the first launch.

My first task as mentor was to calm the pilot down. The nerves caused pilots to not be in place and ready on time, launching a minute or so late, or launching and forgetting to activate the motor.

Also, at the first launch, while following "my" pilot's glider zooming up, from the corner of my eye I saw one glider cut across the line followed by an ominous balsa crunch. I think another glider was involved as well. But due to the waist high weeds, virtually every arrival, no matter how unorganized, was a soft one.

As the gliders were overpowered, most pilots went vertical at launch. That could have been a good tactic with less wind, but with the wind as it was, this would lead to the glider ending up high overhead, being pushed back by the wind behind the landing area, with very little chance of making good time and landing on the spot. Plus that, some had to loop out of the climb, losing precious altitude.

That first flight, with the pressure, nerves, and trying flying conditions, it was hard to get a good flight.

Left to right: mentor, pilot, timer

One of the hard parts of flying in these conditions with rudder/elevator gliders is always not to over react. All that swishing around of the right stick can make you lose altitude in the blink of an eye. I had a hard time to convince a pilot to stop moving his right stick as if he was stirring his coffee.

Those first flights most pilots reached times of four to five minutes and hardly any landing points.

When the time for landing approached, many pilots were fooled by the high speed downwind leg, and turned too late into final. Others tried to "float" in, only to be pushed back by the wind.

Some followed the mentors' advice, and turned on time and at the right altitude, but couldn't get themselves to keep the nose down enough to keep the speed up and stay in control. This resulted in heavy porpoising, eventually leading into a stall, and a hard landing. Thank you, waist high weeds.

A better tactic was to launch at a 60 to 70 degree angle into the wind, ending up at altitude and in an area where there was relatively good air.

After their first flight, things calmed down somewhat. Pilots were starting to relax, reacting more to the mentors' advice, and flight quality increased.

Left to right: mentor Rene Wallage, pilot Erez Blumenthal, and spotter Daddy Blumenthal

All pilots, with Israel Ofek and his Espada in the back row on the left.

The last two flights times of seven to eight minutes were the norm. Even better, landings were getting closer to the spot as well! One of the last flights even ended a few seconds short of 10 minutes, and just off the spot as well!

As with most competitions, there was some mayhem. Some motors decided to part company with the fuse. One even took the ESC and lipo with it, never to be found again. A tail group dropped off at launch. And some propeller blades whirled around, solo. Most damage was repaired/replaced on the spot.

One unlucky pilot had the motormount ripped off, and couldn't do a proper repair, so a friend let him fly his plane instead!

> Most spectacular though, was one glider literally going up in smoke! The result of forcing a 3S lipo in a tight space. The cells ripped and shorted. Lipo, ESC, all the wiring, probably the motor, and maybe the receiver and servos, all gone. A sure reminder of proper lipo handling.

Also, as with most competitions, in the end winners must be announced.

Israel tallied the scores on his laptop, and found that third place was reached, with 3430 points, by Nathanel Silbermintz. Second, with 3804 points, was Eran Hilo. And with 3942 points, in first place was Elad Hamawi.

In general, despite some initial misgivings over the chosen venue, a great time was had by all. The atmosphere was "serious business," but incredibly friendly, and very relaxed. The 2 meter gliders are just perfect for this kind of competition. If postage wasn't so prohibitively expensive I would have a Gentle Lady kit on the way right now. I am genuinely looking forward to the next competition.

Left to right: 3rd place Nathanel Silbermintz, 1st place Elad Hamawi, and 2nd place Eran Hilo

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Right now I have only the one size, but I’m keeping track of other sizes

Above: Interior

Above right: Zipper detail

Right: Available in blue or red, 71" length

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