TEDxNASA: Towards More Bird-like Flight: Thinking Outside the Box

Assumptions are a fact of life, but when they couple to ideas, the ideas become concrete and the assumptions fade into the background. The problem is that the assumptions become solid unseen walls that we use to build the boxes we think inside of in our minds. Until the assumptions are rethought, the solutions cannot change. These limitations are artificial; they are self-imposed.
[image: Al flying hang glider]

I was captivated by flight when I was very young. When I was 12 years old I began messing around with hang gliders. I think about the things I didn't know then, and what I assume I know now.
[image: albatross in flight]

The model of flight for time immemorial had been the flight of birds. This is a photo of a Wandering Albatross. The bird model was used until Wright brothers. Along the way they ran into the problem of adverse yaw. Adverse yaw is a product of induced drag. The high pressure is under the wing and the low pressure over the top of the wing. The air tries to "escape" around the wingtip, and this leaves energy imbedded in the air we can see as tip vortices. So to bank the aircraft, the wing with the greater lift will induce more drag, and so the wing you lift will end up going BACKWARDS. The aircraft will bank LEFT but yaw RIGHT. This is adverse yaw.
[image: 1902 Wright Glider in coordinated banked flight]

The Wrights kept crashing until they added a rudder to control the yaw of the aircraft. We still solve the problem of adverse yaw this way today. We had departed from the bird flight model. [black]

At the same time as the Wrights, Ludwig Prandtl discovered a method to calculate the induced drag of wings, the Lifting Line. *He calculated the Elliptical spanload has the minimum induced drag for wings of a given span* [assumption]. The elliptical spanload solution is taught in all aerodynamics textbooks. *All of this makes adverse yaw a fact of life and direct yaw control, usually vertical surfaces, a necessity.*

The elliptical solution was not good enough for Prandtl. He questioned his own assumptions. If we construct a wing with an elliptical spanload, and calculate the lift along the span, there is a wing root bending moment. This wing root bending moment determines the structure to carry the load. *Prandtl asked the fundamental question: is there another spanload with the same lift and the same structure that produces LESS induced drag than the elliptical spanload?* In 1932 he found the answer, a new spanload with 22% more span and11% less drag (top graphic).
[image: spanload graphic]

Prandtl never carried the thought experiment through to its logical conclusion. Reimar Horten used the new Prandtl spanload (which he called bell shaped), built a series of aircraft and made a fundamental discovery. Horten had to twist the wing to get Prandtl's new spanload. And he found that *the wing tips of a bell shaped spanload have induced thrust* (top graphic). Induced drag becomes negative at the wingtips and pushes forward. Now when lift is increased on the wingtip of a bell shaped spanload, the induced thrust at the wingtip increases. So as the aircraft banks left and it will yaw left as well. *<u>There is no adverse yaw, and vertical tails are not necessary</u>*. [black]

It took me 11 years to reverse engineer that puzzle. Horten did not write out his technique before he died. *And when I calculated his solution, I could not believe that it could be correct. The box in my mind said it could not work.*
[image: Mike Allen & model sailplane]

Fortuitously, I had a student working with me at that time, Mike Allen. Mike was not bound by my conventions. He built a small model using Prandtl and Horten's principles. *<u>The spanload was achieved with twist</u>.* He allowed me to fly it. It worked perfectly. Mike was unencumbered by years of schooling, by the box of the conventional wisdom. He was able to see what I could not, assumptions had clouded my vision.
[image: albatross]

The tip feathers of a bird are very soft at the ends, and only if the load at the tip goes to zero can the feathers remain straight. If birds carried elliptical spanloads, the tips of their wings would bend straight up. Birds must minimize their chest muscles to carry their wing root bending moment. Birds minimize their inefficiency when maneuvering. Birds need to maximize their flight performance. For birds to fit into their ecological niche perfectly, they must solve these problems optimally. To carry their bodies, reproduce, and thrive. Birds have known this all along.

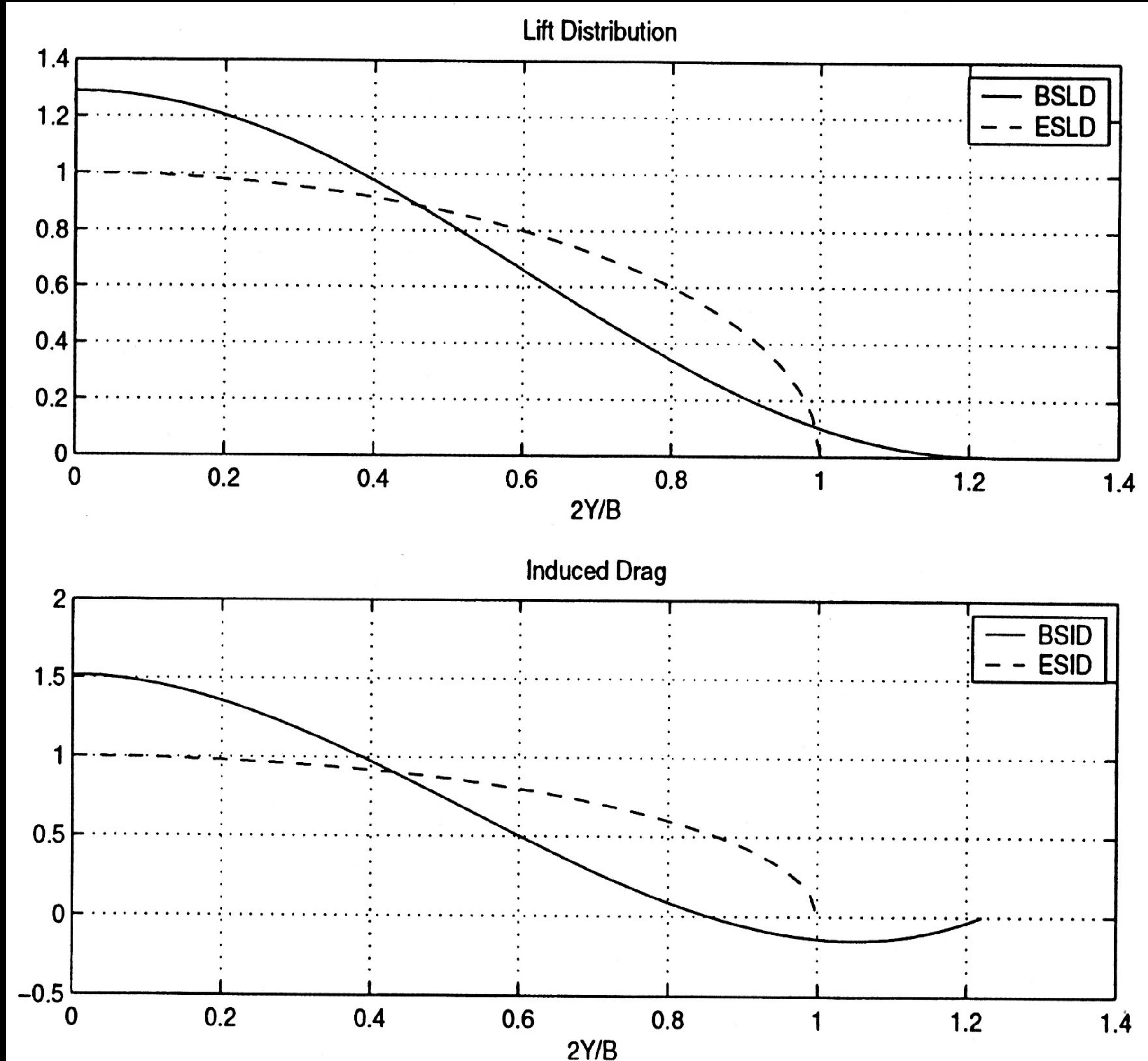
Prandtl created the Lifting Line and the bell shaped spanload to optimize structure and performance at the same time. Horten created the twist for that spanload, and in addition found it solved control too. I recreated the solutions of Prandtl and Horten and Mike Allen built the model to reprove it worked. This is the solution that birds have known about all along. In design, when we reduce a solution to a minimum *the result is clean, simple, elegant, and beautiful. It is the natural solution.*

If we follow this solution through to its conclusion, this idea not only reduces impact by saving fuel, but also in reduced manufacture energy (minimum structure), maintenance and repair (things don't break if they aren't there and elimination of the unnecessary), and this is true throughout the entire lifecycle of the aircraft. This compounds the minimization of the carbon footprint of the aircraft. *We must reexamine the bird flight model.*

Prandtl rethought his assumptions to find a superior solution. To solve today's problems we need to reexamine our assumptions.

And I believe this is an idea worth spreading. Thank you.


Photo by Phil Barnes



Lift Distribution
BSLD
ESLD
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
2Y/B
Induced Drag
BSID
ESID
2
1.5
1
0.5
0
−0.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
2Y/B


Photo by Phil Barnes