

Lesson 9 — Flight: Lift Is a Pressure Bill, and Drag Is What You Pay

TA notes for John D. Anderson Jr., *Introduction to Flight* (5th ed.)

Draft — not yet published

What you're walking out knowing

1. Lift is a pressure imbalance, not magic and not "equal transit time."
 2. Every airplane is a lever: L/D is the leverage ratio, and the drag polar is the whole machine's character in one equation.
 3. Stability is a separate discipline from aerodynamics — and the Wright brothers deliberately built an unstable airplane.
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1. Where lift actually comes from (20 min)

Forget the story you heard in school. Lift is **pressure**, almost entirely. Shear stress on the wing acts mostly in the drag direction, so the upward force is the imbalance between pressure on the lower surface and pressure on the upper surface. That's it. That's the whole secret.

The cause underneath is just two things: **mass continuity and Newton's second law**. Anderson is blunt about this — you cannot get more fundamental. Everything else (Bernoulli, circulation, Kutta) is a restatement of those two.

Two order-of-operations traps to avoid:

- **Downwash is the effect, not the cause.** The wing pushes air down *because* the air is already pushing the wing up. Reversing that order explains nothing — it's like saying the car moves because the wheels turn.
- **"Equal transit time" is false.** Air over the top does *not* speed up to meet air under the bottom at the trailing edge. Section 5.19 of Anderson dismantles this at length; it's the single most persistent myth in aviation, and this lesson kills it.

The math closes through **circulation theory**: the Kutta condition fixes the circulation at exactly the value that makes flow leave the trailing edge smoothly. And note *where* the work happens — most lift comes from the first 20–30% of chord, where the upper-surface pressure minimum sits just behind the leading edge. The front of the wing does the lifting; the back mostly goes along for the ride.

Definition check (say it out loud): Lift is the force component *perpendicular to the relative wind*. Drag is the component *parallel* to it. Both are defined relative to the wind, not the ground.

2. What it costs: the drag polar (20 min)

Here's the whole aerodynamic character of an airplane in one line:

$$CD = CD,0 + CL^2/(\pi eAR)$$

Drag has two halves that move in opposite directions as speed changes. Zero-lift drag (skin friction, form drag) *grows* with speed. Induced drag — the price of having finite wings — *falls* with speed, scaling with the square of the lift coefficient and inversely with aspect ratio. Long thin wings are cheap; stubby ones are expensive.

Their sum is a parabola with a minimum. That minimum is the design point. Everything about cruise performance falls out of it.

Now the leverage idea — the one line to keep from this whole course:

At $(L/D)_{\max} = 15$, the aircraft lifts fifteen pounds of weight for every one pound of thrust spent against drag.

Thrust required for level flight is just $W/(L/D)$, and minimum thrust occurs exactly at $(L/D)_{\max}$. The performance chapter is one identity wearing a costume.

Anderson uses $(L/D)_{\max}$ as the yardstick of a century of progress: Wright Flyer 5.7, SPAD XIII 7.4, and upward from there. One number, seventy years of aircraft evolution.

3. Staying pointed the right way (15 min)

By Chapter 7, the aerodynamicists are done and the airframe becomes a rigid body under four forces. Stability and control is a *separate discipline* — this surprises people, but it's the cleanest cut in the book.

Longitudinal static stability needs two things: a positive zero-lift pitching moment, and a negative moment slope with angle of attack. The whole criterion compresses to one point — the **neutral point**. For static stability, the center of gravity must always sit forward of it.

The distance between CG and neutral point is the **static margin**, and it's a design choice: more margin, more stability and more trim drag; less margin, more maneuverability. There's no free stability.

Two footnotes worth keeping:

- **Stick-fixed vs. stick-free stability differ.** Let the elevator float and the tail's effectiveness changes — an airplane can be stable one way and not the other.
- **The Wrights built an unstable aircraft on purpose** while the Europeans chased inherent stability. Anderson treats this as the founding argument of flight control, and the Wrights were right: a slightly unstable airplane a skilled pilot can control will outmaneuver a stable one every time.

4. Worked example (10 min)

An aircraft weighs 12,000 lb and cruises at its $(L/D)_{\max}$ of 12.

- Thrust required = $W/(L/D) = 12,000/12 = \mathbf{1,000\ lb}$.
- Redesign the wing for $(L/D)_{\max} = 15$: thrust required = $12,000/15 = \mathbf{800\ lb}$. Same weight, 20% less thrust — that's the entire history of aircraft design in one division problem.

5. Quick check (5 min)

1. Why is "the wing pushes air down, so the air pushes the wing up" an incomplete explanation of lift?
2. An aircraft's aspect ratio doubles. What happens to induced drag at the same lift coefficient?
3. Moving the CG aft (toward the tail) does what to the static margin — and to maneuverability?
4. Why did the Wright brothers *want* an unstable airplane?

(Answers: 1 — it reverses cause and effect; the pressure field is primary, downwash follows. 2 — it halves. 3 — static margin shrinks; maneuverability rises, stability falls. 4 — control authority beats

inherent stability; a pilot can stabilize what a designer leaves loose, but no pilot can make a too-stable airplane agile.)

TA's honest footnote

Anderson derives rather than asserts — every claim traces to conservation of mass or Newton's second law, which is why this is the strongest of the three aviation books. But read Chapters 5, 6, and 7 in order and stop: airfoil to drag polar to neutral point is the spine, the rest is context. It will not teach you to fly — the airplane here is a rigid body under four forces, and nothing in the book addresses the human operating it. Pair it with a piloting text and the gap closes.