

The Trailing Edge

August 2024

Straighten Up and Fly Right

A part of learning to be a pilot is figuring out when you are being lied to. You know your magnetic compass lies to you, but you learned how to adjust for that. The airspeed indicator lies, too. It doesn't indicate your groundspeed or even the speed of the air (nitrogen, oxygen, et al) molecules rushing past your airplane in flight. You have to adjust the indicated airspeed for temperature and altitude to get your true airspeed and account for the wind to determine the groundspeed. Well, that's what we had to do before they put that GPS gadget in the panel.

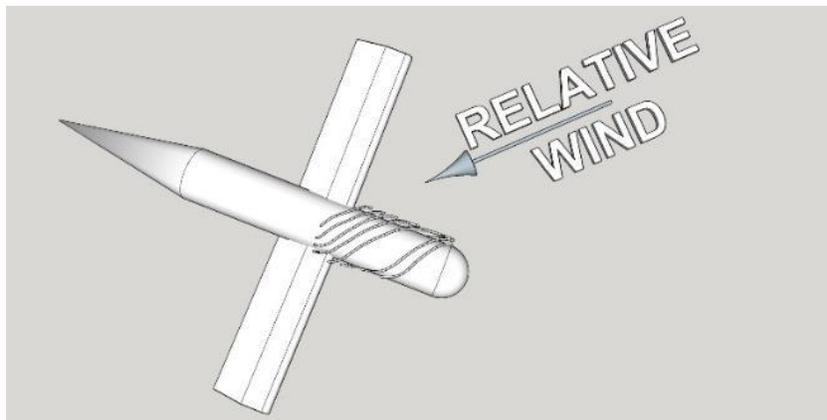
In some cases, the lie has less to do with what happens and more to do with why it happens. I would like to address just such an instance. The mathematicians define "dihedral" as an angle between two planes. Anyone in the aviation community uses the word "dihedral" to refer to the angle at which the wings are tilted up, either at the fuselage or somewhere along the span. As student pilots, we were told that the purpose of that "tilting up" was to give the airplane lateral stability. If the plane gets perturbed from wings level flight, it will tend to return to wings level – unless your back seater is pushing on the flight controls as he tries to reach his box lunch. All of this is as true as it can be. The lie in this story came when you were told why that happens.

You may argue, "Why do I care? I understand how it behaves. That's all I need to know." If that is you, I can't refute your argument. Stop reading. Really, just stop. No one is watching. There will be no quiz. However, if you would like to further understand the phenomenon known as "dihedral effect," please keep reading.

First, let's bring the myth out into the daylight. Then, we can dispatch it to the underworld and further our understanding of what really happens. The myth goes like this: If the bank angle of the airplane is perturbed from wings level, then the lift vector of the lower wing is acting more vertically than the lift vector of the higher wing, and it rolls the aircraft toward wings level. In 1979, I was naive enough to raise my hand, pull the ring on the side of my neck, and recite the myth to my professor and classmates in my Aerospace Systems Design course at the University of Illinois. The professor looked at me and said, "Sum the moments."

Yes! Of course. The lift of each wing is providing a rolling moment about the longitudinal axis of the airplane. Gravity (or the local vertical) has nothing to do with that. If the lift is the same on both wings, there is nothing that would cause the plane to roll back to wings level. There must be something else going on. Indeed, there is, and it has to do with sideslip. When the plane is perturbed from wings level, gravity starts to pull the aircraft through the air sideways. If you had caused the roll with the ailerons, polished aviator that you are, you would have skillfully manipulated the rudder at the same time to keep the ball in the center and the slipping and skidding to a minimum. However, when nature throws the plane a bit off kilter, she is not so careful.

When the plane starts to slip toward the lower wing, it adds a lateral component to the relative wind. Therefore, the wind hitting the lower wing is at a slightly higher angle of attack (AoA) than the other wing. Now, with a difference in AoA there is a difference in lift between the two wings, and the result is a rolling moment that brings the airplane back to wings level flight. We call this "dihedral effect." However, it isn't completely dependent on the dihedral angle of the wings.

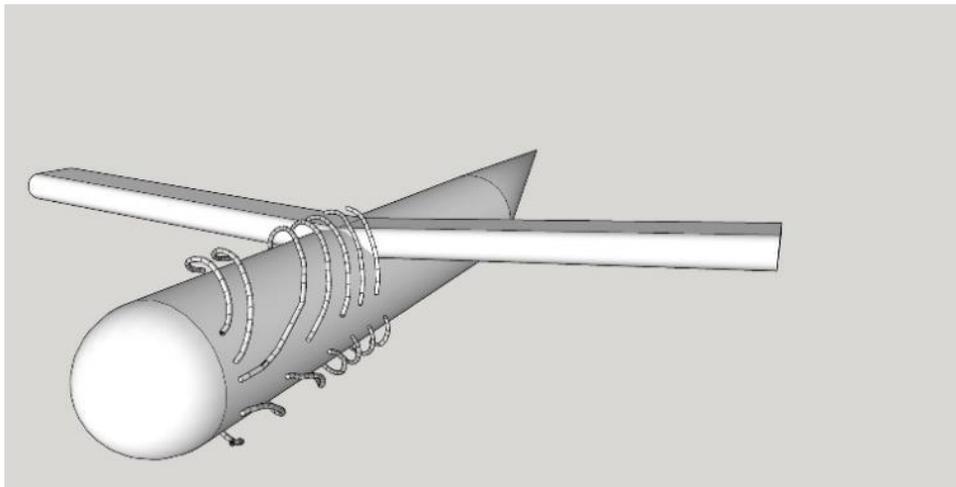


(SIDESLIP ANGLE EXAGGERATED FOR CLARITY)

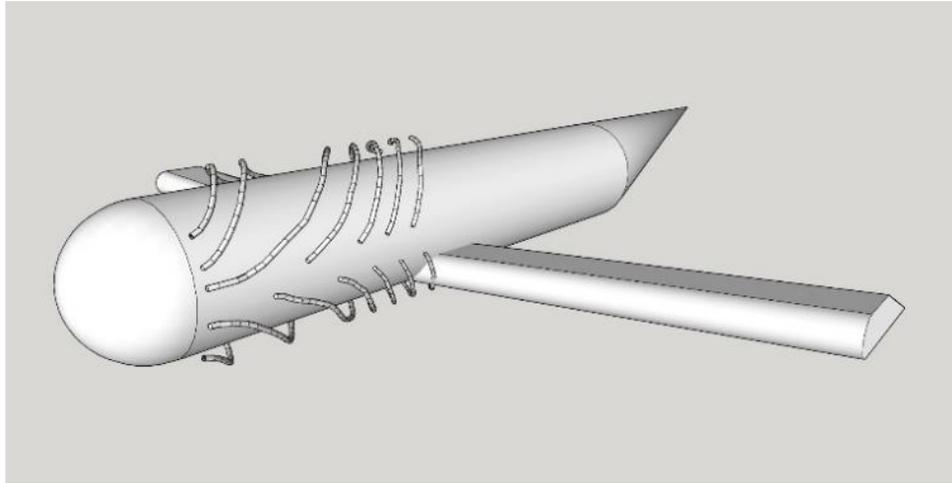
There are, after all, some planes with no built-in dihedral angle that still exhibit some stability due to the dihedral affect. It still has to do with sideslip and the effect on the angle of attack of each wing. Consider the OV-10 Bronco. That airplane looks like they used a giant yardstick for the spar. It's as straight as it can be. Nevertheless, it has some lateral stability baked into the design.



Let's look at what makes this happen. With no sideslip, the air flows down the sides of the fuselage. The flow on both sides is the same. However, when we introduce a bit of sideslip, the airflow must go around the fuselage to get from the upwind side to the downwind side, some over the top and some under the bottom. If the wing is connected to the fuselage in the middle, not the top or the bottom, there is no effect on the AoA of either wing. On the other hand, if the wing is attached to the top of the fuselage as it is on the OV-10 and the Cessna 172, then there is an effect on AoA. The air going up and over the fuselage hits the upwind wing, increasing the AoA near the fuselage. It has the opposite effect on the downwind wing, slightly decreasing the AoA in the region near the fuselage.



For airplanes with low wings, like the Cherokees and Mooneys of the world, the flow around the fuselage has the opposite effect. For this reason, the dihedral of the wing must be large enough to compensate for the destabilizing effect and still offer a positive dihedral effect. Have you ever noticed that low wing airplanes seem to have a lot more dihedral angle? Now you know why that is the case.



It is important, or at least interesting, to note that not all airplanes are designed and built with all that stability in mind. We want our training aircraft to be well behaved and forgiving to our ham-fisted students. On the other hand, we want fighter aircraft to be agile and responsive. When you are trying to roll the lift vector toward the surface-to-air missile that is screaming up toward you, you don't want to have to overcome a lot of lateral stability before the aircraft starts to roll. A lot of fighter aircraft are a bit unstable in one or more axes. With modern fly-by-wire airplanes, we can put some of that stability back in the form of software in the flight control computers. Let's look at a plane that predates all that fly-by-wire technology, the F-4 Phantom II. Despite the lack of automated flight controls, it was equipped with a Pitch Stability Augmentation System. There was no such system for lateral stability. In fact, the original design had no dihedral angle on the wings, even though the wings attach to the fuselage at the lowest possible position. What happened next, it's hard to say. The rumor that floated around the F-4 community said that a fight broke out between the aero guys and the structures team. It might have gone something like this.

Aero team: "We need two degrees of dihedral."

Structures: "Well, you should have thought of that before we designed the wing carry through box."

Aero: "But, it will be unstable! What good will your wing box be if the plane is uncontrollable?"

Structures: "OK. The Navy insisted that it have folding wings. You can have your precious dihedral at the pivot station."

Aero: "Fine! Give us four degrees."

The next time you have a chance to look at an F-4 up close, check out the dihedral angle at the wing fold and tell me you can't hear the slide rules hitting the table and imagine guys with crewcuts, white shirts, and skinny black ties glaring at one another. In the end, the dihedral effect on the F-4 was adequate. In fact, due to some other quirks that got baked into the design, the plane could not be rolled with the ailerons if there was any load on the wings. Nevertheless, pushing on the rudder provided sufficient roll authority. That was all due to dihedral effect.

- Scott "Stormy" Weathers