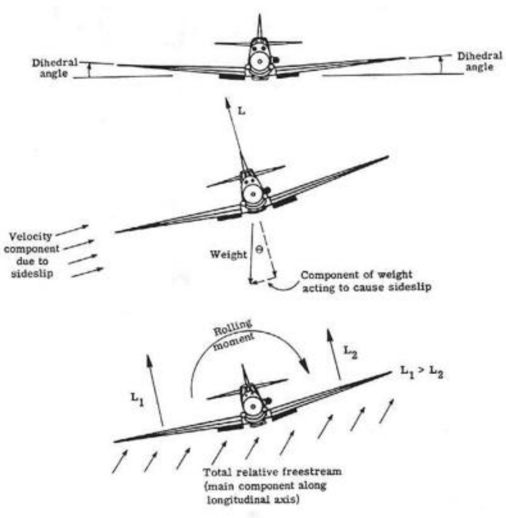
Why? How Much and Where

by: David Andersen

Dihedral is the upward angle of an aircraft's wings. It increases stability in roll, also known as lateral stability. Some airplanes need a lot, others need less or none or even negative dihedral.



Why?

When an aircraft is disturbed from an upright position, it will sideslip toward the down-going wing, increasing airflow along the length of the wing from tip to root. The dihedral angle increases angle of attack to this lateral flow, generating additional lift to restore the aircraft to a level attitude.

Military combat aircraft often have small dihedral. This reduces inherent stability but increases maneuverability. Birds and many modern military aircraft are passively unstable; they depend on active control by on-board computers.

But other forces affect roll stability too. If the center of gravity is below the wing, the weight tends to restore the upright position. This is known as pendulum stability or the keel effect. If the CG is above the wing, the weight is destabilizing. In a bank, the center of gravity may yaw the airplane into the direction of the bank if the CG is well forward, or it may yaw the airplane in the other direction if the CG is well back. In a slip, the vertical stabilizer will be pushed by the side force, yawing the airplane further into the turn. Sweepback of the wing, especially the leading edge, causes greater drag and greater lift on the wing panel that is rotated forward into the relative wind, increasing the roll still further - three to ten degrees of sweepback is approximately equivalent to one degree of dihedral for most model aircraft. Side-thrust in a bank becomes up-thrust in one direction or down-thrust in the other direction. In a turn, centrifugal force on the CG can either reinforce or oppose further bank, depending on the location of the CG. Even the surface area of the side of the fuselage affects the degree of slide slip.

Sometimes these other forces provide enough or too much lateral stability so that dihedral is not needed.

Richard Steine's B-25 has no dihedral in its outer wing panels. Unwanted yaw and roll are minimized if one engine fails. Mid-wing configuration plus inboard dihedral raises the center of lift above the center of gravity, producing pendulum stability - a brilliant balance of compromises. Appearance of negative dihedral is an optical illusion.

If too much, negative dihedral (anhedral—a down-sloping wing angle) may be needed to counter their effects. An example of too much sweepback was the Republic F-105 Thunderchief. It required 45° of sweepback in order to fly at Mach 2. Anhedral was used to offset the dihedral effect and other stability factors of its highly swept wing and tail.

Anhedral in the Antonov 225 compensates for its extremely low center of gravity and reduces unwanted yaw and roll in the event of engine failure.

An airplane without dihedral and neutral in all of the above forces will fly hands-off in level flight and very slowly turn into an ever-tightening spiral towards the ground. Many aerobatic airplanes are intentionally designed this way. By eliminating self-righting forces, the aerobatic pilot has greater control of the attitude of the airplane, i.e., ailerons cause only roll, rudder causes only yaw, elevator affects only pitch and throttle controls only thrust.

How Much?

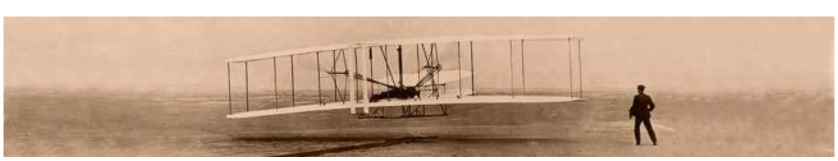
Alas, there can be too much of a good thing. Dihedral bestows stability at the expense of lift. Only the vertical component of lift in level flight actually supports the airplane. It is proportional to the cosine of the dihedral angle. The horizontal component of wing lift, proportional to the square of the sine of the dihedral angle, is wasted. But the effect is small if the angle is small. A wing of 3 degrees dihedral, for example, wastes only 0.137% of its total lift **(cosine 0° - cosine 3° = 0.00137)**. That may be insignificant in most models, but important in a competition sailplane or the long-term fuel costs of an airliner.

The gull wing of the author's Borne Free aileron-less sailplane raises the center of lift above the center of gravity to increase pendulum stability - a desirable form of lateral stability, especially when circling in a thermal. Inboard panels of the wing add to the side area to resist side slip.

- ⇒ **Dihedral in a multi-engine airplane adds to undesirable roll when one engine quits.**
- ⇒ **Dihedral reduces stability in inverted flight and varies roll rate during the inverted part of a slow roll. Rolls become corkscrew-shaped instead of axial.**
- ⇒ **Dihedral makes an airplane more vulnerable to turbulence, especially side gusts.**

Complicating things further, the optimum amount of dihedral decreases with airspeed. It is needed most at very low airspeed, typically when landing. Airplanes with very large speed ranges seek a compromise between low speed handling and high speed instability.

Too much dihedral sometimes causes an annoying phenomenon known as Dutch roll. At high speed, dihedral levels the wing so quickly that momentum carries the wing past the upright position. Then dihedral overcorrects, over-rolling to the other side, back and forth, etc. The nose drops slightly and rises each time it passes through level. This corkscrew motion is annoying to passengers, wastes energy and, for a warplane, interferes with aiming. The F4U Corsair and the V-tailed Beechcraft Bonanza are famously victims of this effect, even in model form. Aircraft designers have a lot of conflicting factors to negotiate.



Anhedral in the Wright 1903 Flyer was intended to resist roll in a crosswind gust. It seemed like a good idea at the time, but it didn't work very well.

Where?

Rudder-only radio controlled airplanes need lots of dihedral. Their only means of turning is by yawing with the rudder. The wing panel that swings forward presents a greater angle-of-attack to the relative wind, increasing lift. The greater lift banks and turns the airplane. For efficiency, this method of turning is best implemented by adding extra dihedral to the wingtips, reducing the total dihedral. The three or four-panel wing, typical of free-flight and rudder-only airplanes, is known as polyhedral. When the nose pulls up, the angle of attack of the outer panels increases at a slower rate than the inner panels. The inner panels stall first. Polyhedral wings do not require the negative twist known as washout.

Jeff Quesenberry's Lavochkin La 7 displays the modest dihedral typical of WW2 single-engine fighters—just enough for hands-off stability during long flights but not enough to interfere with fighter aerobatics or gun aiming or to cause Dutch roll at high speed.

The gull-wing variant is typically used to increase pendulum stability by raising the wing without the drag of cabane struts. The inverted gull-wing of the F4U Corsair was used to shorten the landing gear struts and lower the height of the airplane for below-deck storage.

Bristol Beaufighter after addition of stab dihedral to clear prop turbulence.

Dihedral or anhedral is sometimes added to the tail. Reasons are varied: ground clearance, raising the stab out of turbulent airflow, augmenting the vertical stabilizer, structural necessity, or appearance. Dihedral or anhedral in the stab adds to the total vertical surface area of the tail, effectively increasing the vertical fin area, thus adding to yaw stability.

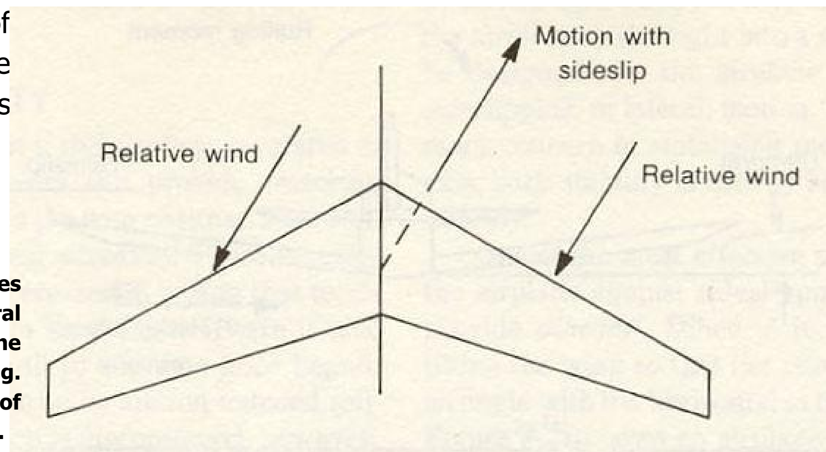
Dihedral in the horizontal stabilizer and the dihedral of the wing are complementary. Sometimes, field trials indicate that a new airplane design has too much or too little wing dihedral. It is generally much easier to modify the dihedral of the stab than the wing. A well-known example is the F-4 Phantom.

C-5 Galaxy demonstrates all forms of lateral stability as it takes off in a cross wind: high wing for pendulum stability, anhedral for roll resistance when engine-out or in a cross wind, swept wing for yaw stability, T-tail in clean air, and stab anhedral matching wing anhedral for efficiency and control.

Mitsubishi Babs, a reconnaissance/courier airplane, does not need the maneuverability of a fighter so it has more dihedral for more stability, especially at lower airspeeds.

Airflow over the tail of the Phantom was being blanked by the wing at high angles of attack. To take the tail out of the wing wake, it had to be lowered. But the tail could not be moved lower on the fuselage because of the jet engine. The solution was to add extreme anhedral to the tail. But this reduced the effectiveness of the wing's dihedral, so dihedral was added to the wingtips.

Another well-documented example is the modification to the Bristol Beaufighter, a twin-engine heavy fighter/bomber. The vertical fin was too small, and the flat horizontal stab was in the turbulence of the massive propellers, causing handling problems at full power. The solution was to add 12 degrees of dihedral to the stab. This would have reduced the effectiveness of the stab by 2% **(1 - cosine12° = 0.02185)** so the area of the stab was increased to compensate. The horizontal lift component of stab dihedral added to the effective area of the vertical stabilizer. Even so, a dorsal fin was added.



When a swept wing yaws, the upwind panel generates greater drag and greater lift due to a difference in lateral airflow of the panels. The difference in drag resists the yaw, but the difference in lift tries to roll the wing. Depending on the wing design, three to ten degrees of sweepback are the equivalent of one degree of dihedral.

Thanks to Joe Grice, Derek Micko and Benny Lanterman for their excellent technical assistance.

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Further reading:

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-- **Understanding Washout**, David P. Andersen, Model Aviation Magazine, March 2012.

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