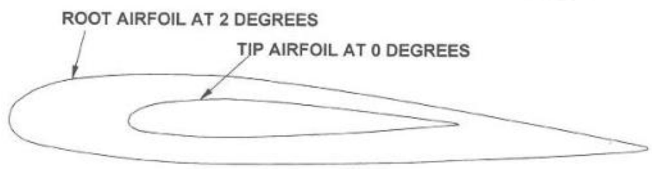
Washout

Why?

How Much and Where

by: David Andersen



Typical Washout Angles for WWII Fighter Models

← Direction of Flight at Cruise Speed ←

Washout is a twist in a wing that causes the wingtip to meet the airflow at a lower angle than the root in normal upright flight. Some planes don't need it; some planes can't fly without it. It's not just to prevent tip stalls!

Why ... Washout causes the root of the wing to stall before the wingtips stall. The subsequent loss of lift in the root area gently lowers to the nose or prevents it from rising further, preventing the entire wing from stalling suddenly and provoking an unwanted snap roll. Stalls do not always occur at low airspeeds. Pylon racers, for example, can stall in high-G turns, sometimes with disastrous results.

At high angles of attack, ailerons become less effective because they are both lifting, and the difference in lift becomes less with increasing angle of attack. Washout causes the ailerons to meet the air at a lower angle. This improves aileron effectiveness at all attitudes, especially at low airspeeds.

In a banked turn, the down aileron increases lift and drag while the up aileron reduces lift and drag. The difference in wingtip drag tends to yaw the airplane in a direction opposite to the turn - "adverse yaw." Washout tends to reduce the effects of adverse yaw but only in the portions of the ailerons that are close to zero angle of attack. Some airplanes are trimmed so that there is less down aileron travel than up travel, called "aileron differential."

Despite its thin and pointed wingtips, Dave Szabo's Spitfire has excellent handling due, in part, to about 2 ½ degrees of washout, slightly more than the full-sized Spit. Low pass before a chandelle shown here.

But aileron differential is only a partial cure. Other designs include engine offset - a solution that causes problems elsewhere. The best solution is for the pilot to counteract adverse yaw with rudder even when flying inverted. The result is called a "coordinated turn."

At high angles of attack such as in a climbing turn, there is the danger that the down aileron, e.g., left aileron in a right bank, can provoke a stall in that wingtip. Such a stall creates a lot of drag in the stalled wingtip, pulling it back and yawing the airplane in the opposite direction of the turn. If the airplane has significant dihedral, a roll in the opposite direction develops as well. This phenomenon is called "aileron reversal" or "aileron snatch" (British). Unfortunately, a pilot's instinct to apply even more aileron deflection makes matters worse. The proper cure is to correct with rudder, not more aileron. Please beware of this when flying your warbird in an inverted climbing turn or victory roll.

Martin Irvine's Aviatik D1 has washout confined to the ailerons. This common practice in WW1 was a structural expedient that simplified assembly.

Wingtip vortex is the tendency of the high-pressure air under the wing to curl around the wingtip and cancel the low pressure air above the wing. This further reduces aileron effectiveness. It also increases wingtip drag that must be controlled by the vertical stabilizer. Washout reduces wingtip vortex and its associated drag.

Although wing efficiency is generally not important in model aircraft, the reduction of wingtip drag via washout improves yaw stability. This is especially important at low speeds and high angles of attack. Washout, therefore, improves lateral stability and rudder effectiveness. But wingtip vortices cannot be eliminated entirely, so ailerons are not effective at the very tip of the wing. For this reason plus the aileron reversal problem, ailerons rarely go all the way to the wingtip.

In highly swept wings, the washed-out wingtips act like a horizontal stabilizer, increasing pitch stability. When carried far enough, it is possible to eliminate the tail entirely. Some flying wings such as the Northrup N9M, are based upon this principle.

Why not ... Too much of a good thing can cause problems if overdone. All the good things that washout does in upright flight can become bad things in inverted flight—loss of aileron effectiveness, non-uniform roll rate, adverse yaw, surprise snap-rolls, aileron reversal. For these reasons, washout is rarely used in fully aerobatic aircraft. For these aircraft, it is important for the aircraft to behave in inverted flight as closely as possible to upright flight. In addition, aerobatic aircraft need to be snap-rolled predictably.

The thin wing of the Airbus A320 has lots of washout for safety.

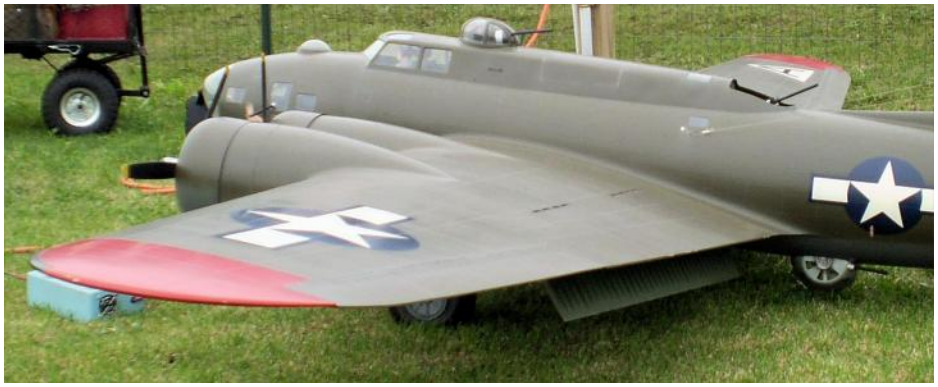
Constant-chord wings as found on the J-3 Cub or STOL aircraft benefit least from washout. They are built to maximize wing area and they need all the lift they can get. Instead of washout, they may use stall strips to soften the stall and shaped wingtips to reduce wingtip vortices in lieu of washout.

Typically, biplanes have their wing incidences adjusted so that the forward wing (typically the top wing in a Stearman or the bottom wing in a Beech Staggerwing) will stall before the rear wing. The ailerons are usually in the rear wing so that good aileron control is maintained even though the other wing is entirely stalled. This is one of the advantages of biplanes over monoplanes. Usually this configuration does not merit washout.

No washout and no incidence in Dave Deschenes' Wildcat, also typical of nearly constant-chord dive bombers.

Leading-edge slats can prevent tip stalls too, but slats are usually combined with washout for an extra margin of low speed control.

Flaps increase the angle of attack of the wing in the flap area by rotating the chord line. In effect, flaps increase washout. Lowering flaps improves pitch stability and aileron control at low airspeeds.



Washout provides good yaw control in Greg Hahn's B-17 in case of engine failure.

Aileron-less models that steer with rudder use the dihedral of the wings for banking. As the rudder yaws one wingtip forward, the angle of attack is increased while the other wingtip decreases its angle of attack. Wash-out would partially defeat this effect, so it is seldom used in aircraft of this type, except perhaps in scale models with very pointy wings.

Washout should be avoided in very lightweight wings that are not stiff enough to resist further twisting in flight. Imagine such a wing in a dive. The root is creating positive lift while the wingtip is generating negative lift due to washout. This twisting force tends to further increase washout if the wing is not stiff enough to resist it. As speed increases, drag increases but net lift becomes zero. A vertical dive equilibrium develops. If there is enough elevator authority to pull the nose up, the washout will suddenly reverse and the entire wing will be lifting, possibly enough to break the wing. If there is not enough airflow over the elevator to pull out, the plane will continue into the ground. Many RC gliders have crashed due to this principle.

How much ... The optimum amount of washout varies from zero to several degrees depending on the following factors:

- High aspect ratio (span/chord) wings need more washout because their thin wingtips tend to stall abruptly.
- Tapered wings need more washout in proportion to the amount of taper.
- High wing-loading requires more washout because it is more prone to tip stalls.
- Underpowered aircraft need more because they must fly at higher angles of attack.
- Thin wings need more washout because they stall abruptly at low angles of attack.
- Multi-engine airplanes need lots of washout for rudder effectiveness in the event of engine failure.
- Biplanes need less ***(see Why Not above)***.
- Aerobatic airplanes need none in order to be symmetric in flight.
- Washout becomes less effective as dihedral increases. The effect is small enough to be ignored, e.g., 6 degrees of dihedral requires an increase in washout of only 10%.

Washout can be added after construction by raising both ailerons a small amount. Recommended for the initial flights of a new model.

For scale models, use at least the amount of washout used in the full-sized aircraft. In general, RC warbirds use about 1 or 2 degrees of washout, adjusted up or down by the factors listed above. Rarely does an RC airplane need more than 4 degrees.

Where ... In most cases, the angle of attack of the wingtip should be close to zero in level flight, generating little or no lift in normal level cruise position, so the washout angle equals the root angle. Typically, washout is distributed uniformly from root to tip. But not always. Consider the following exceptions ...

- The three-piece wings of the Mitsubishi Babs, AT-6 and the Stuka have no twist in their center sections but begin outboard of the landing gear.
- The Focke-Wulf TA 152H high-altitude fighter's high aspect ratio wing has 2 degrees of washout, all of it in the aileron area.

- For some models, such as the nearly constant chord Howard Pete, very little washout if any is needed. But a small amount is included in the wingtips by shaping the leading edge of the outermost rib bay.

Bob Patton's Cessna Aerobat uses drooped wingtips for stall control, typical of Short Take-Off and Landing (STOL) aircraft.

There are several methods of building in washout during assembly: temporary tabs on each rib to hold the rib at the required angle; shims of varying height supporting the spars; tapered full-span sticks upon which the ribs rest during assembly; or setting twist after assembly. Sometimes the ribs and spars can be assembled on a flat surface without washout; then the trailing edge of the end ribs are raised, twisting the structure before the sheeting is applied. Open-structure wings can sometimes be completely built and covered with heat-shrink plastic film; then the wing is twisted while heat is re-applied with a hot-air gun.

A 90-degree sharp edge stall strip is added to the leading edge of the Grumman Lynx leading edge to lower the stall angle in the root area of the wing. This alternative to washout works when inverted too.

What if you forgot to build in enough washout in your model? Or flight tests suggest it needs more? Or maybe you want to play it safe and temporarily include extra washout during those first few flights? Unless the airplane has full-span ailerons, washout can be increased effectively one degree by raising the trailing edge of both ailerons slightly. For a typical giant scale model, this is less than 3/16 inch. Later, after stalls and tight turns have been found to be acceptable, lower the ailerons in small increments until they are back to neutral.

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The author's Howard Pete has washout in only the last rib bay enough for a nearly constant chord wing. Washout in the Pete wingtip is formed by shaping the leading edge in the outer rib bay.

Special thanks to Joe Grice, Scott Russell, Tony Paladino, and Jon Bomers for their individual technical assistance ...

The Northrup N9M flying wing depends upon sweep-back and wash-out for all of its pitch stability. Note the leading-edge slats for an extra margin of stall control at the tips.