

On the 'Wing...

Swept Wings and Effective Dihedral

by Bill and Bunny (B²) Kuhlman

Swept Wings and Effective Dihedral

One facet of tailless aircraft performance has always intrigued us — the ability of swept wing tailless sailplanes to travel at high speed without exhibiting Dutch roll, yet demonstrate excellent spiral stability while thermalling. This differs from what is seen in high performance conventional tailed sailplanes.

The designer of a conventional cross-tailed competition F3B machine must very carefully balance wing dihedral and vertical stabilizer surface area. There is a tendency to Dutch roll at high speed, and opposite aileron must be applied during thermal turns to prevent a spiral dive, even when the aircraft is optimized.

Since both vertical stabilizer area and geometric wing dihedral are held constant during flight, what is it about swept wings which allows them to “violate the rules”?

To begin, we need to go over the fundamentals, and so Parts 1 and 2 of this four part series will be devoted to explaining effective dihedral itself — how it is derived and how it influences aircraft stability.

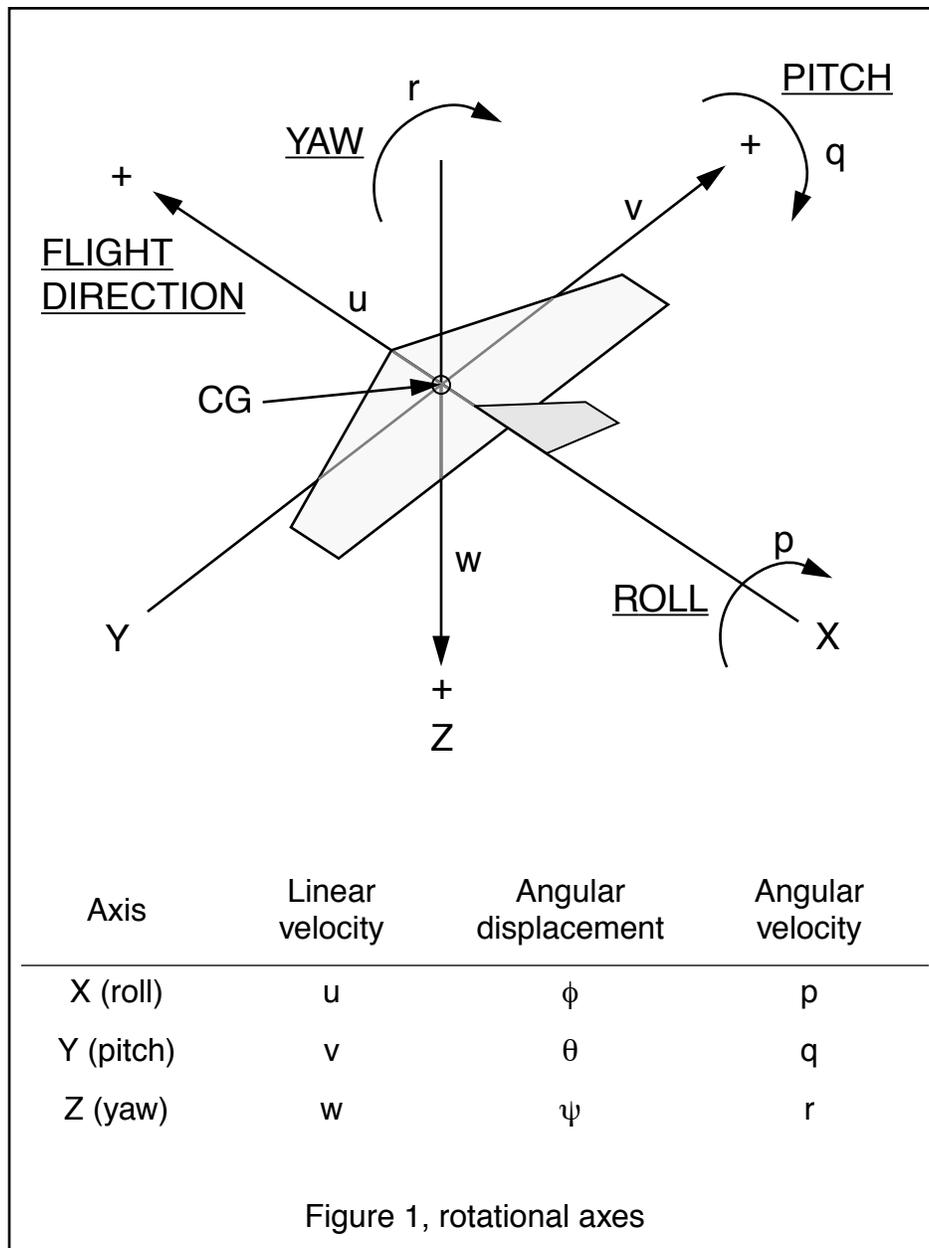
Pitch, Yaw, and Roll

Diagrams of aircraft in which the three rotational axes are noted can be found in most aerodynamics textbooks. Our rendition is included here as Figure 1. In simple terms, the nose of the aircraft can move up and down through an axis which parallels the wing span (pitch, Y axis), and it can move right and left through a vertical axis which passes down through the fuselage in the region of the wing (yaw, Z axis). The aircraft can also be made to rotate around an axis which roughly goes through the nose and tail cone (roll, X axis).

Elevator deflection changes the camber of the horizontal tail (stabilizer and elevator), increasing lift in the direction opposite to elevator deflection. By moving the elevator up or down, the aircraft tail may be lowered or raised, thus raising or lowering the nose. This is a change in pitch (Y axis). The size of the elevator and the distance between the center of gravity (CG) and the elevator determine elevator power. The larger the elevator surface area and the larger the distance between the CG and the elevator, the more elevator power.

If the elevator is deflected upward, the aircraft tail is pushed downward and the nose is thus raised. It must be clearly understood that the elevator controls the wing angle of attack, that is the angle of the wing to the freestream airflow. A larger upward deflection of the elevator will place the wing at a higher angle of attack. However, when elevator deflection is neutralized, the wing will return to its “normal” angle of attack. This is because the horizontal tail acts as a longitudinal stabilizer.

The rudder, when deflected, pushes the tail either right or left. Rudder deflection changes the camber of the vertical tail, increasing lift in the direction opposite to rudder deflection. When the rudder is deflected to the right, for example, the tail swings to the left and the nose swings to the right, inducing yaw, a rotation around the Z axis.



Larger deflections of the rudder will result in greater yaw angles, but the aircraft will return to zero degrees yaw when the rudder is neutralized. The vertical tail thus acts as a directional stabilizer.

Aileron deflection changes the camber of the wing in the region of the aileron. Upward deflection reduces lift, and further deflection may cause negative lift. As one aileron deflects upward, the opposite aileron deflects downward. Downward deflection increases wing lift in the region of the aileron. These changes in lift promote the lifting of the wing for which the aileron is deflected downward, and the depression of the wing for which the aileron is deflected upward. These coordinated actions induce roll, a rotation around the X axis.

While increased elevator deflection increases the angle of pitch and hence the wing angle of attack, and increased rudder deflection increases the angle of yaw, increased aileron deflection increases the rate of roll. Holding a specific wing angle of attack or aircraft angle of yaw is accomplished by steady continued deflection of the relevant control surface, elevator or rudder. Holding a specific angle of bank, however, dictates neutralizing the ailerons. There is no restoring moment when aileron deflection is neutralized and so the wings do not return to level. Instead, the roll rate reduces to zero and the bank angle is maintained.

The horizontal and vertical stabilizers are thus direct mechanism for returning the aircraft to its equilibrium attitude in pitch and yaw, but there is no equivalent mechanism for roll.

Lateral Stability

The above discussion is somewhat simplistic in that roll never takes place by itself. Rather, roll always causes some other motion. In straight and level flight, lift equals aircraft mass. See Figure 2.

First, and most important, roll causes a sideslip. When there is no pitch input to change the angle of attack of the wing, and the airplane is rolled to a specific angle of bank, the vertical lift component is less than the mass of the aircraft. A sideward component is at the same time acting in the direction of the eventual turn. See Figure 3. The aircraft drops and its velocity increases so the vertical lift component will equal the mass. The aircraft accelerates into a circular path because of the sideward lift component. See Figure 4.

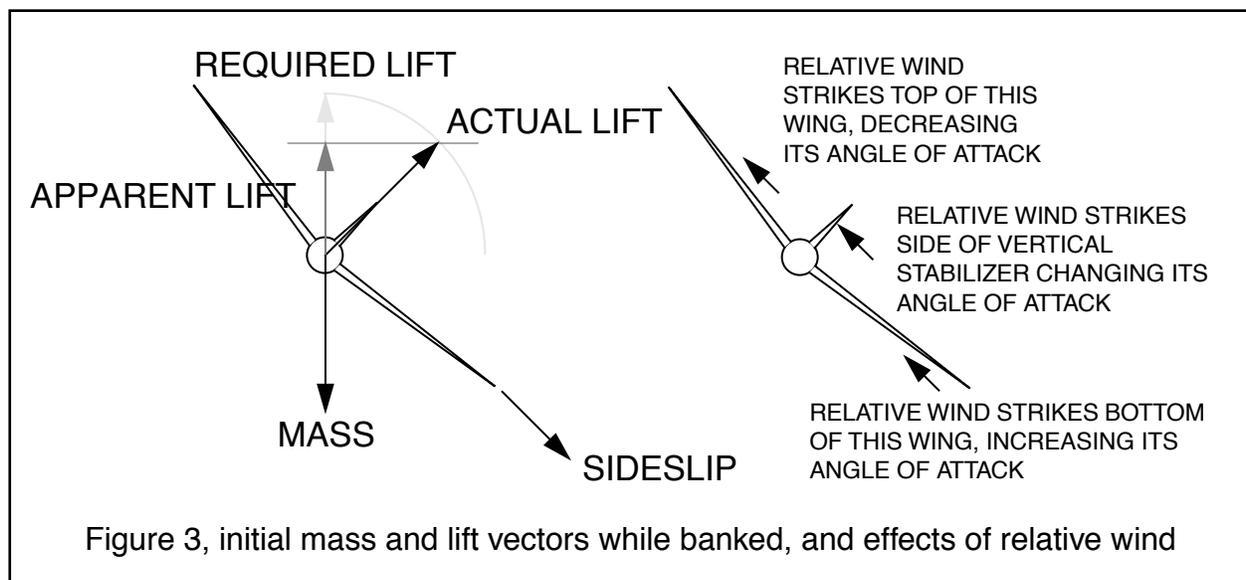
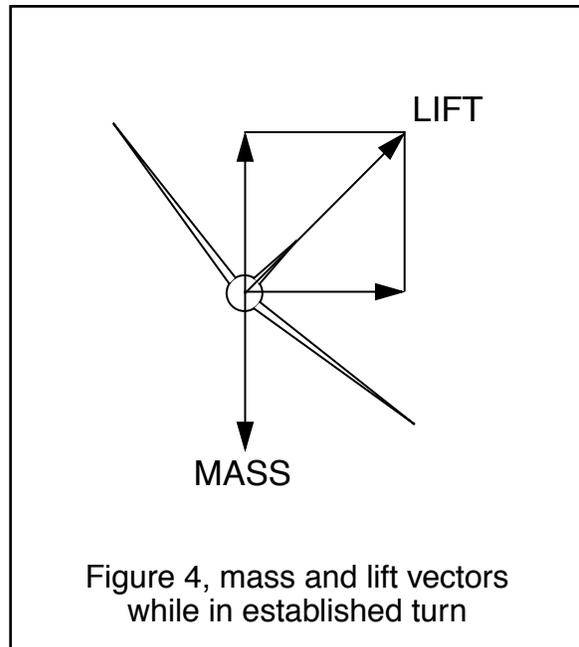
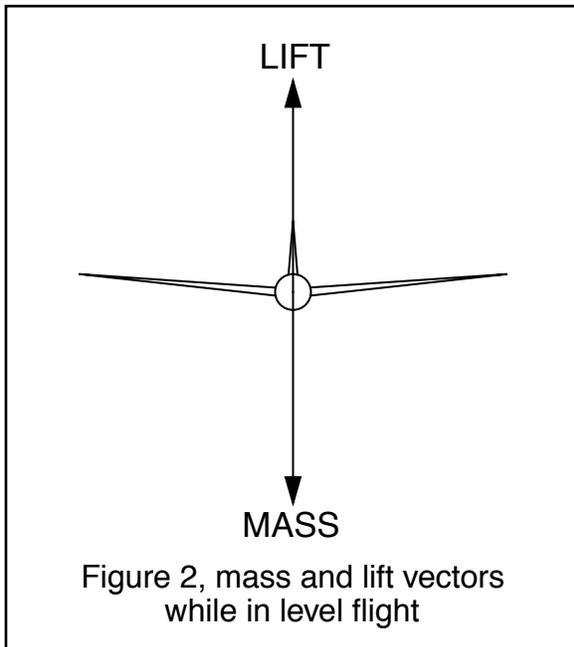
When this process is initiated — the aircraft is banked but the lift is too small, through lack of airspeed or lack of C_L — a component of the mass acts along the wingspan and the aircraft sideslips. It is important to recognize that no component of lift acts along the span, so the lift does not cause the sideslip. Once the turn is established, the lift and centrifugal effects balance the mass, but initially it is the unbalanced mass which causes the sideslip.

As an example, if the aircraft rolls to the right, the aircraft will sideslip to the right. This is equivalent to yawing the aircraft to the left, as the air is coming toward the right side of the aircraft. Such a sideslip to the right may thus be caused by either an initial roll to the right, or by moving the rudder to the left.

If the wing has some dihedral (wing tips higher than wing roots), the sideslip creates a situation in which the lower wing, which is moving into the sideslip, meets the oncoming air at a greater angle of attack than the higher wing. This generates a restoring force. It should also be noted that the lower wing, because it is operating at a greater angle of attack, is generating more drag than the higher wing. This creates a yaw to the left, thus reducing the sideslip. The result of all of these effects is to both reduce the sideslip and restore the wings to level.

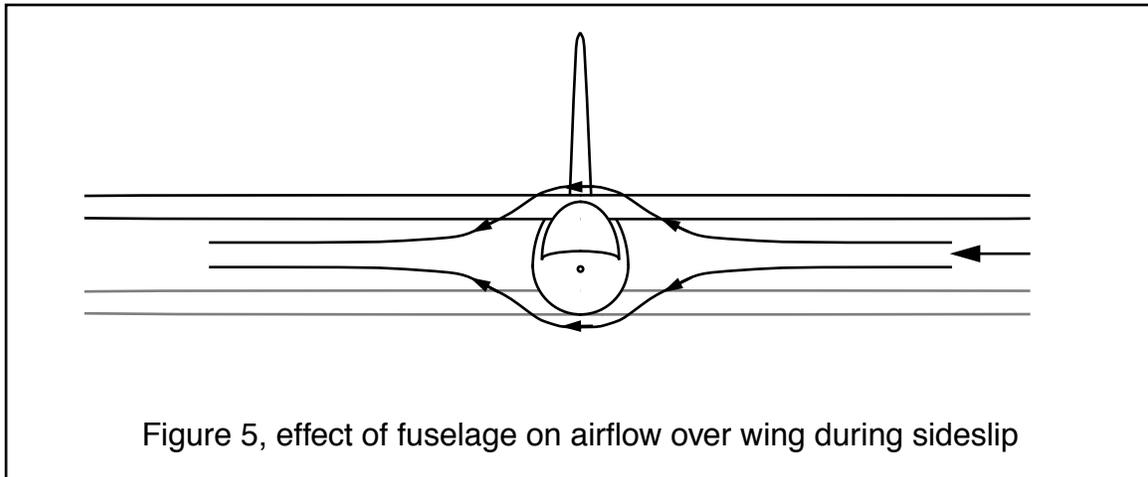
An aircraft is said to have static lateral stability if the right wing rolls upward when there is a sideslip to the right. Because dihedral causes this response to a sideslip, lateral stability is sometimes referred to as “dihedral effect.”

Another contributor to lateral stability is the position of the wing on the fuselage. If the wing is mounted on the top of the fuselage, any sideslip will change the flow of the air over the fuselage in

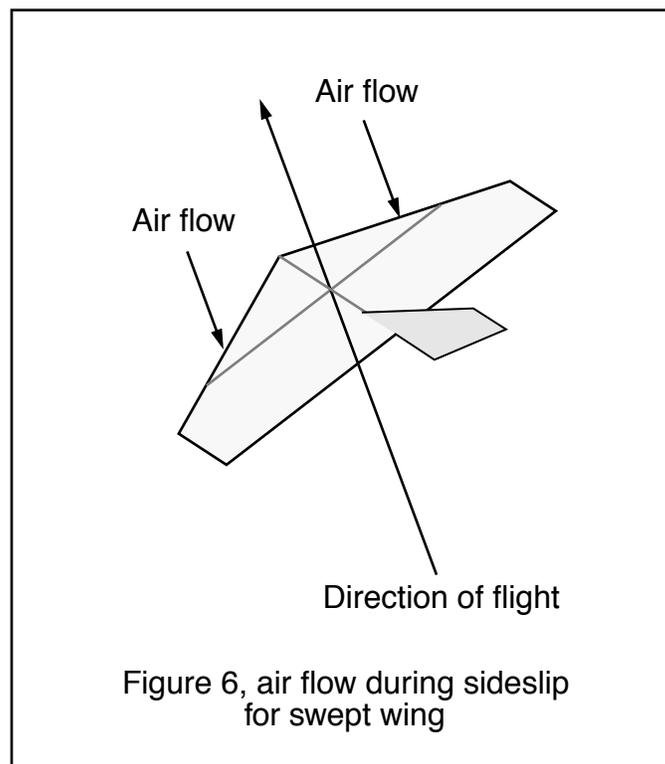


such a way that the low wing, which is moving into the sideslip, will be operating at a higher effective angle of attack. The raised wing, on the other hand, will be operating at a lower effective angle of attack. When the wing is located on the top of the fuselage, the wing acts as if it has some positive geometric dihedral. This is because of the airflow over the top of the fuselage. See Figure 5.

If, on the other hand, the wing is mounted on the bottom of the fuselage, the wing moving into the sideslip operates at a slightly lower effective angle of attack, while the raised wing operates at a slightly higher effective angle of attack. This is due to the airflow over the bottom of the fuselage, and accounts for the observation that high wing monoplanes have very little dihedral, some times none at all, while low wing monoplanes have obviously steep dihedral angles.



As the aircraft rolls to the right, the angle of attack of the left wing is immediately reduced because of the airflow coming from above. The right wing, on the other hand, operates at a higher angle of attack because the airflow is now coming from the bottom. There is an accompanying differential drag effect as well. These effects take place only while the aircraft is actually rolling, however, and hence have a damping rather than a corrective action. That is, if the wings are held at a constant bank angle there is no vertical velocity on the wings, and no damping forces are generated. It should also be noted that if the angle of attack is such that the wing is near stall, the downgoing wing may in fact stall, thus reducing lift precipitously and allowing the already lowered wing to fall.



A swept wing, without fuselage or tail, tends toward lateral stability. This is because the air more directly meets the wing which is moving into the sideslip, creating more lift and, as stated previously for conventional aircraft wings, more drag. Both of these actions result in restoring moments. See Figure 6.

A small restoring force in roll is also generated by the vertical tail if it protrudes from the upper part of the fuselage. See Figure 3.

Yaw-Roll Coupling

Having said that a roll causes a sideslip and then a yaw, it is imperative to note that the reverse is also true — a yaw causes a sideslip and then a roll. The coupling of roll, yaw, and sideslip cannot be separated.

As an indication of these interactions, place a model aircraft with dihedral on a wire such that the wire goes directly from nose to tail through the CG. If the model is canted (rolled) slightly and then pushed forcibly down the wire, the model will not right itself. This is because without sideslip there is no restoring force, only damping forces, as explained in the previous section. In fact, then, it is the interaction of roll, sideslip and yaw which allows the designer to produce a stable aircraft.

Aircraft controlled by rudder only (no ailerons) must have substantial dihedral. As the rudder is deflected, the effective angle of attack of the outboard wing is increased, generating a rolling motion into the turn. Without dihedral, rudder deflection would simply yaw the aircraft, and no roll component would be generated. If the dihedral angle and vertical tail area are correct, the aircraft will continue to circle at a constant bank angle once the rudder is returned to the neutral position. (See also End Note 1, Aileron drag and adverse yaw.)

We often think adverse yaw is the direct result of aileron deflection. Because aileron deflection changes wing camber, it is easy to see that this differentially affects the drag of the wings. The aircraft tends to yaw toward the downward deflected aileron, an action opposite to what is wanted. Rudder deflection must be imparted to counteract this adverse yaw, substantially increasing drag during turns.

But there is a second, and more important reason for the appearance of adverse yaw. We'll let Steve Morris explain...

“Adverse yaw is affected by a drag imbalance between the wings while rolling, but it is not only the drag of aileron deflection that causes this. Imagine the wing is balanced in a perfect rolling motion (constant roll rate) with the ailerons deflected and the rolling motion fully developed so that the span loading is identical to before the maneuver began. This implies the ailerons changed the loading to cause the roll and the motion of the wing induces angle of attack changes that cancel this roll torque when a steady-state roll rate is achieved. The downward moving wing sees a greater angle of attack due to the rolling motion (greatest at the wing tip) and the upward moving wing sees a lower angle of attack. The local lift vectors are tilted forward on the downward moving wing and backward on the upward wing by the rolling motion. This change in lift direction due to the induced velocities of rolling

produces powerful adverse yaw regardless of profile drag changes. The same induced velocities tilt the lift vectors on birds when they flap their wings and this is how they get thrust on the downstroke. Aileron drag is a much smaller part of the adverse yaw than this induced effect.”

Directional Stability and Spiral Instability

In RC sailplanes, if vertical stabilizer area is too large, the pilot must continuously input rudder controls to maintain the correct heading. This is because the aircraft will always tend to turn into any sideslip, and bank more steeply. If corrective commands are not made, the yaw will increase gradually to the point the aircraft is in a spiral — an increasing turn of decreasing radius with the nose pointing downward and speed rapidly increasing and altitude rapidly decreasing. See Figure 7.

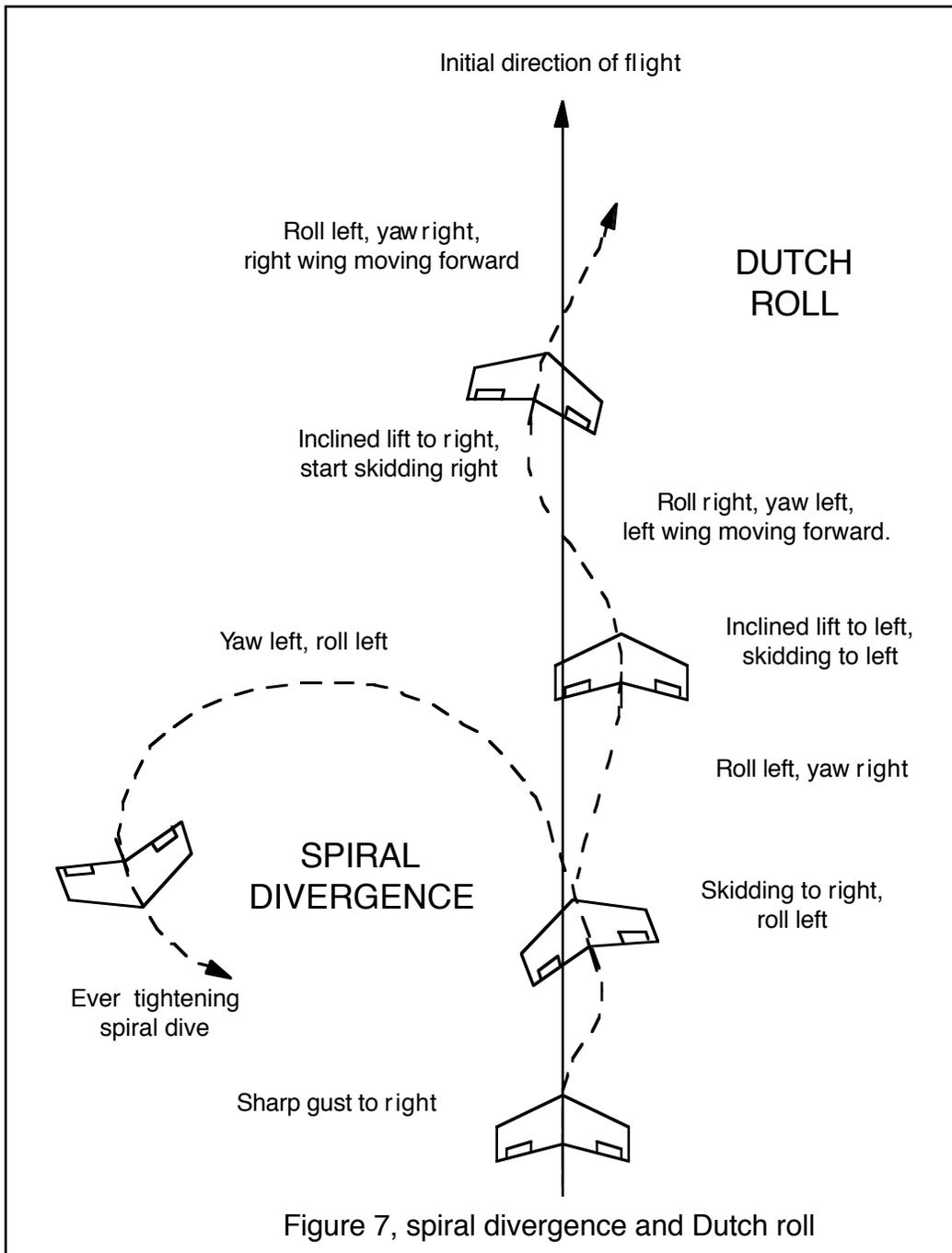
A similar effect takes place if the vertical fin is too large and there is a slight roll. If, for example, the roll is to the right, there is a sideslip to the right. The fin, being too large, reacts to the yaw by turning the aircraft to the right and increasing the bank angle. With a steeper bank angle, sideslip and yaw moment both increase. As in the above paragraph, the aircraft will quickly be in spiral toward the ground. In both cases, the aircraft has too much directional stability, making it prone to spiral instability. See “spiral divergence” in Figure 7.

Steve Morris brought another reason for spiral divergence to our attention. He said,

“Spiral divergence is also strongly affected by C_{lr} , roll torque due to yaw rate, which is a very strong effect on long-span airplanes which fly slowly. The inboard wing is flying very slow compared to the outboard wing when turning and this velocity difference, due to yaw rate, causes the lift across the wing to vary, and the aircraft rolls into the turn. C_{lr} is a big effect on human powered aircraft, hang gliders, sailplanes, and model sailplanes, especially high aspect ratio slow flyers.”

Decreasing vertical stabilizer size decreases directional stability and increases spiral stability. Increasing dihedral effect has a similar action. But it should be noted that most full size aircraft are at least somewhat prone to spiral divergence. That is, the aircraft has too much directional stability, and the pilot is nearly always making very small corrections to prevent a spiral. Why this is so will be clear shortly.

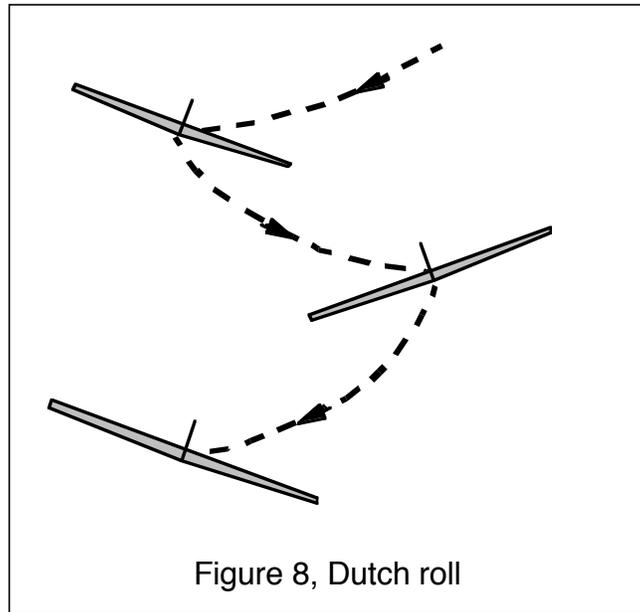
Too much dihedral causes its own problems. If dihedral is excessive, crosswind landings are more difficult as the aircraft is operating in a sideslip, and lateral gusts may induce large roll angles and high roll rates. And there is also an increased tendency toward the notorious Dutch roll, especially at high speeds.



Dutch Roll

A small gust hitting the wing or vertical tail can initiate a rather complex oscillatory motion consisting of roll and yaw which are out of phase with each other. First there is a yaw and roll in one direction, then recovery with an

overshoot to yaw and roll in the opposite direction. From the rear, the tail cone traces a circular arc. See Figure 7 and Figure 8.



While not inherently dangerous, Dutch roll produces a tremendous amount of drag. In conventional tailed RC sailplanes, Dutch roll most often occurs while

flying at high speed. Dutch roll is caused by too much dihedral and insufficient vertical stabilizer area. There is too much spiral stability and insufficient directional stability.

The cure for spiral divergence, reducing vertical stabilizer area and/or increasing dihedral, thus makes the aircraft more prone to Dutch roll. The cure for Dutch roll, increasing vertical stabilizer size and/or reducing dihedral, makes the aircraft more directionally stable and more prone to spiral instability and spiral divergence.

As is usual when designing aircraft, some compromise must be made, and the aircraft then designed around what is seen as the best overall performance.

The Effects of Taper Ratio and Aspect Ratio on Effective Dihedral

Taper ratio affects effective dihedral. Both the included chart and this short discussion assume taper ratio to be defined as tip chord/root chord.

From McCormick, page 544, for a linearly tapered wing, the increment for dihedral angle is:

$$C_{l\beta} = -\frac{a}{6} \left(\frac{1 + 2\lambda}{1 + \lambda} \right) \Gamma$$

where

$C_{l\beta}$ = the rate of change of the rolling moment with sideslip angle (simply put, one degree of effective dihedral is equivalent to a $C_{l\beta}$ of -0.0021);

a = the slope of the wing lift curve slope in radians, adjusted for aspect ratio

$$a = 0.105 \cdot \frac{AR}{AR + 2}$$

λ = the taper ratio (no taper = 1, sharp tip = 0.0);

Γ = the wing dihedral angle in radians, small angles only.

The relationship of taper ratio and effective dihedral is graphically illustrated in the differences between Graphs 1 and 2. Note that effective dihedral is always somewhat larger than geometric dihedral. For the purposes of these graphs, the slope of the lift curve a was adjusted for different aspect ratios. Given the same taper ratio, note that effective dihedral increases as aspect ratio increases.

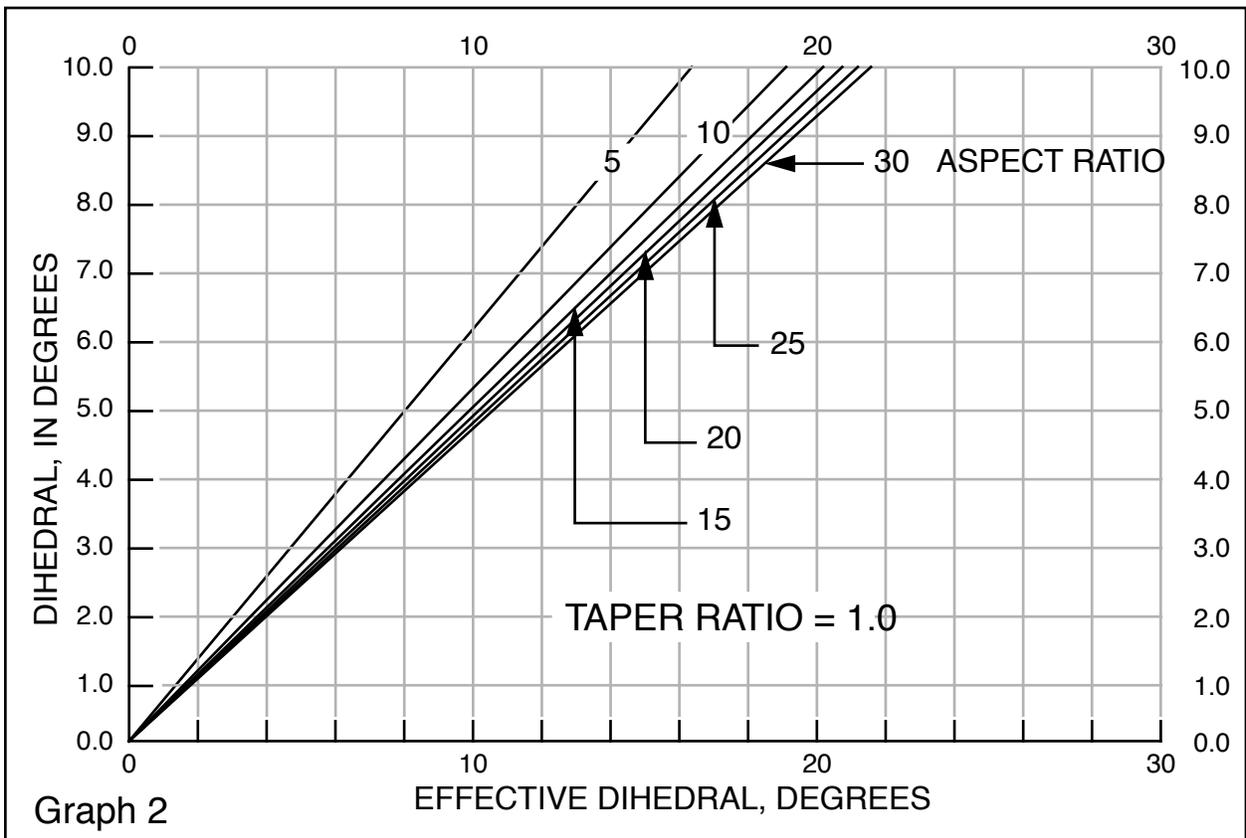
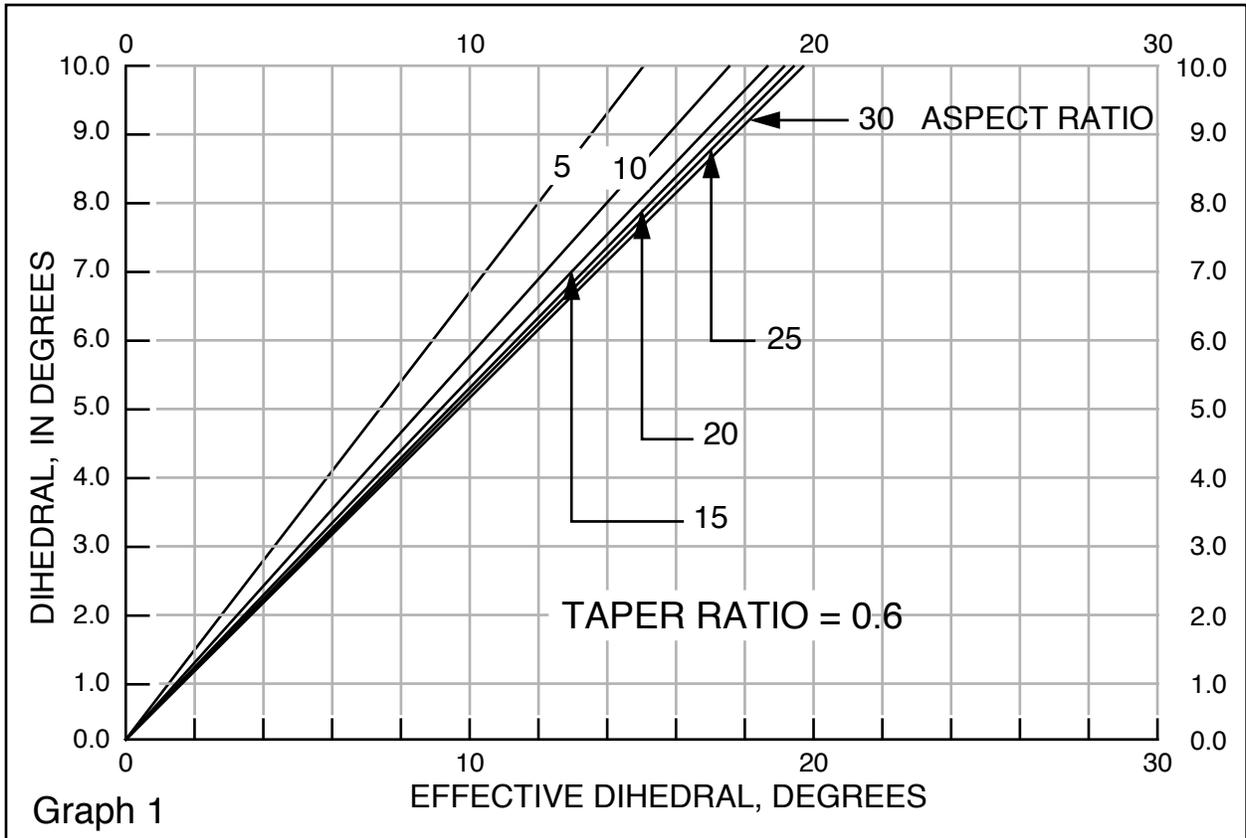
As the taper ratio gets larger (approaches and exceeds unity), effective dihedral gets larger. This is because effective dihedral is influenced by the position of the wing centroid. As the centroid moves outboard with larger taper ratio, effective dihedral increases. The area added at the tip increases the dihedral effect strongly because of its large moment arm.

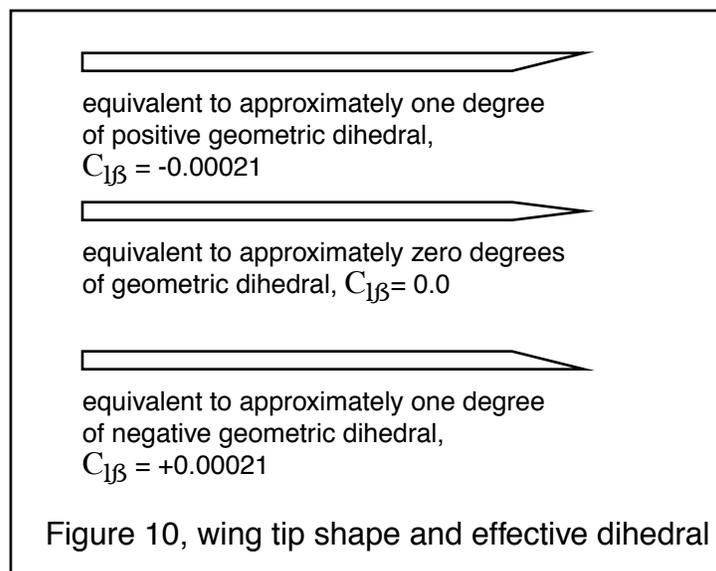
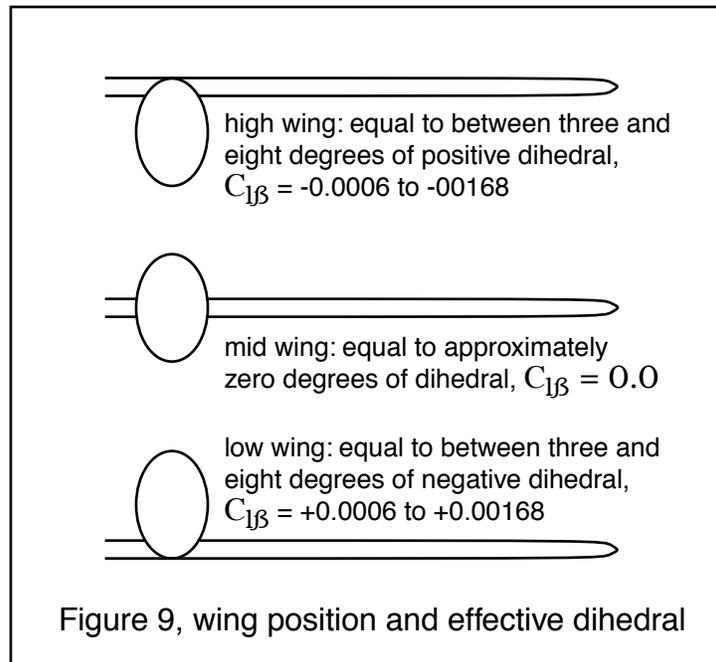
Swept Wings and Effective Dihedral — The Basics

In an ideal world, an aircraft would have adjustable vertical stabilizer size and adjustable dihedral. Dihedral would be reduced and vertical stabilizer area increased during high speed straight line flight. While thermalling, dihedral would be increased and vertical stabilizer area reduced.

Imagine for a moment that dihedral could be automatically adjusted in direct inverse proportion to speed. That is, higher speed would reduce dihedral, while slow speed would increase dihedral. If dihedral could be controlled appropriately, adjustment of vertical stabilizer size would become relatively unimportant.

We usually think of dihedral in geometric terms. That is, we actually see the dihedral when we view the aircraft from the front or rear. We block up the wing tip a certain distance during construction, or see the dihedral angle noted on outline plans in magazines.





But there is also a dihedral effect resulting from certain planforms, contours and from the interactions of various components. We've already noted, for example, that a high wing location provides sufficient dihedral effect to mandate use of only a small additional positive geometric dihedral angle. A low wing location normally dictates a significant amount of positive geometric dihedral, as the position of the wing gives a large amount of negative effective dihedral. See Figure 9. Wing tip contour has a smaller, but still significant, effect. See Figure 10.

Wing sweep also provides some amount of dihedral effect. Sweep back gives positive dihedral effect, while sweep forward gives a negative dihedral effect.

From McCormick, page 547, we find that for a linearly tapered wing, the increment due to sweep angle is:

$$C_{l\beta} = -\frac{1 + 2\lambda}{3(1 + \lambda)} \cdot C_L \tan \Lambda$$

where

$C_{l\beta}$ = increment due to sweep angle, and $C_{l\beta} - 0.00021$ is equivalent to one degree of positive effective dihedral;

λ = the taper ratio;

C_L = the wing lift coefficient;

Λ = the wing sweep angle measured at half chord.

There's a tricky part to this. Note the inclusion of the coefficient of lift, C_L , in this equation. We've several times seen a "rule of thumb" stating three degrees of sweep is equivalent to one degree of geometric dihedral. Contrary to that popular notion, swept wings demonstrate a continuously variable dihedral effect. The amount of effective dihedral is directly dependent upon both the sweep angle, Λ , and the coefficient of lift, C_L . These relationships are shown in Graph 3 (taper ratio = 0.6) and Graph 4 (taper ratio = 1.0).

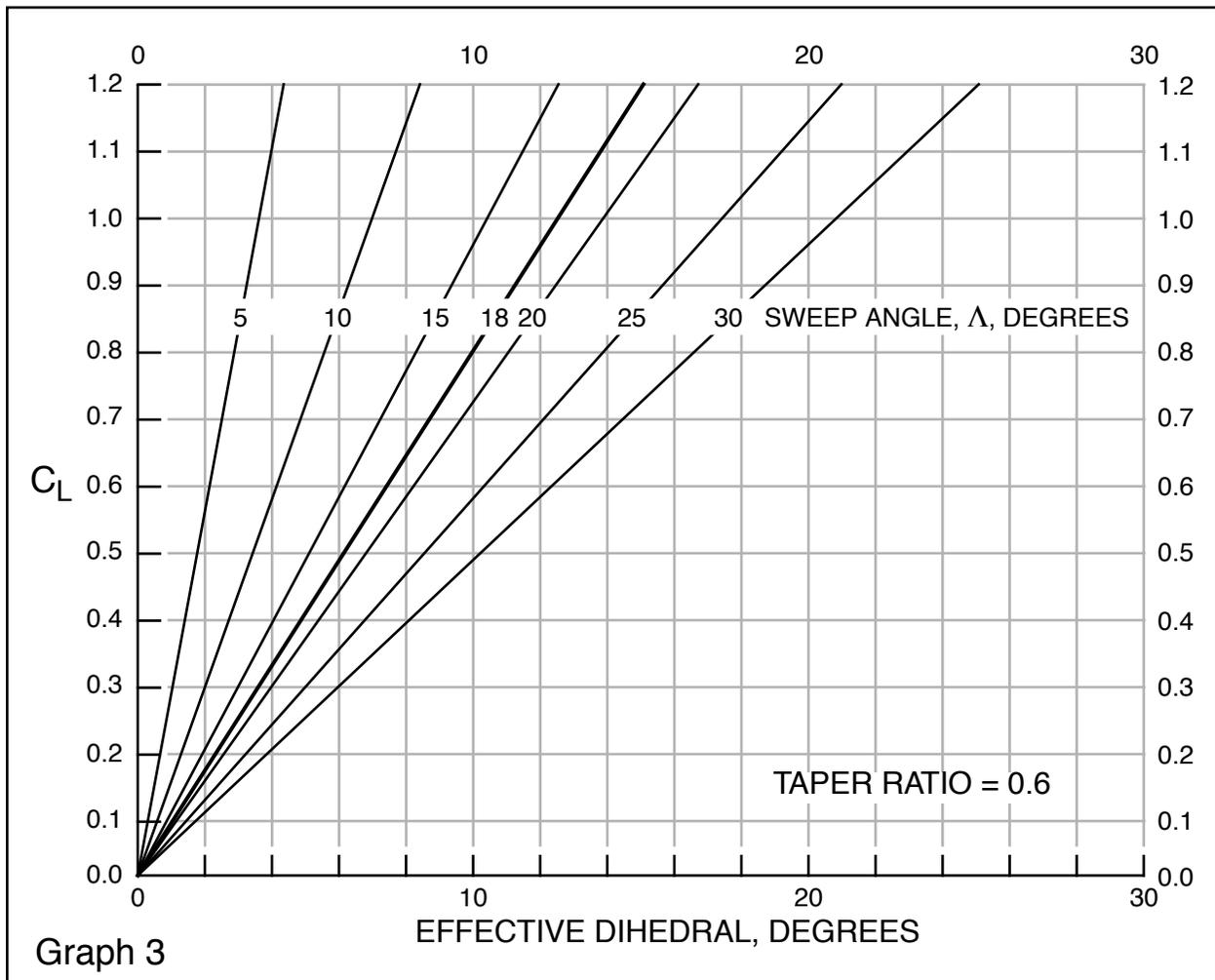
Several points depicted in this Graph are worth noting:

First, if C_L is zero, effective dihedral is zero, regardless of the sweep angle.

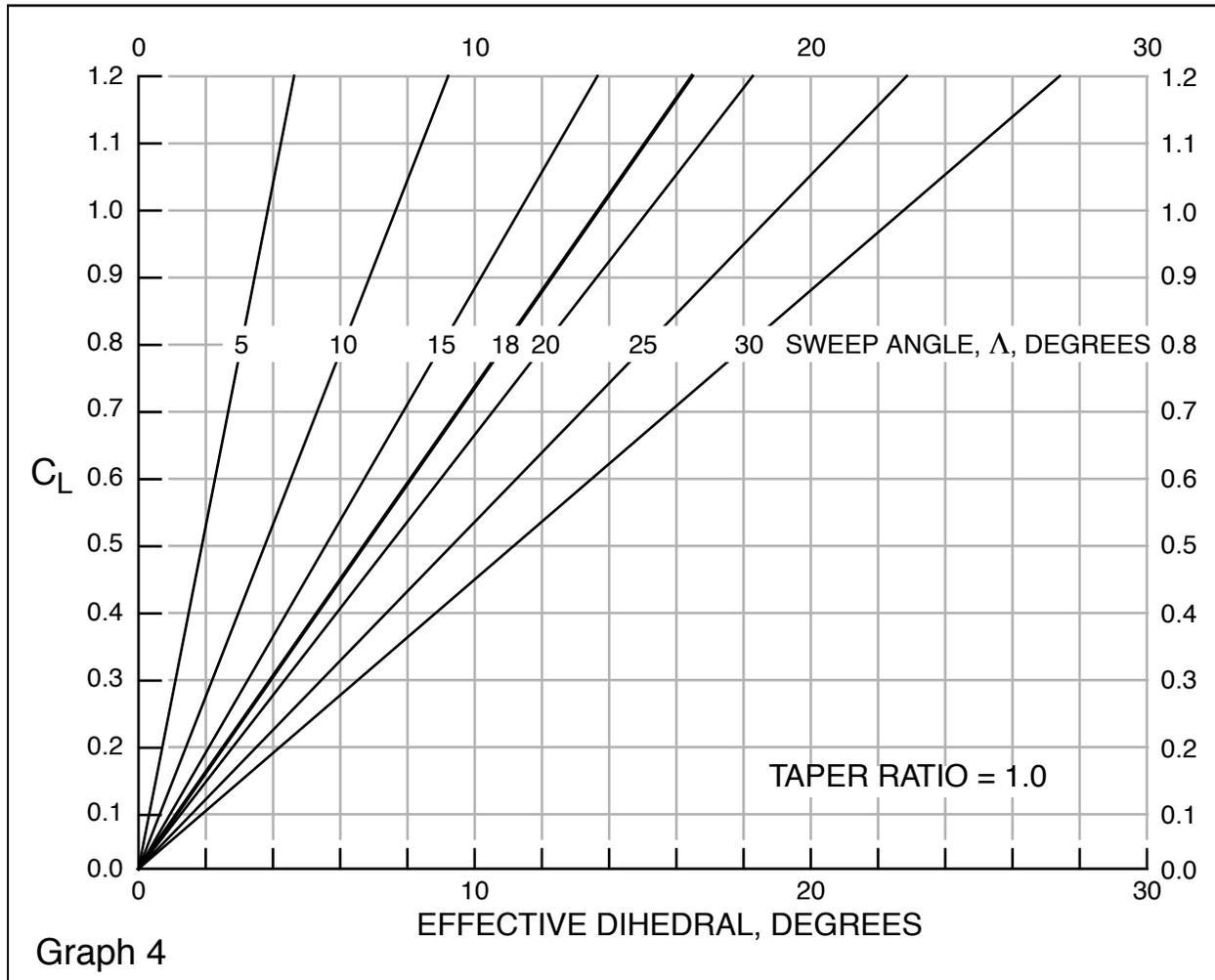
Second, when the wing is swept back, the higher the C_L value, the greater the effective dihedral. This is an important consideration, as it relates directly to swept wing performance characteristics across the aircraft speed range. This is because velocity is directly related to C_L . As velocity decreases, C_L must increase.

Effective dihedral thus decreases at higher speeds, when C_L values are low, as when flying between thermals or racing, and increases at lower speeds and higher C_L values, as while thermalling. This is exactly what we want!

Effective dihedral, as related to sweep, is directly proportional to the wing sweep angle, as measured at the half chord line. Some amount of sweep, usually no more than 25 degrees, produces an amount of effective dihedral which benefits performance across the speed range. Severe sweep angles, however, adversely affect spanwise flow and wing efficiency, and make launching via winch more difficult.

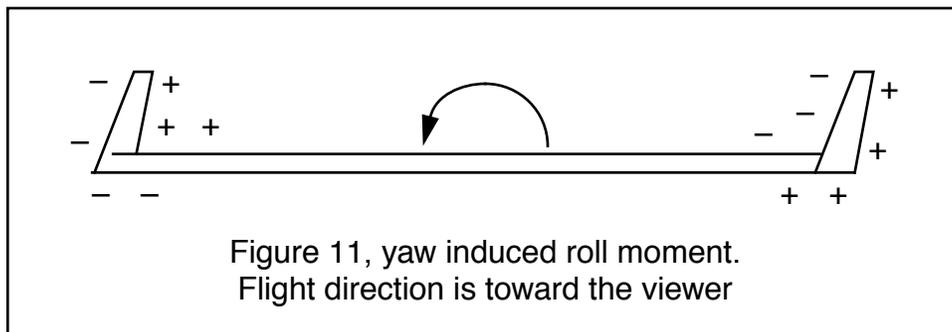


Since lateral stability (dihedral effect) increases with both the sweep angle and the coefficient of lift, there will be variations in aileron effectiveness depending on the flight regime. During those periods when a swept wing is generating a very large coefficient of lift, roll response may be below acceptable levels. It is therefore imperative to have large ailerons which can produce sufficient power at minimal deflection angles.



Winglets

One final factor also influences effective dihedral — winglets. Upright winglets, as normally seen on swept wing thermal duration tailless gliders, produce a substantial amount of effective dihedral. Why this is so is examined graphically in Figure 11.



If winglets are mounted on a plank planform wing, and the wing is then yawed, the forward winglet produces some amount of lift toward the wing. The trailing winglet will produce lift away from the wing. The side of the winglet which is facing away from the oncoming flow therefore has an area of reduced pressure. Adjacent areas of the wing are affected as well. The gross result is a rolling moment which is directly related to the amount of yaw. This effect is maintained when the wing is swept.

From Nickel and Wohlfahrt, page 108, the skid-roll moment for a wing with winglets is the same as that of a conventional wing with the equivalent dihedral angle, EDA (p. 108):

$$EDA = \frac{20h_w}{s}$$

where

EDA = equivalent dihedral angle;

h_w = the height of the winglet;

$s = b/2$, the semi-span.

From this formula it can be seen that taller winglets (those with greater span) produce greater amounts of effective dihedral when the wing span is held constant.

As wing sweep increases, winglet size can be reduced because of the lengthened lever arm. As reducing the height of the winglet also reduces effective dihedral, there is a trade-off of sorts to be reconciled.

Computing Total Effective Dihedral

It is important to realize that the fundamental concept to be understood with regard to lateral stability is the relationship between rolling moment and sideslip. The symbol $C_{l\beta}$ is defined as “roll due to sideslip”; a $C_{l\beta}$ value of -0.00021 is roughly equivalent to one degree of positive dihedral, as mentioned previously.

The total effective dihedral of an aircraft is the sum of all of the effective dihedral increments generated by the planform and its various components. Wing taper ratio, geometric dihedral and tip shape, winglets, position of the wing in relation to any fuselage, wing sweep, and coefficient of lift must all be taken into consideration. Flaps with swept hinge lines accentuate the dihedral effect even further, sometimes making controlled flight impossible.

A vertical tail, if any, also contributes to effective dihedral, as any sideslip generates a rolling moment because of side forces on the fin and rudder.

Swept wings, particularly those which use winglets, may suffer from excessive effective dihedral. Because effective dihedral is directly proportional to the coefficient of lift, roll authority may be lost while thermalling. In extreme cases, severe Dutch roll occurs at low speeds, as during landing.

Wing twist also affects the dihedral of swept wings. Excessive washout can unload the tip so much that the dihedral effect is small — or even reversed at high speeds! — and may produce a wing that can't fly well inverted.

Counteracting Excess Effective Dihedral

Luckily, negative geometric dihedral can be used to inhibit the strong dihedral effect brought on by a combination of high C_L values, severe sweep angles, and/or other factors. But computing how much anhedral is necessary for controllability across all flight regimes does pose some difficulties; there is a limit to how much anhedral (negative dihedral) can be used.

Effective dihedral may be so small at low coefficients of lift that too much geometric anhedral may cause the aircraft to invert at high speed. Or the aircraft may be susceptible to static directional divergence if too much anhedral is used and the angle of attack becomes too great.

Countering excess effective dihedral may also be accomplished by mounting the winglets such that they hang below the wing. This produces a reversed yaw-roll effect, but places the winglets in a position to be easily damaged.

So-called “diffuser tips” are sometimes used in lieu of straight anhedral or downward projecting winglets. Some sources denote this geometry with the term “Stromburg wing.” See Figure 12. The wing has some amount of positive dihedral across the majority of the span, and the wing ends are then bent downward at what seems to be a severe angle. Sometimes toe-in is incorporated in the wing tip by angling the dihedral joint such that it is not parallel to the freestream, thus imparting a twist to the outer portion of the wing.

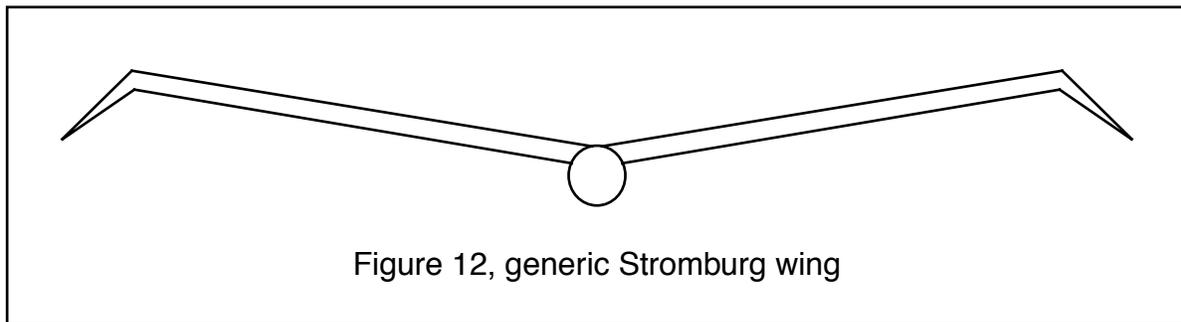
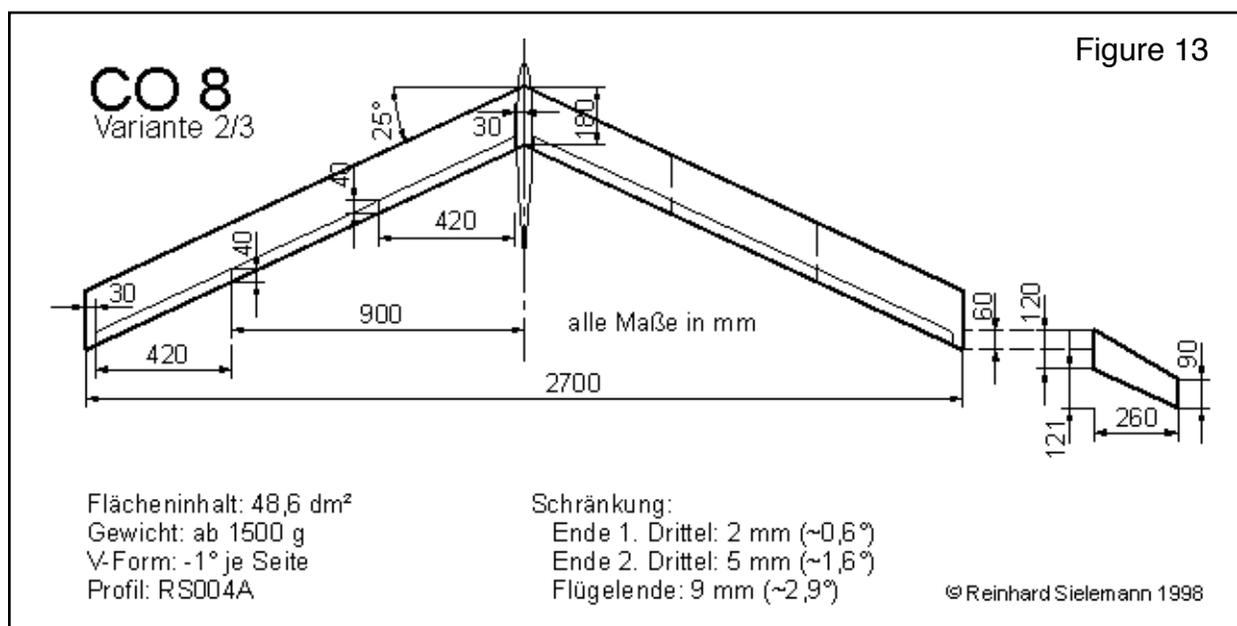


Figure 12, generic Stromburg wing

A Case Study

CO8 V2/3, the latest design from Hans-Jürgen Unverferth (see Figure 13), incorporates one degree of anhedral (negative dihedral). Let's take a look at the various contributors to effective dihedral for this planform.



With a sweep angle of 25 degrees, plus winglets, some amount of compensation is most likely needed. The winglets contribute 3.85 degrees, and at $C_L = 0.1$, the effective dihedral angle due to sweep alone is 1.5 degrees. The difference between the geometric dihedral (-1.0 degrees) and the effective dihedral, (3.85 + 1.5 degrees = 5.35 degrees) is 4.35 degrees. This gives an adequate amount of yaw-roll coupling, and there is not much chance of the aircraft inverting while flying through turbulence.

While thermalling ($C_L = 0.6$), effective dihedral becomes 15 degrees (3.85 degrees + 11.2 degrees). The single degree of anhedral still leaves over fourteen degrees of effective dihedral. This amount of effective dihedral is not so extreme as one might think (see Blaine Beron-Rawdon's "Spiral Stability and the Bowl Effect"). CO8 thermals hands off. An additional benefit occurs during winch launching — the anhedral lowers the center of gravity so towline tension works through a smaller arm, thus inhibiting over rotation during the initial launch phase.

Anhedral and the "Flat Spin"

There is an additional, and somewhat surprising, benefit to be derived from incorporating anhedral. Eduardo Molfino, who lives in Argentina, has been experimenting with tailless sailplanes for some time. Eduardo is a regular contributor to the nurflugel e-mail list on the internet, and was, along with Steve Morris, a reviewer of this article.

Eduardo says,

"I built several swept 'wing models, of several sizes and criteria. Many of them did not survive the initial trimming phase due to brutal crashes. I don't care to recognize my mistakes, because I learn from them. The achieved experience was big, even if I was not able to translate it in formulae. I experienced all the effects described in your essay on every single 'wing I built.

“Here is the interesting part: I found some other problems too, noticeable only under extreme flight conditions. The main stability problem found on most models was the tendency to flat spin when thermalling or steep turning at low speeds. The best models were not falling into flat spins under normal flight conditions, but sometimes in strong turbulent thermals they did. The height losses to recover from flat spins were different for each model, ranging from a few meters to infinite. Some of them never recovered from the flat spin, no matter what you did with commands. Only ground contact stopped them!

“After lots of tests I found a way for the wing to self-recover from flat spins, without pilot input. The main problem on low loaded wings (<25 gr/sq dm) is that the flat spins were some kind of stable rotating stall condition, with such low speeds that aileron deflections were not able to break this “stability” and recover a normal flight path. In extreme cases, this rotation caused one wing tip to fly “forward” while the opposite wing tip was flying “in reverse.”

“Carefully analyzing the situation, the conclusions are: (1) Some airfoils reach a self stabilizing pitch condition when stalled. That means that C_m was achieving high positive values under strong stall conditions, hence the forward CG position was not enough by itself to give “nose down” pitch in order to recover speed and control. (2) Control surfaces have almost no effect due to lack of airspeed and massive flow separation. (3) Aerodynamic forces in this situation are in a new kind of balance that normal control surfaces cannot break. (4) If the CG is lower than this “new balance” lift force, we have a full pendulum equilibrium, hence large flat spin stability. The lower the CG, the stronger the effect — like a rotating parachute.

“Explained in poor terms, the solution was to shift the CG up. This leads to instability on flat spins, hence the model will have a “nose down” and “inverted flight” tendency if aerodynamic forces go to zero for a while.

“The self recovering maneuver in the air is funny. If the wing stalls on a steep turn at low speed, a full turn around the vertical axes will be performed, while the nose goes down pretty fast, sometimes 90 degrees or more. With a small height loss the speed is recovered, and control and stability becomes “normal” again.

“On the practical side, the difference can be made with the ballast position. I fix it high within the airframe, instead of low, and some negative geometric dihedral completes the feature.”

Summary

- Spiral instability is caused by too large a fin area, that is, by too much directional stability.
- An aircraft which is very stable laterally, with large amounts of dihedral, will be unstable directionally and prone to Dutch roll.
- Dutch roll: direction of the turn is always out of phase with the rolling motion.

- The contributors to spiral instability and Dutch roll are in opposition.
- The dihedral effect will remain constant through the angle of attack range if the wing has no sweep. Dihedral effect will increase with increasing C_L if the wing is swept back. The greater the sweep angle, the greater this effect.
- Positive effects of anhedral during launch of swept wing aircraft: lower effective dihedral at high C_L , and tow hook higher in relation to CG.
- Anhedral can also have a positive effect on recovery from a “flat spin.”

Swept wing tailless sailplanes are able to demonstrate excellent spiral stability while thermalling because effective dihedral is increased at high C_L . Since effective dihedral decreases as the C_L gets lower, they show no tendency toward Dutch roll at high speed. During thermal turns, effective dihedral is increased, and opposite aileron is not usually needed to prevent a spiral dive. These are distinct advantages over conventional tailed sailplanes.

Some amount of anhedral may be used to reduce effective dihedral. Anhedral also has a positive effect during launch as it lowers the CG. It should be remembered, however, that since anhedral reduces effective dihedral by a constant amount, regardless of flight regime, too much anhedral can cause the aircraft to invert at high speed.

So, do swept wings “violate the rules”? No, they just behave according to an additional set of rules which take into account the effects of sweep as the coefficient of lift increases or decreases. Once these additional rules are taken into account, the design of a swept wing tailless sailplane is only slightly more complicated than the design of a more conventional tailed aircraft. The increased performance potential is, however, certainly worth striving to achieve.

We hope you’ve benefitted from this examination of effective dihedral and how it is affected by various design parameters. Anyone wishing a printed copy of all of the formulae used in this article need only submit a request to us through either regular mail (B², P.O. Box 975, Olalla WA 98359-0975) or an e-mail message <bsquared@halcyon.com>. This series of four columns will soon be on our web site at <<http://www.halcyon.com/bsquared/effdih.html>>.

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