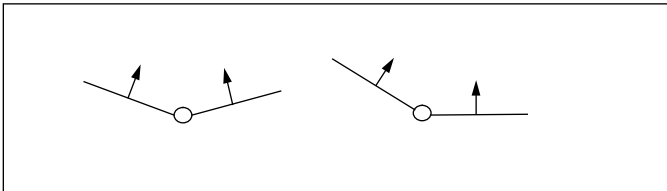


## Topic #3: The Explanation of Dihedral

### Introduction

My previous article on the topic of CG location & pitch stability ended up being quite long, so this time I will keep things short and simple.

Dihedral can be defined as the upward angle given to all or part of a wing. Dihedral is often used to provide roll stability, which is simply the tendency for an airplane to level its wings after some disturbance has banked them. Most beginners are taught that dihedral works because once the plane has been banked by a disturbance, the lower wing is more level than the other one and therefore will produce more vertical lift, thereby righting the plane. However this explanation is not correct since for each wing half the magnitude of the lift vector and the length of the moment arm both remain constant as the airplane is banked. This means there will be no change in any roll moment.



A second explanation sometimes used is the badminton birdie analogy. This is not a good explanation, and a small “thought experiment” might help you see why. First notice that an airplane moves FORWARD through the air, with its leading edges presented toward the oncoming air. Now imagine taking a piece of paper and folding it down the middle so that it assumes a V shape, and dropping it in the same way an airplane flies - with the edge of the paper slicing through the air. Now compare this to dropping the paper crease-first. You should be able to see that the badminton birdie analogy applies only to this second paper drop, explaining why the paper (and the badminton birdie) falls in a stable manner. It does not apply to the first paper drop or to an airplane in forward flight at low angles of attack. There are some similarities at very high angles of attack where drag creates more of the roll forces, but this second explanation is still very inadequate.

Then why does dihedral provide roll stability? The answer lies in yaw-roll coupling.

### Yaw-Roll Coupling

Different airplane designs have varying degrees of yaw-roll coupling. Normally when rudder is used to induce a yaw movement to the left or right, there is an accompanying roll in the same direction. This is called “positive yaw-roll coupling”. Airplanes designed for precision aerobatics will exhibit little or no yaw-roll coupling, while those designed without ailerons (eg. 3 channel R/C trainers) will by necessity show a great deal of yaw-roll coupling so that rudder can be used for banking.

Dihedral is a very effective way of producing yaw-roll coupling. When an airplane with dihedral is yawed, the

effective angle of attack of the forward wing half is increased, with a corresponding increase in lift. The other wing half’s lift is decreased, and it is this difference that produces the roll or banking of wings. (To visualize this better, go back to our V-shaped piece of paper.)

It is now easy to explain the real reason that dihedral provides roll stability. When an airplane is banked by some disturbance, it immediately starts a sideways & down movement called a slip since the lift vector changes direction resulting in less vertical lift and more horizontal lift. This slip causes a change in the direction of the oncoming air that looks like yaw. For example, if the wings bank left, then a slip will begin that is down and to the left. From an onboard point of view, the airstream will seem to be coming from slightly to the left of the original direction. This is now similar to a rudder-induced yaw to the right, so yaw-roll coupling causes a correcting roll also to the right. At high angles of attack we have an additional yawing effect: The roll itself causes more of the airstream to come from the side of the airplane.

### Swept Wings

It is interesting to look at swept wing aircraft in the context of dihedral. For sweptback wings there is a positive yaw-roll coupling as was described above for dihedral. When the airplane yaws, the forward wing seems to increase in wingspan and the rear-going wing seems to decrease in wingspan (from the head-on point of view of the airflow). This creates a difference in lift between the two wing halves. Once we have yaw-roll coupling, roll stability can be explained in the same way as for dihedral. In fact a common rule of thumb in airplane design is that 10 degrees of sweep has about the same stabilizing effect in roll as one degree of dihedral.

There is one major difference when roll stability is caused by sweep rather than dihedral: The stabilizing effect is linked with the amount of lift being produced by the wing. When no lift is being produced, there will generally be no yaw-roll coupling and therefore no stabilizing effect. This explains why sweep provides roll stability in both upright and inverted flight. This is not true for dihedral, which is very destabilizing during inverted flight. Sweep turns out to be an excellent choice for giving roll stability to airplanes designed for aerobatics.

### Summary

That’s it for another installment of “From the Aeronautics File”. The main ideas we talked about were:

- The usual explanation of why dihedral provides roll stability is not correct.
- Yaw-roll coupling is at the heart of the real reason dihedral works.
- Dihedral roll stability is triggered by the slip that results after a bank.
- Swept wings provide roll stability in very much the same way as dihedral does.

Next time I plan to provide the straight dope on a very controversial topic: The Downwind Turn. Prepare to have your beliefs shaken as I tackle this myth-riddled topic.