Rudder: What is it REALLY for?

by
Budd Davisson, appeared in Flight Training Magazine

One of the more maddening aspects of instructing pilots who already have their license is to be continually exposed to a rather curious dance in which their feet realize they are supposed to be doing something but they neither hear the music, nor feel the rhythm. In other words, their feet are confused and don't know exactly what they are supposed be doing or when. So, maybe it's time to examine the rudder's purpose in the greater scheme of things and see what it can do to make our lives better.

The rudder is a widely misunderstood control because, when used properly it does so many different things in so many different situations. The ailerons and elevators are probably jealous of the rudder because they are fairly uni-dimensional in their application—they only do one thing. But the rudder? That guy is flapping around back there and involved in so many different aspects of flight that it's the renaissance man of control surfaces. This is curious, considering that all it does is move the nose left and right.

No one has any doubt what stepping on the rudder does. Step on the left pedal and the nose moves left and vice versa. So, what's the big deal? The big deal is that the rudder is asked not only to be part of the normal control mix in making turns, but it is the control that has to cancel out, or control, lots of other interacting forces that occur in differing amounts at different times in different flight regimes. It's more than just the guy who helps us make turns, although he often is being ignored in that, his primary duty, as well.

The rudder isn't really a primary control. It's a "fixer" control.
The rudder is there to "fix" things that would go wrong because of the way various forces affect the airplane. In the air, it doesn't make the airplane do anything (a gross generality, I know, but bear with me). It doesn't make the airplane turn: it's the aileron's job to set up the bank that causes the turn, but the rudder does make it turn correctly. It doesn't make the airplane climb, that's what the throttle and elevator are for, but the rudder does make the airplane climb more efficiently. It doesn't cancel out a crosswind, another aileron job, but it does make the results more pleasant. And on and on. So what exactly does the rudder do?

The rudder's primary purpose in life is to "purify" flight situations by eliminating unwanted yaw, thereby keeping the airplane aerodynamically clean (intentional slips not withstanding). There is a whole list of forces the rudder has to fight against and no place is this more clearly demonstrated than in the simple turn, where, as with most regimes of flight, there is an aerodynamic villain just itching to cause efficiency problems. In this case, it's adverse yaw.

The Common Turn: Rudder Versus Adverse Yaw

Nothing in life is free and this is especially true of aerodynamic lift. Increase lift and you increase drag. That's nothing more than an ugly fact of life that we have to deal with. So, when we bank the airplane by putting the outside aileron down, and the inside one up, we've asked for more lift on the outside wing and less on the inside wing. This is another way of saying we've increased drag on the outside wing and decreased it on the inside one. So, what happens when there is more drag on the outside wing than on the inside one? Simple, that extra drag pulls the outside wing back, so the nose yaws to the outside of the turn. Enter the rudder to save the day. A little inside rudder is applied along with the ailerons, which kills the yaw and keeps the nose turning.

A rule not to be violated: as long as an aileron is deflected, there is unbalanced lift/drag on the wings and rudder is needed to kill the unwanted yaw. However, as soon as the bank angle is established, the ailerons should be neutralized, which means the rudder is no longer needed. No aileron, no rudder. Period.

Takeoffs and Gyroscopic Precession

Gyroscopic precession is a curious phenomenon in which you try to move a spinning object, e.g. a gyroscope, and the spinning motion changes the direction the force is acting so the result is a move 90 degrees to the original line of force. The effect is greater for large, heavy objects such as propellers. So, if you forcibly move a spinning propeller, such as when the tail is lifted on a tailwheel airplane, even though the force was applied in a downward direction (tail goes up, nose goes down), the resultant motion includes an urge to move left.

On smaller, lighter airplanes, like a Champ or Cub, where the wooden prop may weigh less than 15 pounds, the effect is barely noticeable. On something like a two-place Pitts Special where the prop weights over 60 pounds, the movement is more obvious. That same prop, on a larger airplane, however, won't have as much effect because the airplane will be heavier than the little Pitts so the precession forces will be resisted by inertia.

The yaw caused by precession is easily handled with just a little right rudder pressure, although on really healthy airplanes, like a P-51 Mustang, part of the required pressure is applied by preset right rudder trim but you'll still need to put a fair amount of right leg in it (been there, done that).

Climbs and that Dastardly Torque (supporting role by spiraling slip stream)

Torque is often blamed for the sudden turn to the left, when the tail is picked up on a tailwheel airplane, but precession is actually the villain there. Torque is a radial action that tries to twist the airframe opposite to the direction the prop is turning. If the airplane is on the ground, with the gear firmly planted, it can't twist the airplane because the landing gear is stopping it. On really high-powered airplanes, e.g. the Mustang, some torque effect is felt on the ground because it is trying to compress the left gear leg.

Where torque effect is most strongly felt is right at the moment of lift off. Here the gear is leaving the ground and the airplane is slow and in its most vulnerable moment of flight. On most GA airplanes, the effect is slight because the prop is light, the power low and the airplane fairly heavy. However, as the power to weight ratio improves (bigger motor, lighter airplane), the airplane will try to drift left (assuming clock wise prop rotation as see from the cockpit) as it comes off the ground and some right rudder will be needed to keep the nose straight and kill the drift.

On higher performance airplanes, the Pitts being one, if left to its own devices, the airplane will almost instantly start drifting to the left at about a 15 degree angle.

On all airplanes, repeat all airplanes, during the climb, when the airplane is slow and the power high, the ball is going to want to slide to the right and rudder will be needed. Okay, granted, on common GA airplanes of the Cessna/Piper type, the ball will barely be nudging out of center and it's easy to argue that rudder isn't needed. But, that's absolutely not the case. If the ball is even slightly off center, the airplane is trying to climb with the nose yawed to one side, which means it's dirty and less efficient than it should be. A lot of horsepower is being wasted trying to drag the airplane through the sky sideways and that just doesn't make good sense, when just a touch of rudder will clean it up.

Climbing Turns—the plot thickens.

When climbing the airplane there's more at stake than simple rate of climb. Sooner or later, you're going to have to turn the airplane, when still in the climb, and this is where an understanding of torque and the rudder is necessary.

In a climb the torque (assisted by spiraling slip stream) is constantly trying to yaw the airplane left and what you do with the rudder in a turn in that situation changes depending on whether you're turning left or right. In a left turn, you don't need left rudder; you just need less right rudder. In a right turn, you need more right rudder. In fact, in a climbing, full-power left turn in most airplanes you'll probably be carrying a little right rudder through the turn to keep the ball in the middle and the airplane properly in trim.

The good news in this situation is that your butt will be moving back and forth in the seat and, if you listen to it, it'll tell you when need to be paying more attention to the ball.

Approaches, P-factor and an Erratic Skid Ball

If you'd like to see a clear demonstration of the interplay between power, torque and P-factor (asymmetric thrust/drag caused by the prop) try this little exercise the next time you're flying: set up a best rate climb at full power and leave your feet off the rudder.

See where the ball settles: it'll be off center to the right. Then, holding the same speed, which is probably the same as, or close to, POH glide speed, bring the power back, lower the nose to a glide attitude and see what the ball does. It'll be off to the right in a climb and will gracefully slide to the left in the glide as torque is exchanged for P-factor.

When you kill the power on downwind for a power-off approach (you do practice power-off approaches right?), you'll see the ball slide to the left. It'll be more obvious in some airplanes than others. That means the nose is to the right, the airplane is dirty, and you're losing altitude faster than is necessary. If you turn left onto base in that condition, while you're in the turn the airplane is not only dirty, but now the nose is to the right and slowing down the turn so it takes more time to get through the turn and you spend much more time with a wing down in a dirty condition than you would if coordinated. Because of that combination, you loose much more altitude than necessary. Plus, you're skidding away from the runway in the turn, which is the same thing as loosing altitude. All in all, not a very efficient way to fly an airplane.

A little touch of left rudder in the approach will keep the ball in the middle and greatly increase your airplane's ability to glide. Most airplanes need only a hint of rudder, but if you watch closely, you'll see that it is needed.

The Forward Slip and Unwanted Altitude

Although we should be constantly trying to keep the ball in the center and the airplane coordinated there are times when that's absolutely not the case and the rudder is the primary player in this one. If the airplane is put into a bank and held there by displaced aileron and enough rudder is applied in the opposite direction to cancel out the turning tendency and keep the airplane flying in a straight line, that's your classic forward slip. The wing is down, the nose is pointed in the opposite direction and the airplane flies straight ahead.

The airplane may be flying straight ahead, but it is in an unbelievably high-drag configuration. It's flying sideways and unless a lot of power is fed into the equation, the airplane is going down. Fast! And that's the actual reason for the forward slip in the first place, losing altitude in an accelerated manner.

By using opposing rudder and aileron on final, with the power off, the resulting super high drag configuration causes the airplane to come down faster than it would normally. Because slipping controls can be applied to any degree, the drag can be used to increase the rate of descent just a little or a whole lot, as it is needed. It can be varied constantly allowing you to fine tune the glide slope to put you exactly where you want to be on the runway.

The Side Slip and the Villainous Crosswind

If the above combination, where rudder exactly balances the bank angle, isn't balanced, e.g. there isn't enough rudder to balance the bank angle, then the airplane will move in the direction of the down wing, unless, of course, there's a crosswind from that side, which holds it in place. In this case, just enough rudder is applied to keep the nose straight down the centerline and enough bank angle is held that it balances the crosswind with the result that the airplane flies straight ahead, but with the wing down and the nose on the line of travel.

So, What is the Rudder Really For?

Getting back to the original question: the rudder is the magic tool that reaches in and cleans up what would otherwise be some pretty ugly regimes of flight. Can you fly without understanding it? Of course, but you won't be flying correctly and your airplane will be both inefficient and less likely to go exactly where you want it to go. So, it's your choice. Fly right or fly wrong. Not much of a choice is it?