EZ RUDDERS

Some of Aviation's More Interesting Moments

Conventional airplanes have a single rudder, usually attached to the trailing edge of a fixed vertical stabilizer. Together, they comprise the vertical tail. The stabilizer provides directional (yaw) stability by weathervaning the plane into the relative wind. Properly designed, it should perform this function without pilot participation. It always works to eliminate sideslip, which is a relative wind not "on the nose" but from some angle to the left or right of the airplane's longitudinal (nose to tail) axis. The vertical stabilizer is, after all, a wing, and the sideslip angle is analogous to the angle of attack on the main wing. Increasing the sideslip (say, from the right, as in a left yaw) increases the lift of the vertical tail (to the left), swinging the nose back (to the right) into the relative wind. If the sideslip angle is too great, the vertical tail can stall, and the airplane would lose the major contribution to directional stability provided by the vertical stabilizer.

The rudder provides directional control. It is used to yaw the airplane either to assist the stabilizer with minimizing the sideslip, as in turn coordination, or to intentionally cause sideslip, as in a slipping approach to land. While the rudder's primary function is yaw control, deflecting it causes several other things to happen to the airplane.

A quick look at the effects of rudder deflection in a conventional airplane should lay the groundwork for a similar look at the EZ rudder configuration. (The term "EZ" is meant to convey the generic design with these features: canard, swept wing with tip-mounted vertical tails, rear-mounted engine with pusher prop. It is not a statement of design credit or particular manufacturer.)

FORCES AND MOMENTS

Airplanes are said to have six degrees of freedom. Three translational: up/down, left/right, and fore/aft. Three rotational: pitch, roll, and yaw.

Step on the left pedal and the rudder deflects trailing-edge-left. This creates a force, or lift, to the right. Since the lift can be treated as a single force acting through an airfoil's center of pressure (CP), and since the airplane rotates around its center of gravity (CG), a yawing moment is created. The magnitude of this moment is the force of the rudder lift times the moment arm or horizontal (longitudinal, actually) distance between the rudder's CP and the airplane's CG as depicted in Figure 1. More pedal — more moment — more yaw (sideslip, actually). The sideslip does not continue to increase because an equilibrium, or balance of yawing moments, is reached. The airplane's overall directional stability provides a restoring yawing moment equal and opposite to the one caused by the rudder deflection. So, a constant rudder displacement should result in a constant sideslip, although the airplane may continue to yaw (as in a flat turn).

Suppose the rudder's CP is above the airplane's CG as it is on most conventional planes. The same rules apply, so a **rolling** moment to the right is created. The strength of this moment is determined by the lift force of the rudder and the vertical distance (moment arm) between the rudder's CP and the airplane's CG (Figure 2). Since this moment arm is generally much shorter than the longitudinal one, the roll due to rudder deflection is usually a much lesser effect. The airplane's dihedral effect and other less significant effects, which act in the opposite direction, also help to mask the roll due to rudder deflection.

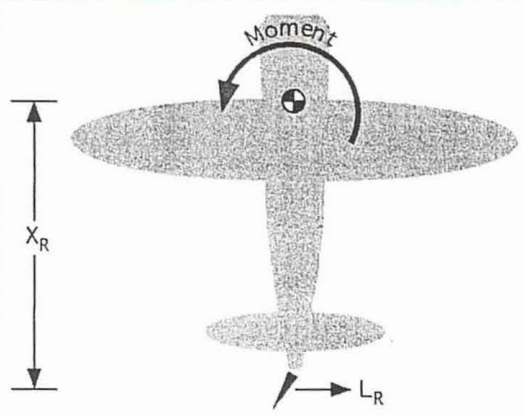

Figure 1
Yaw Moment = $L_R \times X_R$

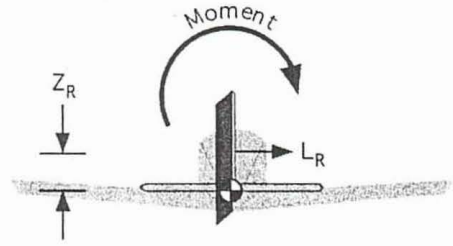

Figure 2
Roll Moment = $L_R \times Z_R$

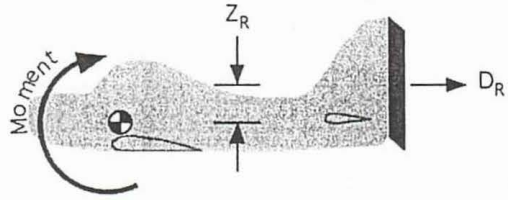

Figure 3
Pitch Moment = $D_R \times Z_R$

Rudder deflection causes an increase in drag of the vertical tail. This additional drag force acts parallel to the relative wind. Since this force acts above the airplane's CG, a nose-up pitching moment is created as shown in Figure 3. Again, due to the short moment arm involved and the typically small drag increment, pitching moments due to rudder deflection are usually not noticed. *That is not to say such moments are always insignificant. The F/A-18 uses rudder toe-in for just this reason. Its twin rudders are deflected inboard with weight on the wheels to provide the additional nose-up moment crucial to aircraft carrier operations.*

That takes care of the three rotational effects, but the translational results remain. The lift force to the right caused by left rudder deflection acts on the entire airplane, moving it to the right. This one is very difficult to observe because it is masked so well by the yaw effects.

To paraphrase a teacher who knows a lot about the subject, drag is drag. As such, the drag added by rudder deflection acts to slow the entire airplane. It better slow the **entire** airplane.

Finally, there's the up/down degree of freedom. The vertical orientation of the rudder precludes any direct contribution in this axis. If the rudder is canted, however (for example, on a twin vertical tail airplane), rudder deflection directly applies a lifting force in the up/down direction as well as the left/right direction. A deflected canted rudder provides a pitching moment due to its vertical lift component in addition to the pitching moment addressed earlier caused by the drag increment.

To summarize the non-canted, single vertical tail situation, every rudder deflection causes a sideways lift force and an aft drag force which cause translations. Because the rudder's CP is behind the airplane's CG, rudder deflection generates a yawing moment. If the CP is above the airplane's CG, a rolling moment is also generated. A pitching moment occurs if the drag force acts above the airplane's CG.

THE EZ STUFF

Now, take the vertical tail and put it somewhere besides the aft end of the fuse-

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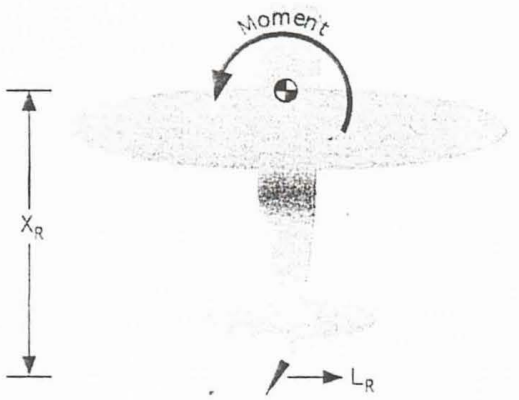

Figure 1
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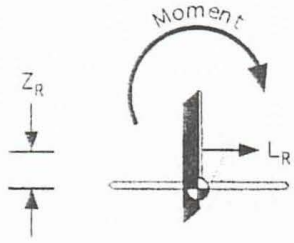
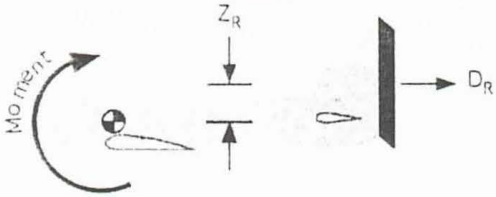


Figure 2
Roll Moment = $L_R \times Z_R$



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Now, take the vertical tail and put it somewhere besides the aft end of the fuse-

lage. Why? Because in the case of EZ designs, there's a propeller in the way. EZ's have swept wings. For the speeds most EZ designs fly, sweeping the wings back is not in the best interest of wing performance. It is, however, a way to get the vertical tail far enough back to provide the necessary directional stability. Of course, symmetry is a factor, so these designs incorporate two vertical tails.

In conventional airplanes, stepping on one pedal causes the other to move aft. This makes sense since both pedals control a single rudder surface which can be deflected both directions. EZ designs incorporate two separate yaw control systems. The left pedal deflects only the left rudder outboard, and the right pedal deflects only the right rudder outboard. Rudders do not deflect inboard for good reasons.

Rules are rules, so everything about forces and moments, translations and rotations which were cited for the conventional airplane also apply to the EZ's. Suppose the left pedal of an EZ design is displaced. The left rudder deflects outboard or to the left. The drag and (sideways) lift forces still act above and behind the airplane's CG, so the airplane experiences the same translational and rotational effects as the conventional airplane. In this design, however, the vertical tails are also displaced laterally, introducing additional effects.

The drag increment of the deflected rudder causes the airplane to yaw to the left, because it has a moment arm which is half the wingspan. There was no yaw caused by rudder **drag** in the conventional airplane, because it was located on the plane's centerline, i.e. no moment arm. The rudder-drag-induced yaw of the EZ design is favorable for coordinating turns. That is, left pedal causes a left yaw due to the left rudder's drag acting to the rear at a lateral distance from the plane's CG in addition to the rudder's lift acting to the right at a longitudinal distance from the plane's CG (see Figure 4).

If the right rudder were also to deflect left when stepping on the left pedal, its drag would attempt to yaw the plane right. Its lift is still providing a left yawing moment, but the drag moment would work to oppose it (Figure 5). There would also be a rudder/wing-trailing-edge physical interference issue to contend with if the rudders deflected inboard. *Rutan's Voyager had two vertical tails, one at the left end of each nacelle, but only the left one had a rudder. This was a weight saving measure which sacrificed some handing qualities. The rudder deflected both ways, but the airplane was better suited to left turns.*

Toe brakes are not required in the EZ design. This design allows wheel brakes to be actuated by continued pedal displacement after full rudder deflection has been achieved. This is one way to ensure maximum "rudder drag" during landing rollout prior to brake use. Perhaps landing with a high crosswind could inhibit use of both brakes because of rudder requirements. *The space shuttle's split rudder deflects both ways to help slow it down after landing.*

Another toe brake issue is discriminating between that last little bit of rudder deflection and the first little bit of wheel brake. In a toe brake set-up, which control the pilot is using is fairly obvious. Good design in an EZ configuration should provide tactile cues regarding this transition. That is, end-of-rudder/start-of-brake should be readily evident through pedal feel.

Some pilots like to fly with a significant force on both rudder pedals all the time. Because one can't be moved without moving the other in conventional designs, it is sometimes easier to modulate tiny displacements this way. This obviously won't work with EZ designs. In fact, several guest pilots admit readily to flying with the rudders deflected for most of the flight. Taken to an extreme, the opportunity to land with the brakes on exists. *The Australian-designed Eagle X-TS had a single, bidirectional rudder, and stepping on one pedal caused the other to move aft. The wheel brakes, however, were actuated by applying force to both pedals simultaneously, regardless of pedal displacement. This arrangement required a careful, conscious effort to step on only one pedal at a time to avoid unintentional braking.*

Figure 4

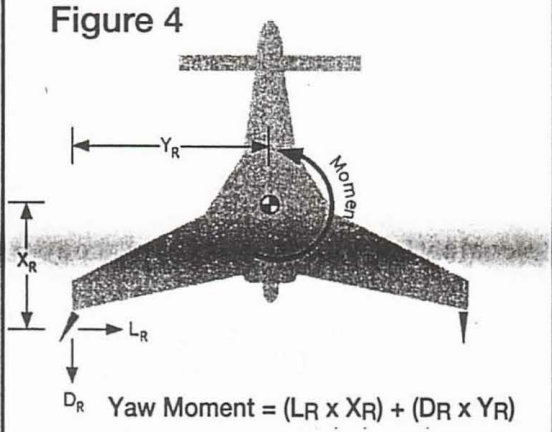
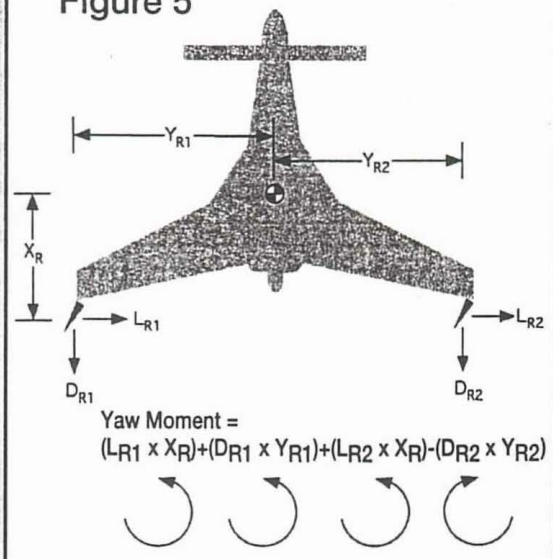


Figure 5



Removing the rudder from the propwash can also remove some early takeoff roll controllability. The rudder of a conventional airplane typically affords some degree of directional control almost as soon as the throttle is pushed forward. EZ-design rudders are not bathed in the propwash, so their effectiveness is delayed until the airplane has gained sufficient speed.

On the more advantageous side of tip-mounted vertical tails is potential vortex control. Properly installed, they can serve as winglets. Winglets use wing tip vortices to the airplane's advantage by garnering a lift component in the forward direction, adding an increment of thrust. For this thrust effect to outweigh the drag penalty, strong wingtip vortex activity is generally necessary, for example — higher angles of attack or high altitude operations. Considering the number of new business and airline jet designs incorporating winglets, this is no small factor in fuel consideration (for jets, anyway).

Perhaps a bit of a stretch, but two independent systems offer a degree of redundancy although each rudder deflects only in one direction. A jammed or otherwise incapacitated rudder on one side should not affect control of the other rudder. While not truly redundant, this arrangement may be exploited during an emergency crosswind landing.

Independent rudders offer a speed brake or air brake possibility. Deflecting both rudders equally negate each other's yawing moment but still provide the drag increase. Of course, pitching moments and vertical translations (for canted vertical tails) are still there. *Simultaneously deflecting both rudders in the Velocity produces virtually no pitching moment. Doing the same thing in the Berkut, however, causes a mild nose-down pitch. Yes, nose-down. Although the rudders' CP is slightly above the airplane's CG, there's a more dominant effect. Outward-deflected rudders increase the effective camber of the inboard vertical tail, causing lower pressure on that side. Since that lower-pressure flow affects the flow over the outboard section of the main wing, the lift of the main wing is affected. In this case a lift increase occurs at the outboard section of the main wing which is behind the plane's CG, and that causes the nose-down moment.*