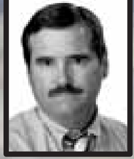



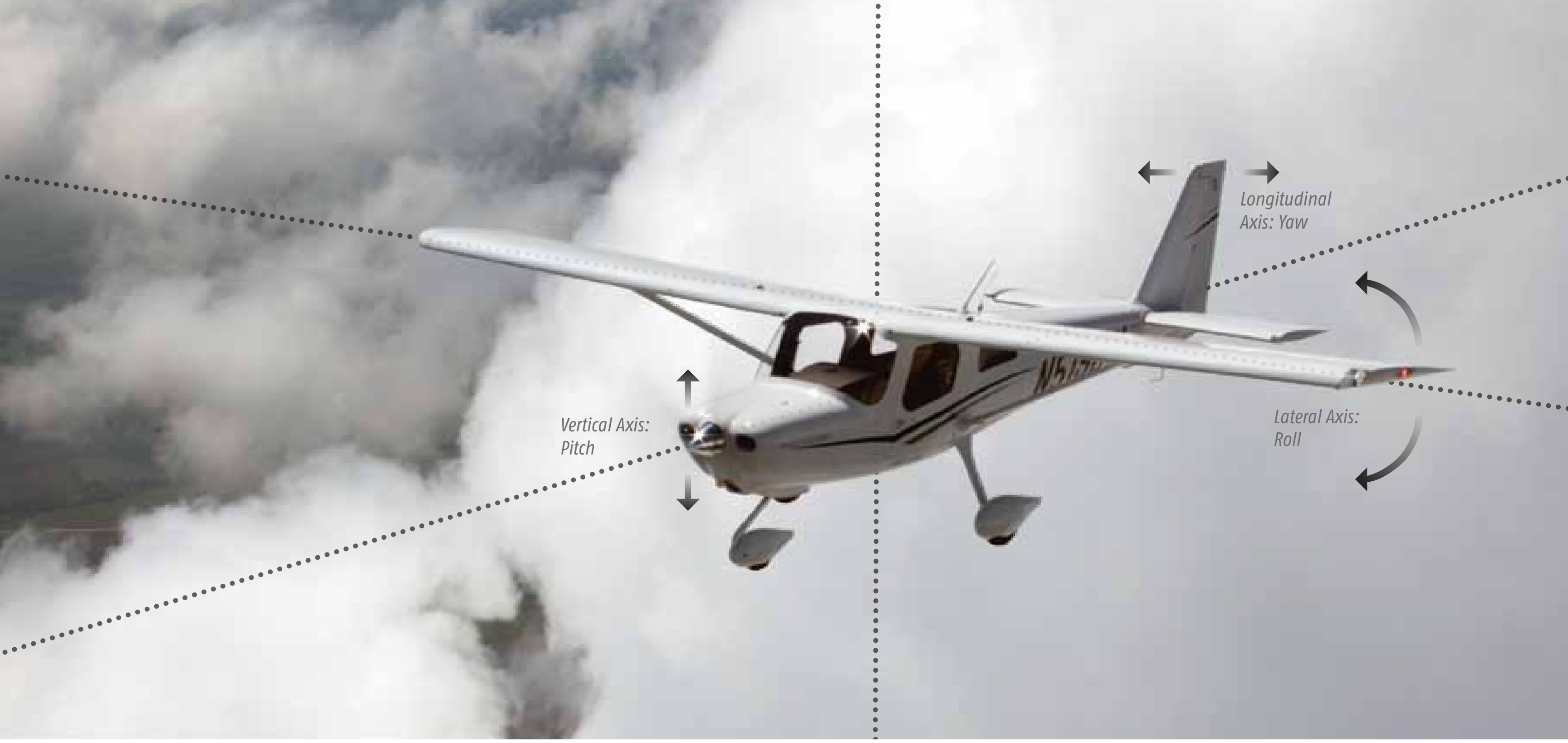


# Good Flying Qualities Add Safety

Balancing stability, stick force, and control harmony

**I WAS STANDING BESIDE** Burt Rutan watching the exotic Voyager fly over Oshkosh in the summer of 1986. Dick Rutan and Jeana Yeager would fly the twin-boom push-pull piston twin around the world nonstop and without refueling the following December.

I said to Burt that the configuration of the Voyager didn't look like it would be very stable. Burt said the airplane was actually unstable. I was astonished. I said, "You mean it's not very stable, or close to neutral?" And he said again, "It's unstable."

What basic stability in an airplane means is that the airplane will attempt to return to its trimmed flight condition when it is disturbed. In other words, a stable airplane will fly straight and level until the pilot makes a control input or turbulence changes the airplane attitude.

A well-designed automobile with the proper caster and proper camber and toe-in of its suspension does the same thing. On smooth, level pavement a properly functioning car will maintain a pretty straight path.

Try to imagine a car—or an airplane—that instead of wanting to continue straight ahead is constantly darting one way or the other with no warning and no control feedback to the pilot or driver. That's how the Voyager flew.

Burt went on to tell me that the lack of stability was so great that his brother, Dick—a former military jet pilot of great experience—could only hand fly the Voyager in good weather conditions, and then only for short periods before fatigue from the necessary concentration became too great. Hand flying the Voyager on instruments or in turbulence would be a true emergency situation.

The Voyager team solution to the impossible flying qualities of the airplane was essentially full-time use of the autopilot, a modified Bendix/King system. The autopilot was a rudimentary fly-by-wire system that is used in all recently designed larger jets and



PHOTOGRAPHY BY **BRADY LANE**

has been used in fighters for decades. The computers in the autopilot or fly-by-wire system don't care that the airplane is unstable because their electronic brains concentrate totally on the task of maintaining attitude. The human brain can't maintain that level of focus indefinitely, but computers can. The Voyager team labeled a number of functions "mission critical," meaning if they failed, so would the mission. Near the top of the list of mission critical items was the autopilot.

The Voyager is an extreme example of bad flying qualities, but it makes the point that all airplanes are easier to fly, and thus safer, when the flying qualities are right. This concept didn't get much attention until after World War II. Before then, airplanes just flew like they did—some better than others, but there was no real effort to identify and design in good flying qualities. But in the late 1940s a group working under the military—the National Advisory Committee for Aeronautics (NACA), the predecessor of NASA, and later Calspan, an aerospace and transportation research and development company—created a standard for good flying qualities and how those qualities reduce pilot workload and enhance the success of an airplane's mission.

### THE COOPER-HARPER SCALE

What these test pilots and engineers determined is that the best airplane would essentially fly itself. Test pilots use the Cooper-Harper scale to rate the flying qualities of an airplane, and the scale is upside down from most rating systems. Under Cooper-Harper, the best flying airplane rates a 1, not a 10. The logic is that a good airplane requires the least pilot input and compensation for shortcomings in flying qualities. Using engineer logic, one represents the least pilot compensation to achieve the desired performance, so that's why the Cooper-Harper scale is upside down compared to the perfect 10 assigned to certain movie stars.

Stability is obviously an essential flying quality. How do you know if an airplane is stable? Trim off the control forces and pull the nose up, or push it down, and release the stick. If the airplane returns to its trimmed airspeed, it has basic stability. All certified airplanes must have solid, positive stability, and any airplane except those for extreme missions such as the Voyager should be very stable, too.

In addition to stability, a good flying airplane should have appropriate stick forces and control harmony. Designing in stability is a pretty straightforward exercise of locating the center of gravity (CG) and center of lift. But getting the control forces right is much more complicated, and many airplanes, particularly small ones, don't succeed.

Control force is a measure of how much pilot effort it takes to maneuver the airplane. In pitch, the measure is the number of pounds of force on the stick required to add a *g* of loading to the airplane. In the ideal airplane the stick force is linear, meaning the same increment of force on the stick is needed to add the equivalent increment of loading, or rolling or yawing rate.

The other major component of flying qualities is the harmony—or lack of it—across the three control axes. Roll forces should be the lightest, followed by pitch force, with rudder forces being the greatest of the three. A rule of thumb for control harmony is a ratio of 2-4-6, where 2 is the roll force, 4 the pitch force, and 6 rudder force. This harmony of control forces makes the airplane easiest to control and requires the least pilot effort and concentration, and thus makes the airplane potentially safer.

But few airplanes achieve ideal control harmony because, well, it's hard to do. Most airplanes, particularly small ones, end up with pitch being the lightest of the forces by far. Some pilots think light pitch forces make an airplane nimble and maneuverable, but light pitch force can really add to the pilot's workload.

Getting the pitch force right in small airplanes is difficult because the elevator must have a lot of authority at low airspeeds to flare the nose up on landing, or to hold the tail down if it is a taildragger. When flying at higher airspeeds, that elevator authority can be too great and pitch the airplane up or down with very little force on the stick.

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On the other hand, it's difficult to lighten the force on the ailerons to make them lighter than for pitch. The aileron is small compared to the area of the wing, so it's being asked to do a lot of work. Short span, wide chord ailerons can be effective, but generally they require more force than a long span, narrow chord aileron. But flaps and other wing design features often don't leave enough space for a long span aileron.

### MECHANICAL TRANSLATION

Then there is the basic mechanical issue of translating control column or control stick motion into movement of the control surfaces. For the elevator it's a really straight shot to run control cables through the fuselage, and the movement of the control is in the same direction as elevator movement. It's the same for the rudder. But routing control cables and pushrods to ailerons is far more complicated with many points of added friction and difficulty in creating the same mechanical advantage that is available for the elevator and rudder.

Pitch control forces are also impacted by location of the CG, while roll force remains essentially constant. An airplane with good control harmony while loaded to a forward CG can become way too light in pitch with the CG at the aft limits.

The FAA's certification rules do not require pleasing control harmony. There are maximum stick forces specified that an airplane cannot exceed, and there are phrases in the rules like "normal pilot strength" or "no unusual pilot skills," but ideal harmony among the control forces is not a rule. However, the rules do require that stick force be positive, meaning it always takes more force on the controls to increase the pitch, roll, or yaw rate.

Most certified airplanes—except for the smaller and lighter ones—end up with some type of artificial force added in pitch in order to meet the rules for positive stick force across the CG and operating airspeed range. The most common artificial force system is a spring that pulls the control wheel forward, adding force when the pilot tries to pitch the nose up. The down spring would almost certainly not be required when flying with a forward CG but is necessary to keep stick force positive with the CG all the way aft.

Another technique for adding pitch force is the bob weight. A weight mounted on a lever arm is attached to the down circuit of the elevator controls. The weight applies a steady nose-down force, but its real function is to add stick force per *g*. When the airplane pitches up or down, *g*-force amplifies the force of the weight through the lever, increasing the nose-down or -up force the pilot feels through the controls.

Over the decades airplane designers have learned many techniques to tailor control force and harmony. The pressure of the certification rules has been a factor, but more important is the competition of the market. A nice flying airplane is simply more desirable and has a better chance to succeed.

I find it interesting that the one light airplane I have flown that comes closest to the perfect 2-4-6 control force harmony is the Cessna 162 Skycatcher. The light-sport aircraft rules are the least stringent when it comes to flying qualities, but Cessna engineers set their own standards and met them. With a clean sheet design, and the experience of building thousands of two-seat trainers, the Cessna people knew how to design the control system and the control surfaces and where to locate the control hinges to achieve near perfection. Good flying qualities are essential for safety, but also for learning. I think the 162 may be the most effective trainer Cessna has ever built.

### THE MOUNT MITCHELL RIDE

To get to the southeast coast and on to Florida and the Bahamas from our still new home base in Muskegon, Michigan, I have to fly over the southern part of the Appalachian Mountains. Actually, it is the Black Mountain chain of the Appalachians, the highest mountains east of the Mississippi River, that are the issue.

*Mount Mitchell is the highest peak in North Carolina.*

Mount Mitchell is the star of western North Carolina's mountains topping out at 6,684 feet. Mount Mitchell is just northeast of Asheville and is so special that it is the center of an enormous state park, the first state park in all of North Carolina. The peaks of the Black Mountain ridgeline are pretty uniform, so it's sometimes hard to pick Mount Mitchell out from other summits, several of which are only a few hundred feet lower than Mitchell.

Lots of people—probably most—love mountains. But I hate mountains. Maybe if I didn't fly, I would come to love those big rocky lumps, but I do fly, and mountains only mean one thing to me—turbulence and bad weather. And Mount Mitchell delivers both.

To avoid flying over the mountains and on my way southeast I file over the Spartanburg (SPA) VOR, which takes me a little east of the direct course to Savannah or on to the east coast of Florida. The route usually keeps me out of the clouds that stick to the Black Mountains most days, but the turbulence is another matter. If the wind aloft is from the west, there are going to be bumps, usually pretty big bumps, as I pass the mountains.

Not long ago Stancie and I were cruising along in nice smooth clear air headed southeast with the wind blowing off the right wingtip and not doing much of anything to our groundspeed. We had a good view of the mountains as the cloud bases were above the peaks, which is not often true. It seemed like we were past the turbulence danger zone when I said something stupid like, "Guess there are no bumps today." Seconds later the airplane started climbing, the autopilot pushed the nose over to maintain altitude, and I yanked the throttles back to keep airspeed under control. Then we hit the wake of the mountain. The airplane shook violently for about 15 to 20 seconds with stuff, and us, bouncing around the cabin. Suddenly, the turbulence ended and we sailed on in clear skies and a smooth ride.

Mount Mitchell is named for a professor from the University of North Carolina who first determined its elevation. Professor Mitchell died on the mountain when he fell off a cliff into a waterfall, was knocked unconscious, and drowned. I plan to keep an eye on that mountain and be ready for what it can dish out. Maybe someday I'll even get to fly past it in smooth air. EAA

**J. Mac McClellan**, EAA 747337, has been a pilot for more than 40 years, holds an ATP certificate, and owns a Beechcraft Baron.



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