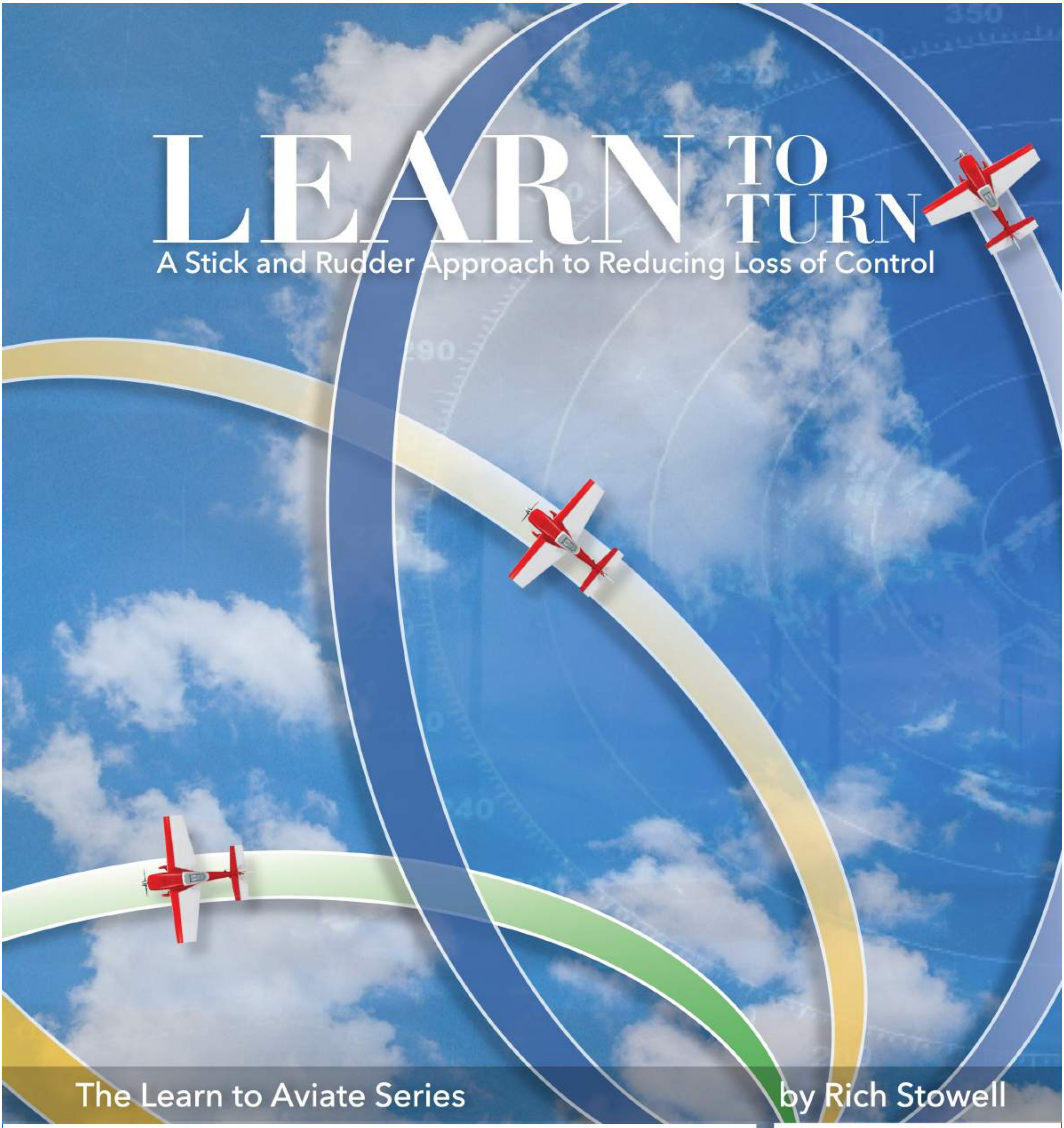

LEARN TO TURN

A Stick and Rudder Approach to Reducing Loss of Control

The Learn to Aviate Series

by Rich Stowell

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Learn to Turn

A Stick and Rudder Approach to Reducing Loss of Control

The Learn to Aviate Series by Rich Stowell

Rich Stowell Consulting
Meridian, Idaho

www.RichStowell.com | Rich@RichStowell.com

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Lead those who want to climb the mountain with you;
leave behind those who don't.

—the way of the Sherpa

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Front Matter

Disclaimer

The *Learn to Turn* booklet and its companion content (collectively, the assets) are intended to be teaching aids to expand a pilot's understanding of turn dynamics in three dimensions. The information and techniques presented in the assets are as accurate, complete, and authoritative as possible. However, there may be errors and omissions, both typographical and in content.

The assets should be used as a general guide only and not as the ultimate source of aeronautical principles or procedures. The assets are designed to complement and supplement other aviation texts, as well as formal flight instruction. For additional reference materials and recommended reading, refer to the Bibliography.

Stalls, spins, and other unusual attitudes, whether intentional or unintentional, can be life threatening. The assets are not a substitute for actual flight training or for proficiency in the techniques and maneuvers described. The author and publisher strongly recommend you receive hands-on flight training only from qualified flight instructors experienced in *Learn to Turn* exercises and techniques, using only well-maintained airplanes that are properly loaded and approved for the maneuvers to be flown, with the appropriate safety equipment—including parachutes when required—before attempting any of the maneuvers and scenarios described in the assets.

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As stated in the Federal Aviation Regulations, Part 91, Section 91.3, Paragraph (a):

> **The pilot in command of an aircraft is directly responsible for, and is the final authority as to, the operation of that aircraft.**

Foreword

Having just reinstated my CFI after ten years of inactivity, I found myself semi-retired and ready to embark on my later-in-life vocation: professional airport bum.

I stopped by to see my old friend, Clay Phelps, owner of our local flight school. I found him with his wife, Judy. She asked, "What are you going to do with your CFI?" I half-heartedly replied, "I'm thinking of getting a haircut and seeing if the local flight school has any openings." With a sheepish grin she said, "See you tomorrow." I did not know that would be the start of a life-altering process.

So, I did the paperwork, checked out in the school's planes, picked up a couple of intro flights, and started teaching. Simple stuff. A few weeks into this, Judy announced that I was going to be her next Emergency Maneuver Training (EMT) instructor, and that we would start in the morning. She handed me Rich Stowell's *EMT* book.

I love to read. I went home and dug right in. Great stuff and well written. Thought provoking and excellent material to explain basic stick and rudder flying. My previous teaching material had come purely from the FAA *Airplane Flying Handbook*; this was a refreshing change.

It was all fine up to page 49. I'd been reading for a couple of hours; it was now 11:30 pm. Here's what I read:

> Current flight training typically focuses on only two elements pertaining to turns: First, the rudder doesn't turn the airplane. Second, the horizontal component of Lift is the force that turns the airplane. Many training handbooks and flight instructors, however, fail to continue beyond this to identify the true turn control. Consequently, many pilots know which control surface doesn't turn the airplane, but aren't sure which of the remaining two really does. When pressed to name it, many respond that ailerons turn the airplane. In actuality, the **elevator** is our primary turn control.

I read it again. And again. I was stunned, astonished, amazed. I threw the book across the room! I grabbed my dogeared FAA handbook and read the usual stuff about the horizontal component of lift. I re-read Rich's passage, grabbed a model airplane, got clear on the concept, and went to bed.

Judy proved it to me the next day in the school's Citabria. After holding a pilot certificate for 30 years, this was without a doubt the most pivotal moment in my development as an aviator. I became a card-carrying member of Rich's church, preaching the gospel.

Mark King
Master CFI-Aerobatic
FAA Gold Seal CFII, MEI
Emergency Maneuver Training, Aerobatics, Tailwheel
CP Aviation, Santa Paula, CA

Preface

In October 2015, the National Transportation Safety Board invited me to Washington, DC to participate on the "Training Solutions" panel during the forum, *Humans and Hardware – Preventing General Aviation Inflight Loss of Control*. Relevant parts of my remarks follow.

The status quo in aviation education is unacceptable. Those of us who provide spin and upset recovery training see the results of our training system on a daily basis. Member Weener has referred to loss of control (LOC) as a "stubbornly recurrent safety challenge."[1] Recurrent indeed.

In 1944, Wolfgang Langewiesche observed that, "Almost all fatal flying accidents are caused by loss of control during a turn."[2] He concluded that, "pilots, as a group, simply don't know how to turn."[3] Little has changed in the 70-plus years since.

Fatal LOC accidents continue to occur most often during the maneuvering phase.[4] If broken out as its own category, LOC while maneuvering would rank third on the list. Except for the ability to mimic only the most basic of turns, pilots, as a group, remain unconsciously incompetent with regard to maneuvering flight.

According to aviation safety pioneer Jerome Lederer, "Every accident, no matter how minor, is a failure of the organization."[5] These pilots entrusted the aviation education system with their safety and well-being. They believed we would teach them how to maneuver an airplane. And we failed them.

Simply stated, we have a training delivery problem.

We can try to push all the doctrine and standards and curricula and technology and products we want into the training pipeline. But absent a concerted effort to significantly improve the delivery system, none of these enhancements will yield the safety dividends we envision.

Responding to the loss of control problem in commercial aviation, the International Civil Aviation Organization (ICAO) recently published its *Manual on Aeroplane Upset Prevention and Recovery Training*. The manual promotes an integrated approach to training designed to maximize the learning experience:

- Academics: laying a strong and factually correct foundation of aeronautical knowledge.
- Simulation, which can be as sophisticated as a Redbird FMX, or as simple as visualization techniques similar to those used by air show pilots before they fly their aerobatic routines.
- And on-airplane training: the live experience that cements the concepts and techniques introduced through academics and simulation into a positive and enduring learning experience.

This is the way flight training could and should be conducted at all levels. And it is the way it used to be. The Wright brothers established the first flight schools in the US. Guess what their training methodology was?

- Detailed ground school
- Simulation using a functioning mock-up of their flyer
- On-airplane training….

Somewhere between the Wrights and ICAO, we got lost. We've deviated from a proven flight plan. Perhaps we've forgotten where we were trying to go in the first place. The ICAO manual serves as a reminder, a course correction. A path back to what the Wright brothers understood: acting in the best interests of our students also serves our interests.

Recalibrating won't be easy. According to AOPA, educational quality and customer service make up 75 percent of a pilot's training experience.[6] Of all the obstacles on the path to the private pilot checkride, AOPA found the quality of instruction to be a persistent issue and a weak link in the chain.[7]

Students will put up with a lot to become private pilots. What most won't tolerate, however, is poor treatment and poor instruction. So, many eventually quit. Yet a minority does reach the next level. Increasingly unfulfilled and unconfident, some of them eventually drop out of aviation. Others are destined to become accident stats discussed during forums like this. But we are talking about real people. People who at one time were inspired by flight; who were excited about joining the aviation community….

The general aviation fleet is enormously diverse. Not everyone will use [a] supplemental angle of attack [system]. Not everyone will take advantage of new technologies and training products. But at some point, everyone will interact with a flight school or an instructor. And everyone needs to learn to turn.

There is more to flying than merely teaching to the test. Seeking perfection—unattainable though it may be—requires a commitment to higher standards and lifelong learning. Imagine what general aviation might look like if:

- Most flight schools focused less on the Hobbs meter and more on developing long-term participants;
- Most of those who became flight instructors did so because they were passionate about teaching, not because they were incentivized into it strictly to log hours for something else;
- Most students became private pilots instead of dropping out;
- Most pilots were motivated to invest in recurrent training;
- The successful outcome of a maneuver genuinely was never in doubt; and
- Loss of control ceased to be the dominant cause of fatal accidents.

Learn to Turn is part of *The Learn to Aviate Series*. The goal is to inspire pilots to strive for the correlation level of learning. Further, the series offers:

- Tips and techniques pilots deserve for flying to become everything they imagined it would be;
- Essential hacks to advance a pilot's knowledge and skills quickly; and,
- Tools to enhance a pilot's awareness and prevention of common accident scenarios.

Thanks to funding by Avemco Insurance Company and Hartzell Propeller Inc., *Learn to Turn* includes several educational assets that are available to everyone for free. Please share this with others!

—Rich Stowell

Acknowledgments

This booklet and its companion content represent the collective efforts and dedication of many people over many years. I gratefully acknowledge the help, insight, and encouragement provided by the following:

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My wife, Jan, for being extraordinarily supportive and understanding for so many years.

Some of this content has appeared in other forms by the author.

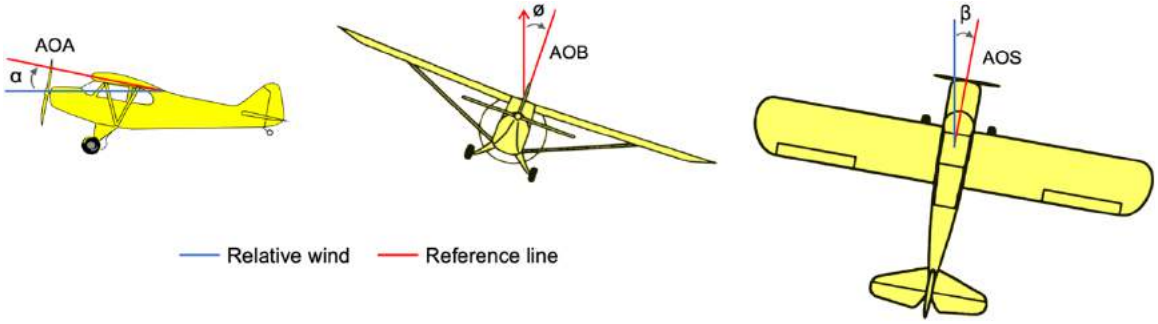
Definitions & Symbols

Academic training. Training that places an emphasis on studying and reasoning designed to enhance knowledge levels of a particular subject.[8] This is *Learn* in Community Aviation's training framework.[9]

AOA (α). Angle of Attack. The angle measured from the relative wind to the chord line of a given wing, airfoil, or other lifting surface. Most commonly, AOA is used as it relates to the main wing of the airplane.

AOB (ø). Angle of Bank. The orientation of the wings relative to the horizon measured as the angle from the upward vertical to the yaw axis of the airplane.

AOS (β). Angle of Sideslip. The angle measured from the relative wind to the airplane's longitudinal (i.e., roll) axis. By definition, AOS is the angle of attack of the fuselage. See *Sideslip*.



AOPA. Aircraft Owners and Pilots Association.

Bridge training. Additional training designed to address shortfalls in knowledge and skill levels so that all trainees possess the prerequisite levels upon which a given training program was designed.[10]

CAS. Calibrated airspeed.

CFI. Certificated Flight Instructor.

Coordinated Flight. Yaw-cancelled flight (i.e., no sideslip); otherwise, it is uncoordinated flight.

DPE. Designated Pilot Examiner.

EAA. Experimental Aircraft Association.

EMT. Emergency Maneuver Training.

FAA. Federal Aviation Administration.

FSTD. Flight Simulation Training Device.[11]

GAJSC. General Aviation Joint Steering Committee.

$G_{Cockpit}$ (G_C). The load factor that would be registered on a typical G-meter installed in the cockpit; the G felt by the pilot as a result of elevator inputs (i.e., $G_C = L/W$). Also denoted as *n*, g, G_Z, and G. See *Load factor*.

$G_{gravity}$ (G_g). Represented as the ratio W/W acting toward the earth. By definition, $G_g = 1$.

G_{Radial} (G_R). The portion of $G_{Cockpit}$ acting in the geometric plane of the turn; the centripetal or radial G acting toward the center of a curving flight path. The turning G, which is the "result of a change in direction such as when a pilot performs a sharp turn, pushes over into a dive, or pulls out of a dive."[12]

Hazard. An ever-present latent, performance-robbing condition or trend that inhibits excellence and “could bite hard when combined with other environmental factors.”[13]

HCL. Horizontal Component of Lift.

HOV. Horizontal, Oblique, and Vertical geometric planes.

IAC. International Aerobatic Club.

IAS. Indicated airspeed.

ICAO. International Civil Aviation Organization.

ICAS. International Council of Air Shows

Judgment. “The mental process of recognizing and analyzing all pertinent information in a particular situation, a rational evaluation of alternative actions in response to it, and a timely decision on which action to take.”[14]

Just Noticeable Difference (JND). Also known as the *difference threshold*, this is the minimum level of stimulation that a person can detect 50 percent of the time. For example, if you were asked to hold two objects of different weights, the just noticeable difference would be the minimum difference between the two weights that you could sense half of the time.[15]

L. The total lift produced by the main wing of an airplane.

Load factor. The apparent weight expressed as the ratio of an airplane’s lift to its weight (L/W), and denoted as n, g, G-load, G_Z, G, and G_C. See $G_{Cockpit}$.

LOC-I. Loss of Control-Inflight.

Negative G (−G). The result of pushing sufficiently on the elevator control to cause the lift vector to emanate from the bottom surface of the wing, regardless of airplane attitude relative to the horizon.

Negative training. Training that unintentionally introduces incorrect information or invalid concepts, which could decrease rather than increase safety.[16]

NTSB. National Transportation Safety Board.

Oblique. Any tilted plane between the horizontal and the vertical.

Pitch attitude (Θ). For vertical turns, “the angle measured from the upward vertical to the lift vector.”[17]

Positive G (+G). The result of pulling sufficiently on the elevator control to cause the lift vector to emanate from the top surface of the wing, regardless of airplane attitude relative to the horizon.

Practical training. Describes training that places an emphasis on the development of specific technical or practical skills, which is normally preceded by academic training.[18] This is *Do* and *Fly* in Community Aviation’s training framework.

Proprioception. “The unconscious perception of movement and spatial orientation arising from stimuli within the body itself.”[19]

Proverse roll. When rudder is applied as a primary input, it induces some roll in the same direction. For example, applying left rudder also results in some left roll, right rudder results in some right roll.

Primary. Of first rank, importance, or value; principal, basic, fundamental.[20]

ROC: Rate of climb. A positive rate of climb means the airplane is climbing; a zero rate of climb means it is in level flight; a negative rate of climb means it is descending.

ROT: Rate of turn.

Scenario-based training (SBT). A training method that "uses a highly structured script of real world experiences to address aviation training objectives in an operational environment."[21]

Sideslip. Flight "with a component of airflow from one side. *Skid* is…away from the centre of the turn. *Slip* is…towards the centre of the turn."[22] Descriptors regarding the state of sideslip are skidded, slipped, and coordinated flight. See *Angle of sideslip*.

Situational awareness (SA). "The accurate perception and understanding of all the factors and conditions within the four fundamental risk elements [PAVE: Pilot, Aircraft, enVironment, External pressures] that affect safety before, during, and after the flight."[23] "A general, applicable definition describes SA as 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future'"[24]

Spin. The helical descending flight path resulting from simultaneously (or nearly simultaneously) stalling and yawing an airplane.

Stall. Most commonly, the turbulent separation of otherwise smooth airflow from the main wing of an airplane coupled with an uncommanded pitch change.

TAS. True airspeed.

UPRT. Upset Prevention and Recovery Training.

V. Airspeed. On most performance diagrams, shown as calibrated or true airspeed.

Vector. A quantity characterized by magnitude and direction. Examples: an airplane flying at 100 knots on a heading of 030 degrees; a car traveling southbound on the freeway at 60 mph.

VFR in VMC. Visual Flight Rules in Visual Meteorological Conditions.

W. The weight of the airplane.

Section 2

Dive Right In

Bottom Line Up Front

> *The elevator is the motivating control for all circular maneuvers,*
> *such as turns, chandelles, lazy eights, and loops.*
>
> —Sammy Mason
>
> *S.A.F.E. Flight Instruction Manual*[25]

We use the elevator to manage the shape, type, and quality of turning flight.

Reactions to these statements range from “nothing new there” to “shock and disbelief.” If yours was the latter, you might experience something akin to the stages of grief as you take in this material: denial, anger, bargaining, acceptance. How rapidly you move through the stages will be a function of your mindset. The more fixed the mindset, the slower the progress; the more open you are to new learning opportunities, the faster the progress. The fact that you are reading this is an excellent sign already!

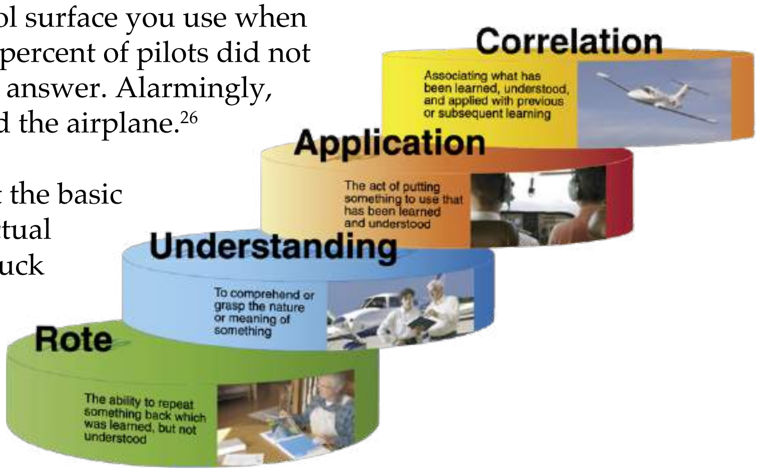
Frequently Asked Questions

Following are frequent questions and comments about *Learn to Turn*, many of which arose in the Bargaining stage.

Why is it important to know that the elevator is the turn control?

Loss of control while maneuvering is the perennial top cause of fatal flying accidents. When asked, “What is the primary control surface you use when turning an airplane,” eighty-three percent of pilots did not recognize “elevator” as the correct answer. Alarmingly, one-in-four believed rudder turned the airplane.[26]

The FAA teaches instructors about the basic levels of learning.[27] Regrettably, actual flight training too often remains stuck at the rote level as students are drilled on procedures designed to pass checkrides. True situational awareness, however, demands correlation-level



knowledge of what our controls do. Deeper understanding of the performance consequences of our control inputs results in more precise flying and reveals the connections between seemingly unrelated maneuvers. It is also important to use correct terminology when describing those performance consequences. For example, the consequences of aileron inputs are roll, bank angle, and adverse yaw. With respect to yaw, the airplane is either coordinated (yaw cancelled), or uncoordinated (skidding or slipping). Elevator is the primary means of controlling:

Angle of Attack: Are we stalled or unstalled; what is our margin to the wing's critical angle of attack?

Airspeed: Are we fast or slow; are we operating at an appropriate speed?

G-load: Is our flight path straight or curving; what is our margin to aerodynamic and structural design limits?

At the correlation level of learning, the outcome of a maneuver truly would never be in doubt. All pilots would know that rudder does not turn the airplane—it cancels yaw, allows them to slip, and skids them into a spin. Pilots would understand just how many variables they are juggling when manipulating the elevator, that "back pressure on the stick, tightness of turn, *g* load, nearness to the stall, are all really the same thing."[28] They also would realize that loss of control ending in a spin results from stalling and yawing, that a stall/spin does not happen *to* the pilot, but *because of* pilot inputs.

Although pilots can perform rudimentary level turns to certification standards, too few are able to describe the mechanics of turning flight accurately. Thus, the *Learn to Turn* worldview is this:

- Airplanes follow one of two flight paths: either a straight line, or a curve;
- These flight paths can occur anywhere in space, i.e., in the horizontal, oblique, or vertical planes; and,
- These flight paths are controlled primarily with elevator inputs.

Who else characterizes turns as not just "horizontal," but also "oblique" and "vertical"?

In *Maneuvering Flight – Hazardous to Your Health*, the AOPA Air Safety Foundation addresses accidents resulting from loss of control while maneuvering. Therein, stall/spin accidents included those occurring while in "nose-up and nose-down flight attitudes, in turns and during pull-ups (vertical turns)."[29]

The *Air Show Performers Safety Manual* states, "A pull out from a vertical dive is a turn of one kind."[30] *Stick and Rudder* notes, "Everything that is true of the [level] turn…is true also of the pull-out from the dive, the flare-out from the glide, the pull-up into a loop—in short, of any curving of the flight path upward."[31] And the US Naval Air Training Command, as well as the US Air Force Test Pilot School, present maneuvering performance in terms of horizontal, oblique, and vertical planes.[32]

Is elevator-as-turn-control a new concept?

No, but specifically identifying the elevator as our turn control typically is not done during normal flight training. Elevator-as-turn-control often is glossed over or omitted in many aviation texts, though examples where the elevator is shown to be the turn control can be found. Consider, for example, wording in different editions of the FAA *Airplane Flying Handbook*:

Level Turns (horizontal): The 2004 handbook states, "The elevator…. 'pulls' the nose of the airplane around the turn."[33] This key point is conspicuously absent in the 2016 handbook.

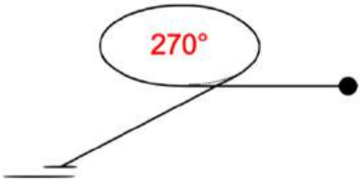
Chandelles (oblique): "After the appropriate bank is established, a climbing turn should be started by smoothly applying back-elevator pressure…"[34]

Eights-on-Pylons (oblique): The 2016 handbook describes this as "the most advanced and difficult of the ground reference maneuvers…. unmatched for developing intuitive control of the airplane."[35] The 2004 handbook says, "The instructor should emphasize that the elevators are the primary control for holding the pylons."[36] This key point, however, is conspicuously absent in the 2016 handbook.

Round Out (vertical): "The round out is a slow, smooth transition from a normal approach attitude to a landing attitude, gradually rounding out the flightpath…. Back-elevator pressure is gradually applied to slowly increase the pitch attitude and angle of attack (AOA)."[37]

The Revelation

I was transfixed. My mind raced as my eyes darted among the aerobatic symbols scribbled on the blackboard. It was a simple question, part of casual conversation in the hangar. Aerobatic competitor and instructor Dave Byrne asked what the focus was during the aerobatic turn. I was a private pilot with about 120 hours total time, and had recently competed in my first aerobatic contest. Yet I was struggling to come up with the answer. After what seemed like an hour, I responded.



"Elevator?"
"Yes, of course. It's what makes us go in circles."

Of course! My flying up to this point had been mechanical, as if painting by numbers. My sense of feel was underdeveloped. I was not seeing the finer details yet. More importantly, I had not made the connections between various maneuvers.

As I studied the symbols again, patterns began to emerge. Maneuvers were built of lines, angles, and curves. The relationship between turns and loops, pullups and pullouts came into focus. I wondered, "Why wasn't this kind of information presented during my flight training?" I had flown with six different instructors in three states by this time. Why hadn't any of them mentioned this?

On the heels of that chat in the hangar, former US Unlimited Aerobatic Team member and flight instructor Bill Thomas released *Fly for Fun*. I read Langewiesche's *Stick and Rudder*. And I studied Sammy Mason's *S.A.F.E Flight Instruction Manual*. All of these reinforced the concept of the elevator as our turn control. Why wasn't this clearly stated in the typical training materials I had read?

The revelation freed me from the rote level of learning. It changed my entire approach to becoming a better pilot, and informed how I would teach as a flight instructor.

Are you suggesting that elevator is the most important input?

No, just trying to raise awareness of the multi-faceted role the elevator plays when turning—a role often obscured by the predominance of shallow-banked, level turns. Regarding level turns in particular, pilots should be taught not only the coordination of aileron and rudder during roll in and roll out, but more importantly the proper coordination of "back pressure and bank" during the turn itself.[38]

I was taught the horizontal component of lift turns the airplane—is this wrong?

In the context of level turns, it is indeed the horizontal component of the lift force that is responsible for curving the flight path. But simply saying, "horizontal component of lift" does not tell us who manipulates the lift force, or how that is accomplished. By definition, the lift vector has magnitude and direction. Regardless of the angle of bank, it is what the pilot chooses to do (or not do) with the elevator that determines not only the size of the lift vector, but even whether it emanates from the top or bottom surface of the wing.

As a thought experiment, imagine an airplane and pilot both capable of performing any maneuver imaginable. Visualize the airplane in level flight. The pilot rolls to 30 degrees of bank. How many kinds of turns are possible at this point? How about these:

ACTION: the pilot pulls +1.2G on the elevator.
CONSEQUENCE: the lift vector emanates from the top surface of the wing with a horizontal component exactly sufficient for a level turn.

ACTION: the pilot pulls less than +1.2G on the elevator.
CONSEQUENCE: the lift vector continues to emanate from the top surface of the wing, but now with a horizontal component insufficient for a level turn. The result is the start of an oblique descending turn.

ACTION: the pilot pulls more than +1.2G on the elevator.
CONSEQUENCE: the lift vector continues to emanate from the top surface of the wing with a horizontal component greater than necessary for a level turn. The result is the start of an oblique climbing turn.

ACTION: the pilot pulls +4G on the elevator.
CONSEQUENCE: the lift vector continues to emanate from the top surface of the wing as the airplane begins an oblique inside loop.

ACTION: the pilot pushes −4G on the elevator.
CONSEQUENCE: the lift vector now emanates from the bottom surface of the wing as the airplane begins an oblique outside loop.

But I use ailerons and rudder to turn.

True at the start of a coordinated level turn or chandelle, but we operate in a three-dimensional environment with myriad turn possibilities. Others have stated it thus: *When turning, I first need to bank the airplane with aileron and rudder into the direction of the turn*. This is untrue for a slipping turn, an outside rolling turn, an inside loop, or the round out for landing. The challenge in *Learn to Turn* is to think more broadly about the mechanics and attributes of turning flight.

But won't the airplane turn if I let go of the stick or yoke?

It depends on the elevator trim setting. In wings-level flight, for example, the airplane could arc into a climb, remain level, or arc into a descent. In a shallow bank, the airplane could begin a climbing turn, remain in a level turn, or begin a descending turn. Realize that the elevator trim setting is equivalent to an elevator input.

But can't I turn with rudder alone?

"Turn" is reserved for the conditions described previously, namely: curving the flight path with elevator inputs. Further, the primary purpose of the rudder is to cancel yaw; otherwise, we experience skidding or slipping flight.

Yaw certainly can influence turn performance. Compared to a coordinated level turn, for example, skidding tends to increase turn rate and reduce turn radius, whereas slipping tends to slow turn rate and increase turn radius. While there are practical applications for slipping turns, there are no practical applications for skidding turns other than to enter a spin.

Some pilots nevertheless have performed limited turning flight initiated with rudder. A closer look at the dynamics, however, reveals the following string of events. In level flight, assume the pilot applies left rudder only:

- Primary consequence – the airplane yaws to the left
- Secondary consequence – the airplane banks to the left
- Tertiary consequence – the airplane likely turns to the left

Proverse roll accompanies the rudder input. As the airplane banks, it turns not because of the rudder input or the attendant bank, but because of the elevator trim setting. Different elevator trim settings will yield different turn performance. The "turn with rudder" notion—poor piloting technique in normal flying—is a roundabout way of getting the elevator vis-à-vis its trim setting to do what it does: curve the flight path.

Imagine you have a nail, two pieces of lumber, a hammer, and a rock. Can you nail the lumber together using the rock? Sure! But why use the rock when you have a perfectly good hammer—designed to do this very job—at your disposal? Using the rudder to get you to the turn is like using the rock to build your house. Even in scenarios where elevator control has been compromised, using rudder to turn is an inelegant solution to precise aircraft control.

What about times when we might "use the rudder as an elevator"?

The elevator, rudder, and ailerons are angle of attack controllers. Elevator controls AOA of the main wing; rudder controls AOA of the fuselage (aka, angle of sideslip); ailerons control local AOAs near the wing tips. The rudder gives us limited control over the AOA of the fuselage for coordinated, slipping, or skidding flight; it would be hard pressed to do all that the elevator does for us.

Knife edge flight is an interesting case. Try this thought experiment: With the airplane banked at 90 degrees, what must the pilot do to continue along an essentially straight flight path? See Appendix A for the answer, but don't just turn to it—try to puzzle it out first!

How sustainable are turns that have been uncoordinated by too much rudder?

Skidding turns—especially those from base to final, or while attempting to turn back to the runway after an engine failure on takeoff—are precursors to loss of control. Properly managed slipping turns, on the other hand, can be useful in scenarios such as a jammed aileron or rudder, or split flaps. Slipping turns can be an effective way to lose additional altitude in the traffic pattern as well.

Regarding level turns, why don't you include centrifugal force like the FAA does?

In the words of physicist-pilot John T. Lowry, "there is no centrifugal force or even centrifugal pseudoforce acting on the turning airplane."[39]

Why do you emphasize G-loads rather than forces in turns?

One of the five recommendations from the "Curricula" breakout group during the 2011 *Pilot Training Reform Symposium* was to emphasize load factor and angle of attack awareness.[40] Moreover, *Learn to Turn* content is informed by two key performance diagrams: Bank Angle vs. G-load (ø-G), and Speed vs. G-load (V-G). Thus, normalizing the traditional discussion about forces to G-loads provides consistency. Converting force to G-load offers other operational and mathematical advantages as well, for example:

- The link between our elevator inputs and G-load is intuitive;
- Our proprioception is attuned to changes in G-load;
- A cockpit G-meter provides useful information independent of aircraft weight; and,
- Turn performance equations are easily expressed in terms of G-load.

Isn't it dangerous to talk so much about the elevator?

Statistics on fatal loss of control suggest we are not emphasizing the role of the elevator enough. The systemic failure of the training industry to ingrain in pilots what the controls actually do, especially when maneuvering, is the reason pilots unknowingly make the wrong inputs at critical times.

But what happens if a pilot, rushing the final turn for whatever reason, doesn't bank the airplane enough, over-rudders, then pulls back because the pilot remembers "elevator makes the turn tighter"?

This is an inaccurate description of the classic skid-spin scenario, which goes something like this: The pilot overshoots the runway centerline while turning final. Feeling pressured, the pilot misapplies the rudder believing it will tighten the turn. Instead, the nose of the airplane slices through and below the horizon in yaw. The pilot reacts to this by pulling the elevator control aft, believing it will bring the nose back up.

The consequence of the misapplied elevator is an increase in angle of attack, which presents as a decrease in speed and an increase in G-load. Should the speed and G-load trends converge on the airplane's stall curve, an accelerated stall occurs in the presence of yaw. Though the pilot had intended a different outcome, the airplane departs toward a spin as commanded by the pilot.

Just make the airplane do what you want it to do.

This advice presupposes that pilots know how to manipulate the controls properly for the desired outcome. The pervasiveness of fatal loss of control accidents, however, tells a different story. Further, "just do it" is a poor approach to teaching complex physical skills.

Elevator controls your flight path, except when it doesn't because of a stall.

Stalls do not happen *to* the pilot; they happen *because of* the pilot. Pilots are active participants in flying; their actions have consequences. In the case of upright flight, pulling on the elevator increases angle of attack, which presents as a change in speed, G-load, attitude, flight path, or some combination of these. Whether turning or not, whenever the pilot causes the aerodynamic limit of the wing to be reached, the consequence will be separation of airflow and a change in flight path unless and until the pilot resets the angle of attack with the elevator.

Is all the confusion the result of a poor definition of "turn"?

Confusion arises when instructors fail to push learning to the correlation level by helping students connect the dots. Maneuvers tend to be taught as compartmentalized units, delinked from each other. Take the ground reference maneuvers turns around a point and rectangular course, for example. The principles learned in turns around a point apply to the 90-degree segments in the rectangular course. Yet rectangular traffic patterns too often end up being skewed because pilots do not apply the wind correcting concepts learned in turns around a point.

Let's start connecting the dots.

Program Structure

Throughout the lifelong gathering of experience,
it is better to be a teacher or a learner than an example.

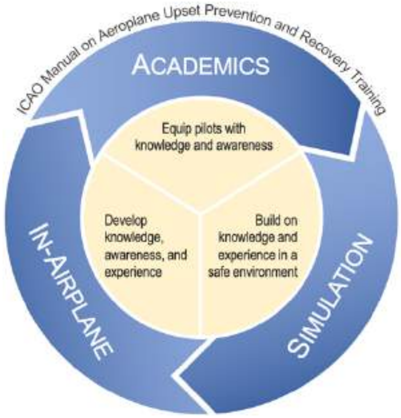
—Robert L. Cohn
They Called it Pilot Error[41]

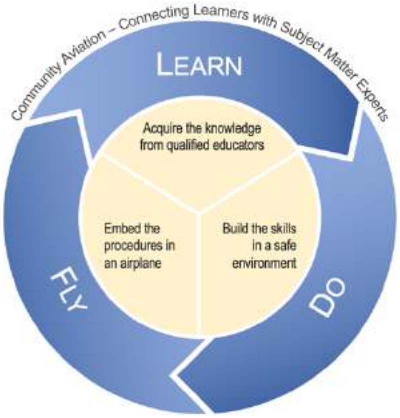
Flying involves a complex set of physical and mental skills. Peak performance requires good coordination not only between our hands, eyes, and feet, but also between our mind, body, and emotions.

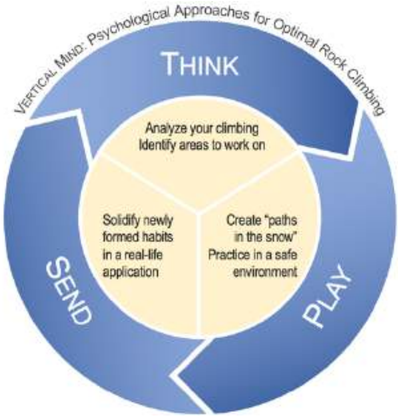
Framework for Optimal Learning

While most pilots recognize that the cockpit of an airplane is a lousy classroom, a lot of instruction tends to occur mostly, if not entirely, in the airplane. While most also recognize that flying skills are perishable, practice slows or stops altogether once pilots leave the formal training environment.

Optimal learning experiences, however, consist of three integrated parts in a continuous cycle. For example, the framework for optimal UPRT includes academic, simulation, and in-airplane training. Community Aviation's version is *Learn-Do-Fly*. Other activities that demand peak performance follow a similar framework. Consider the approach for optimal rock climbing, which is described as *Think-Play-Send*.







Learn to Turn adopts the *Learn-Do-Fly* framework:

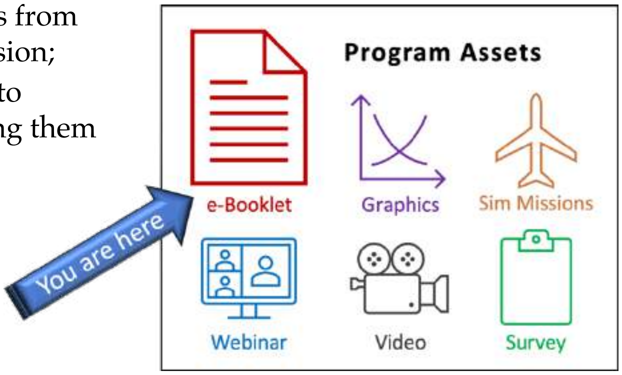
- LEARN – acquire the knowledge from qualified experts
- DO – build the skills in a safe environment
- FLY – embed the procedures in an airplane

The content that follows is the *Learn* part; the suggested training exercises, the *Do* and *Fly* parts. All three parts are essential to achieve peak performance when flying. The challenge is to work through the cycle, refine what has been learned, and repeat. Treat your flying as a lifelong learning process.

The Assets

The *Learn to Turn* program is free and has several digital assets. With its academic content and training exercises, consider this booklet as your primary asset. Supporting assets include:

- A separate collection of enlarged graphics from this booklet to facilitate classroom discussion;
- Simulator missions—configure your sim to practice the training exercises before trying them in an airplane;
- A 28-minute webinar recording;
- A 12-minute video; and,
- A pilot survey—please take a few minutes to complete the online survey once you've gone through the material.



While this booklet is available from various sources, Community Aviation hosts all the program assets here:

https://www.CommunityAviation.com/Learn-to-Turn

Section 3

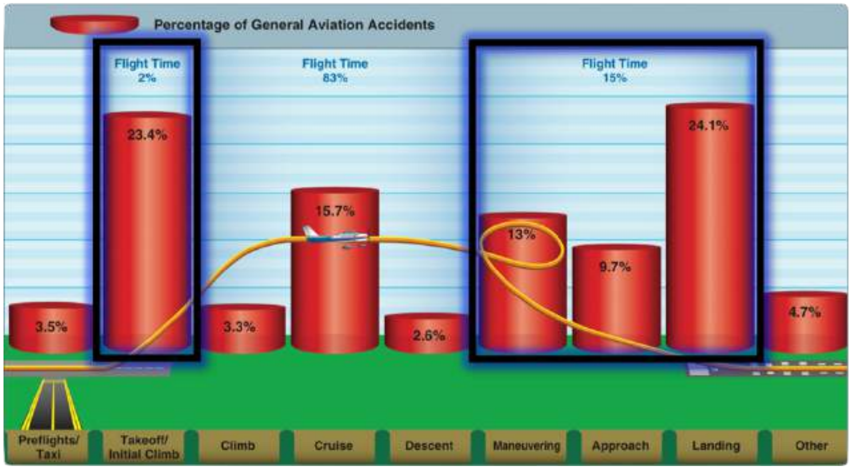
The Status Quo

The Problem

Error control will never be engineered out of existence with technology.
—Dr. Tony Kern
Blue Threat[42]

Inflight loss of control is the leading cause of fatalities in aviation. It dominates among homebuilts, in general aviation as a whole, and in the commercial jet fleet worldwide. For the period 2001–2010, the GAJSC found more fatal general aviation accidents resulting from LOC-I than from the next five occurrence categories combined.[43] Further, one-in-four of the fatal LOC-I accidents occurred during the maneuvering phase alone.[44]

The maneuvering, takeoff and initial climb, approach, and landing phases accounted for 64 percent of the fatal accidents.[45] Pilots spend just 17 percent of their flight time operating in these phases, yet this is where 70 percent of all aviation accidents take place.[46] Compared to cruise flight, these phases involve higher angles of attack, greater potential for distraction, and more opportunities to mishandle the controls.



Accordingly, LOC-I has been a focus not only of FAA Safety Stand Downs, but also of NTSB's Most Wanted Lists. NTSB also hosted the forum, *Humans and Hardware: Preventing General Aviation Inflight Loss of Control* to discuss, among other topics, pilot training solutions and equipment and technology solutions.[47]

Stubbornly Recurrent

NTSB Member Earl Weener has called LOC-I a "stubbornly recurrent safety challenge."[48] Stubborn indeed. Consider these observations, for example:

1944: "Almost all fatal flying accidents are caused by loss of control during a turn."[49]

1973: Turning flight preceded at least 60 percent of fatal stall-only accidents.[50]

1980: "Many pilots do not reach a complete understanding of what makes an airplane turn. Such an understanding is certainly worthwhile, since many accidents occur as a direct result of losing control of the airplane while in turning flight."[51]

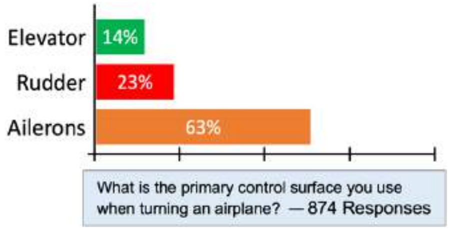
1993–2001: Twenty-seven percent of all fatal accidents and 41 percent of fatal stall/spins occurred while maneuvering.[52]

"Every one of these pilots who has spun in was a product of the system, the product of a certificated instructor."[53] What is it about maneuvering flight that has entrenched it as a top cause of fatal LOC-I for so long?

Flawed Assumptions

While attempts to improve stall/spin awareness and encourage technologies to reduce LOC-I certainly have merit, what if the underlying issue is more basic than that? We naturally assume pilots are competent at turning. After all, turning is fundamental to flying. Turns are introduced practically on day one of flight training. Pilots do turns all the time. But if pilots thoroughly understood and were competent with turns, why do some intentionally skid into a spin when overshooting the turn to final? Botch their attempt to turn back the runway following engine failure on takeoff? Lose control during low-level survey and patrol operations? These pilots actively drove their loss of control by applying precisely the inputs necessary for a stall/spin.

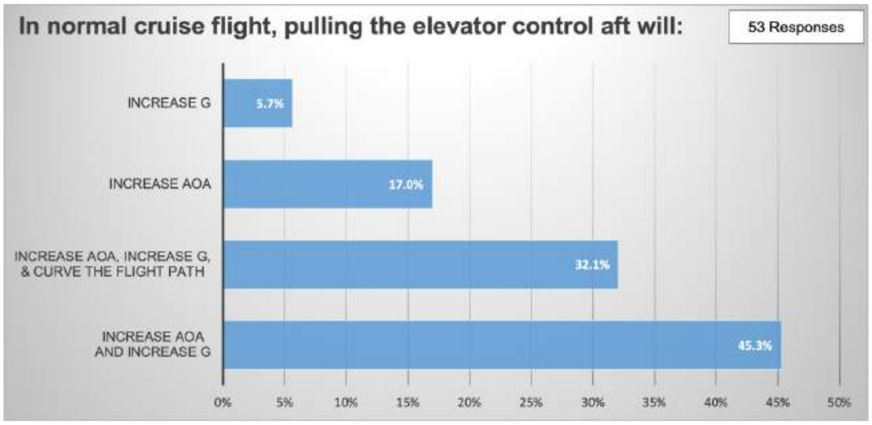
We have been teaching turns the same way for decades, with the same results. Perhaps it is time to critique the methodology. As part of several safety programs, for instance, nearly 900 pilots responded to the question, "What is the primary control surface you use when turning an airplane?"



Sixty-three percent chose ailerons; 23 percent, rudder; fourteen percent, elevator. Eighty-six percent did not recognize "elevator" as the correct answer. Nearly one-in-four believed rudder turns the airplane—a shocking finding considering the FAA's decades-long efforts to inform pilots that rudder does *not* turn the airplane.[54] The 2016 edition of the *Airplane Flying Handbook*, for example, mentions the use of rudder during turns at least four times.[55]

A different question was posed to those attending an FAA Wings webinar in 2021: "In normal cruise flight, pulling the elevator control aft will…" Fifty-three pilots chose one of four options:

a. Increase G
b. Increase AOA
c. Increase AOA, increase G, and curve the flight path
d. Increase AOA and increase G



Only about one-third said pulling the elevator control aft would increase AOA, increase G, and curve the flight path. Forty-five percent said it would increase AOA and increase G, but did not correlate this with curving of the flight path. One-third of the respondents had logged 101–500 hours of flight time, nearly one-fourth had 1,001–3,000 hours, and one-fourth had more than 3,000 hours. Regarding the type of flying they generally did, eighty-six percent selected "Personal GA."

Skill Retention

"The retention of pilot flight skills is a critical factor in the overall safety and efficiency of general aviation operations."[56] Furthermore, "Having unrealistic expectations about your training level and, more importantly, your training retention level, is a major error."[57] One study, for example, quantified the degradation in flying skills of a group of private pilots.[58] The study period began with the private pilot checkride and ended 24 months later. The top seven skills exhibiting the greatest composite degradation follow:[59]

Pattern Operations

1. Landing (non-towered field)
2. Traffic pattern (non-towered field)
3. Short field landing

Turning Flight

4. Accelerated stall
5. Steep turns
6. S-Turns across a road
7. Turns around a point

Skills 1–3 can be categorized as "pattern operations," while skills 4–7 can be categorized as "turning flight." The tasks that exhibited "relatively large amounts of skill loss over the 2-year retention period all are operationally critical. Their importance stems from the fact that some (e.g., landings on short runways or at uncontrolled fields) are of direct use in operational settings, while others (e.g., ground reference maneuvers) are more abstract and involve basic skills that underly the execution of the former tasks."[60] The ability to judge and manage pitch rate, for example, is central to landing. The transition from descending to leveling off just above the runway is about vertical turn management; so, too, is holding off the airplane without ballooning.

Pilots are taught to mimic basic and mostly level turns. Many never progress to the application or correlation levels of learning vis-à-vis the whole maneuvering flight envelope. The importance of cue development typically is not emphasized during training, either. "Instead, cues more often are learned unsystematically through experience."[61] Unguided experience often leads to attaching significance to wrong or irrelevant cues. For instance, when quizzed while in a level turn, pilots routinely fail to identify the elevator as the control they are using at that moment to bend the flight path. The most obvious cue—and the one to which pilots attach undue significance—is bank angle. This supports the observation that pilots "do not know what makes an airplane turn."[62]

Details matter, yet a lot of pilots—including CFIs—are unable to explain various maneuvers by accurately positioning the control surfaces on a model airplane. Some are hesitant—in some cases, they flat out refuse—to see a loop as a variant of the level turn.

Evidence suggests the flight training industry long ago succumbed to the twin demons of complacency and perceived competence.[63] We have been complacent about the way we teach turns, thereby leaving pilots with a false sense of competency. The result is often a pilot who “possesses basic flying skills but lacks satisfactory understanding of aircraft performance and its underlying principles.”[64] Deficiencies in knowledge and experience are magnified during critical flight operations such as takeoff and initial climb, maneuvering, approach, and landing. Absent better awareness about turn dynamics, the ability to prevent or recover from LOC-I will continue to be compromised.

Technology

**Tech•nol•o•gy | \ tek-’nä-lə-jē **
Anything humans create that solves a problem or makes life easier.
Examples: Pencil, J-3 Cub, Vortex Generators, iPad.

We tend to be quick to assume that technology is the best solution to the LOC-I problem. Some point to the approach to technology taken by the military and the airlines as a model for general aviation. Airline and military flight environments, however, are highly structured; the pilots, selectively chosen, extremely well trained, and actively engaged in continuous recurrent training and evaluation. Technology applied in that context would be expected to enhance already superior levels of knowledge and skill.

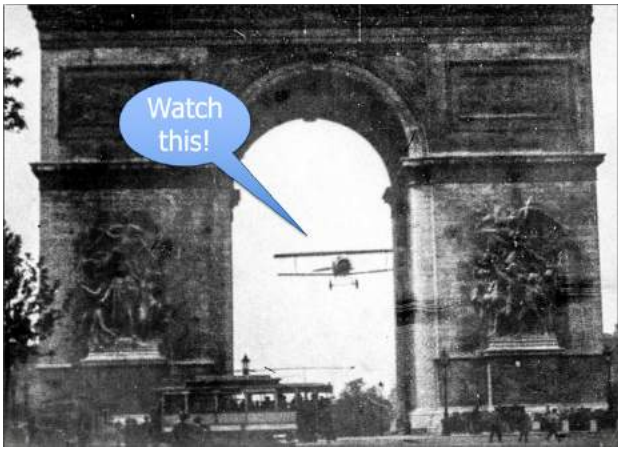
In contrast, general aviation is far less structured. It has a significantly larger pilot population. It is open to anyone who can meet minimum (and varying) standards of skill and precision. Recurrent training is largely optional. Contact flying is the norm (i.e., daytime VFR in VMC using outside visual references). Add in known deficiencies in knowledge and skill about turning flight and it is unlikely the full benefits of purely technological fixes will be realized. When used appropriately, technology certainly can reduce accidents. It is most effective when it complements superior skills; less so if used as a crutch or band-aid to cover weaknesses in skills. “Despite all the changes in technology to improve flight safety, one factor remains the same: the human factor which leads to errors.”[65] In the context of general aviation flying, usually “it is not about the hardware, it is about the ‘software’”—the pilot at the controls.[66]

Operational Errors

> *Every accident, no matter how minor, is a failure of the organization.*
>
> —Jerome Lederer
>
> Aviation Safety Pioneer[67]

Pilot error historically has been cited as a cause or a factor in more than 80 percent of aviation accidents.[68] These errors are "the result of very complex processes…. Another factor often involved is the abrupt onset of emergency conditions…"[69] In commercial aviation, pilot-induced accidents are the most frequently-identified cause of LOC-I, with four of the top five reasons sharing common ground with general aviation accidents:[70]

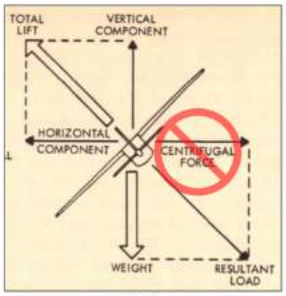
- application of inappropriate control inputs;
- poor energy management;
- distraction; and
- improper training.



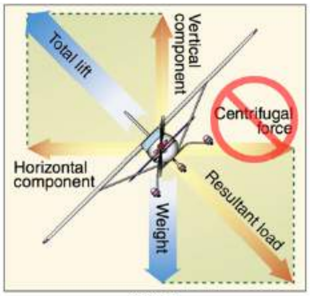
Pilot error can be subdivided into tactical and operational errors. Tactical errors are attributable to the pilot's own behavior. Typically, these errors are preceded by the phrase, "Watch this!" Classic examples include buzzing, choosing to press on despite deteriorating weather ahead, and performing unapproved maneuvers.

Operational errors, in contrast, can be traced back to errors or omissions committed during the transfer of knowledge between aviation educators and their trainees. "Imprecise, inaccurate or incorrect descriptions of basic maneuvering principles, or the maneuvers themselves, frequently lead to misconceptions that hinder the progress of air show pilots working to improve their skills."[71] This applies to all pilots.

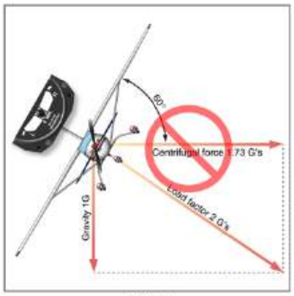
A common example is the false notion of centrifugal force in turns. Not only is this incorrect, but it also needlessly complicates the academic discussion. Nonetheless, it has been perpetuated in FAA handbooks for decades.[72]



1980



2008



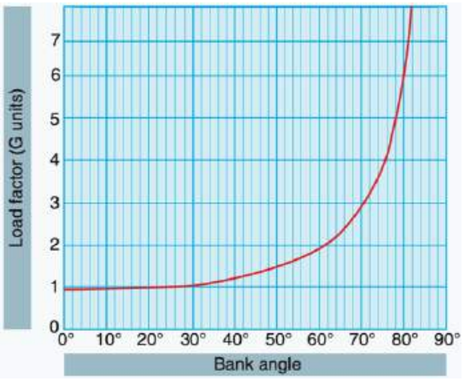
2016

The flight training system has tended to indoctrinate pilots into thinking only about horizontal turns. To answer the challenge, "what turns an airplane," pilots memorize the response, "the horizontal component of lift." This notion apparently is so important that it merited at least sixteen mentions in the 2016 edition of the *Airplane Flying Handbook*. But airplanes are capable of climbing and descending turns. Occasionally, pilots manage to flare their airplanes for landing, too. How do these types of turns fit the "horizontal component of lift" narrative? In general, "any condition in which the aircraft's lift is not equal to its weight will result in a curving flightpath…"[73]

Statements such as "the horizontal lift component…begins to turn the airplane and not the rudder" make an apples and oranges comparison between a force and a flight control.[74] Although rudder can be used to manipulate force, it is not a force. We should be comparing forces to forces, and flight controls to flight controls.

Speaking of force, there is no "G force"—it's G, G-load, or load factor. By definition, "G" is a ratio of forces; it is a dimensionless number. Thus, statements like, "The increased G force of a turn feels the same as the pull up from a dive, and the decreased G force from leveling out feels the same as lowering the nose out of a climb" should read, *the increased G of a turn feels the same as the pull up from a dive, and the decreased G from leveling out feels the same as lowering the nose out of a climb*.[75]

The diagram of bank angle versus G-load (ø-G) is an example of a missed opportunity for thought-provoking discussion.[76] As we'll see later, a lot of operationally useful information can be coaxed out of the traditional ø–G diagram to provide pilots with deeper insight not only about turning flight, but also about stall speeds and design limits without the need for additional charts and diagrams.



Many statements appearing in training materials are deceptively appealing, but inaccurate. Look at the difference between these inaccurate statements and the clarified ones:

INACCURATE: "As the turn is being established, back-elevator pressure should be smoothly increased to increase angle of attack. This provides the additional wing lift required to compensate for the increasing load factor."[77]

CLARIFIED: Additional lift does not compensate for increased load factor. Rather, the pilot applies back pressure on the elevator, which increases the load factor, which indicates that lift is increasing.

INACCURATE: "Total lift must increase substantially to balance the load factor or G-force (G). The load factor is the vector resultant of gravity and centrifugal force."[78]

CLARIFIED: As before, the pilot applies back pressure on the elevator, which increases the load factor, which indicates that lift is increasing. Further, "G-force" is not a thing, and "there is no centrifugal force or even centrifugal pseudoforce acting on the turning airplane."[79]

INACCURATE: "At a constant altitude, during a coordinated turn in any aircraft, the load factor is the result of two forces: centrifugal force and weight."[80] And "The horizontal lift component acts parallel to the Earth's surface opposing centrifugal force."[81]

CLARIFIED: Load factor is a consequence of the pilot pulling back on the elevator control. Centrifugal force is not in play here; thus, the horizontal component of lift is unopposed.

Sixty degrees of bank is a common reference point used to illustrate the relationship between bank angle, G-load, and level turns. Consider what is wrong with these statements:

- "A 2g turn is achieved by banking the airplane at an angle of 60 degrees"[82]
- "in a 60-degree bank, the airplane is experiencing a 2-g acceleration."[83]
- "increasing the bank angle increases the load factor."[84]

The implication in each case is that a 2G turn happens by virtue of the 60-degree bank; ignored is the role of the pilot as the lead actor in the process. Turns do not happen *to* the pilot. They happen *because of* the pilot. In the first example, a 2G turn (given sufficient energy) is initiated *any time the pilot pulls 2G*, regardless of the angle of bank. In the second example, the airplane does not experience a 2G acceleration *unless the pilot commands it*. In the third example, increasing the bank angle does not increase the load factor; it increases the load factor *required of the pilot* to sustain a level turn.

This is no trivial matter. The pilot must command not only the desired angle of bank, but also the commensurate G per the ø-G diagram. The pilot must roll to 60 degrees of bank and must pull 2G. Failure to apply the requisite G results in a different kind of turn: a climbing turn with more than the required G; a descending turn with less than the required G.

Perhaps the most egregious error committed by the flight training industry is unnecessary ambiguity in identifying which control we use to bend the flight path into a circle. Scouring the literature and reading deeply, however, one can find the information:

- Level turns
    - 1941: "Use just enough back pressure on the stick to make the nose follow the horizon."[85]
    - 1944: "An airplane is turned by laying it over on its side and lifting it around through back pressure on the stick."[86]
    - 1985: "It is back pressure applied after the bank is established that makes the plane turn."[87]
    - 1993: How to perform accelerated stalls in coordinated turns at 30 degrees of bank to demonstrate compliance with Part 23 certification standards: "Reduce speed by steadily and progressively tightening the turn with the elevator…"[88]
    - 2004: "The elevator…. 'pulls' the nose of the airplane around the turn."[89]
- Chandelles
    - 2004 and 2016: "After the appropriate bank is established, a climbing turn should be started by smoothly applying back-elevator pressure"[90]

The reality is surprisingly straightforward: airplanes are relegated to flight along straight lines and curves, and those paths are controlled primarily with the elevator. At the correlation level of learning, the myriad flight paths possible at a given angle of bank become readily apparent.

Acknowledging the Hazard

We all make mistakes. It is difficult to be accurate 100 percent of the time when teaching complex material. The challenge for aviation educators is to be alert for errors and omissions because inadequate knowledge or training can create a latent hazard.[91] That hazard "becomes more risky when it is unknown, unaccounted for or underappreciated."[92] The overabundance of low quality, fragmentary information about turns is a quantifiable hazard—poor communications/information transfer raises the probability of error by a factor of 5.5.[93]

The risk associated with maneuvering flight has been well documented. It is not as if pilots have been superbly trained and are doing the absolute best they can, yet continue to fall victim to random circumstances beyond their control. Instead, pilots actively (and inadvertently) continue to propel themselves into LOC-I. Even though pilots can cause rudimentary turns to happen under normal circumstances, it seems they have not been given the in-depth education and experience to master turning flight.

Risk unquestionably has been compounded by misinforming and undertraining pilots about turning flight. So, is it fair simply to blame LOC-I on pilot error in every case? Let's find out what those who provide specialized training in unique and critical flight environments contend with as a result of systemic deficiencies in primary flight training.

What The Specialists See

The old saying, "close enough for government work" is not good enough
a couple hundred feet above the ground.

—Jim Traub
Retired National Flight Training Specialist, National Park Service[94]

Pilots who fly in support of programs such as resource and animal surveys, search and rescue, and wildland fire, as well as those who fly in mountain, canyon, and backcountry environments typically spend a lot of time maneuvering while low and slow. Providers of low-level and backcountry training programs, as well as EMT and similar UPRT programs, often devote time to helping trainees improve their basic flying skills.

Two questions were posed to experts in low-level and backcountry flying. Their observations are paraphrased below.

Why do you emphasize turn-related review and training exercises in your training programs?

> Much of the flying in various land management agencies occurs in maneuvering flight close to the ground. Distractions inside the cockpit such as radio work and crew interaction, and outside the cockpit such as terrain, density altitude, wind, and mission target demand that the pilot has a second sense for the aircraft and its performance. Similar to having a mastery of the instruments prior to flight in IMC, mastery of maneuvering flight is essential during low-level operations.
>
> Tight turns—sometimes in opposite directions, and often in quick succession—are part and parcel of flying in the confined areas of the backcountry. The natural horizon can be difficult to discern with sloping terrain; thus, steeper bank angles are discouraged as they tend to be disorienting and can steepen unknowingly. To compensate for the somewhat restricted angles of bank, slower speeds are used to reduce not only the turn radius, but also the G-load required to turn.
>
> Evaluating the ability of trainees to turn and then working on exercises to improve or reinforce their skills is top of the list. And to reduce the dangers of an inadvertent stall/spin, it is critical for backcountry instruction to emphasize the importance of coordinated flight and angle of attack awareness. Topics and tasks reviewed include:
>
> - How airspeed affects turn radius;
> - How to control airspeed (and thus, AOA) by maintaining a constant pitch attitude using visual references; and,
> - How to perform normal and emergency course reversals in the backcountry environment.

Regarding proficiency and competency, what are the recurring issues you see when pilots perform turns?

> Pilots are products of their training. Many who go through general aviation flight training lack a solid understanding of what makes an airplane do what it does, and its performance limits. For example, failing to compensate for adverse yaw is a recurring theme, especially when rolling out of turns, and especially when the flaps are deployed. Pilots also lack the ability to explain what they are doing, which makes it difficult for them to self-critique and improve. It is hard to unlearn bad habits developed during primary training as well; this becomes even more problematic when poor training meets low-level operations.
>
> Pilots tend to fixate on where they want their turns to stop, while ignoring the wealth of other information available regarding the quality of their turns. Target fixation seems to inhibit their kinesthetic sense of coordination, as well as their ability to see the effects of adverse yaw. During an approach, this often results in significant skidding coupled with unwanted pitch changes that destabilize the approach. On final, this presents as a tendency to use only the ailerons to correct for runway alignment issues. These habits seem to be exaggerated in the backcountry environment.
>
> Flying is seasonal for a lot of pilots, even for those who fly light airplanes for a living. They get rusty on the basics and need recurrent training. Deficiencies may not be noticeable at altitude, but they become readily apparent during critical flight operations.

The above observations are not unique to low-level and backcountry training. Instructors who provide spin, upset prevention and recovery, and aerobatic training have noted similar things for decades.

Unfortunately, poor understanding and lack of basic skills also show up during seemingly routine flights. A high-profile example was the 2006 accident involving a Cirrus that crashed into a Manhattan apartment building while attempting to turn around in the East River VFR Corridor.[95] What can be done about it? Up next, a solution.

A Solution

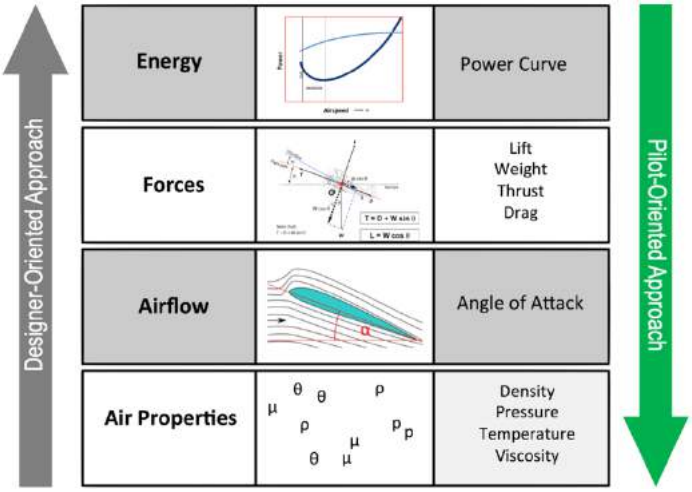
If one's images of the airplane are correct, one's behavior in the airplane will quite naturally and effortlessly also be correct.

—Wolfgang Langewiesche

Stick and Rudder[96]

The general aviation fleet will remain diverse. Improved standards, technology, and products will continue to be pushed into the aviation pipeline. But not every airplane will end up with a supplemental angle of attack indicator or similar technologies, and not everyone will be able to afford the latest technologies or products. Absent a concerted effort to improve pilot performance during turns, these enhancements alone are unlikely to yield the desired safety dividends. The reason: whether the airplane is commercially manufactured or homebuilt, powered by reciprocating or jet engines, or equipped with or without the latest technology, human behavior ultimately determines the fate of each flight.

We can reduce LOC-I accidents through "education, technologies, flight currency, self-assessment, and vigilant situational awareness in the cockpit."[97] Four of these elements point directly at the pilot. Flying is a "three-dimensional environment through which you will maneuver in an infinite number of planes, ranging from the pure vertical, through the oblique, to the pure horizontal."[98] While we might be restricted to certain parts of the flight envelope by such practicalities as energy state, airplane design, operating and regulatory environments, and competency, our ability to make connections at the correlation level has no such constraints.



The traditional approach to flight training is designer-oriented, where trainees are treated like engineering students to start, and pilots later. Alternatively, "an integrated, energy-centered, top-down training approach will lead to a better mental model of how the airplane works."[99] Tie pilot actions to performance consequences right from the start, i.e., "if you do this, the airplane will do that." From there, drill down into the other layers only as necessary.

Pilots touching the controls are the common thread; hence to the extent possible, we'll take a pilot-centric approach to improve skill and mitigate LOC-I here. Moreover, there is a difference between *need to have*, *nice to have*, and *neat to have* piloting skills. For example, we need to be able to execute myriad turns properly, especially during critical phases of flight. It would be nice to earn a tailwheel endorsement someday, and it would be neat to be able to perform an inverted ribbon cut during an air show. Where does over-emphasizing the limiting "horizontal component of lift" fit in? Does every aviation topic merit the same focus as developing the critical skills needed to avoid LOC-I?

The best way to engage pilots in training is to appeal to their primary motivations to fly: autonomy, mastery, and purpose.[100] Pilots in general aspire to improve their skills; they want better information about flying techniques. If we can "provide them with the knowledge and tools to recognize and prevent their personal mistakes, most people who care about their performance will do so of their own accord."[101] The basis for developing and retaining our flying skills hinges on the ability not only to recognize the appropriate cues, but also to respond correctly to those cues.[102]

Assumptions

Though *Learn to Turn* draws on information from diverse sources, the focus is on light airplane pilots flying light airplanes. Basic knowledge of the parts of an airplane and its axes and control systems is assumed. Unless noted otherwise:

- *Configuration* refers to a specific combination of airplane weight and balance, as well as power, flap, and landing gear settings.
- *Wing* refers to the main wing of the airplane.
- *Stall* is used in its classic sense—airflow separation from the wing with an uncommanded downward pitching motion.
- *Lift* always implies drag.
- *Speed* is calibrated airspeed (CAS).
- *Design limits* assume elevator-only inputs.
- Use of elevator trim is equivalent to an elevator input.
- References to G, G-load, and *n* refer to the load factor that would be registered on a typical G-meter installed in the cockpit; it is the G felt by the pilot as a result of elevator inputs (also shown as $G_{Cockpit}$, G_C).
- G-loads and stall speed multipliers are rounded off to one or two decimal places depending on the context.
- *Coordinated flight* means yaw has been cancelled. *Stick and Rudder* describes a coordinated turn as "a clean nice curving of the flight path without skid or slip…"[103] *Stalls, Spins, and Safety* states, "healthy turns are ball-centered, neither slipping nor skidding."[104] Note that coordinated flight does not mean the rudder necessarily is neutral, only that yaw is being cancelled.

Assume coordinated, positive-G flight in smooth air, with a clockwise-rotating propeller relative to the pilot, and a properly rigged airplane and competent pilot both capable of performing any maneuver in any attitude. (Except for a few illustrative examples, the negative G envelope is beyond the scope of this discussion.)

Section 4

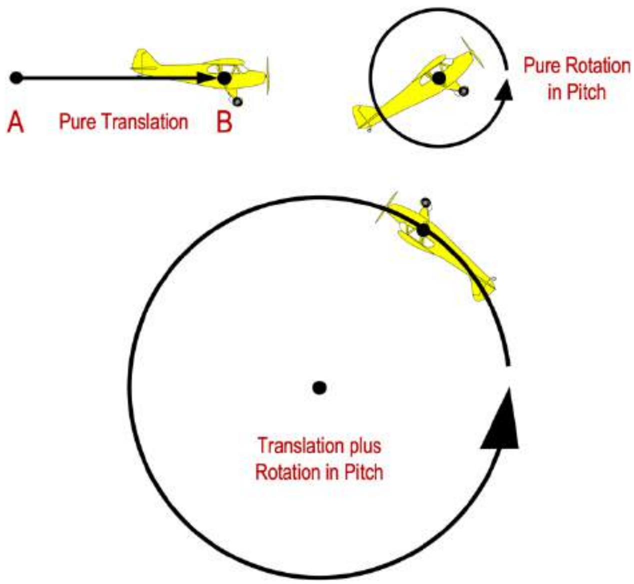
Bridge Training

Basic Object Motion

Any turn can be considered part of a circle.

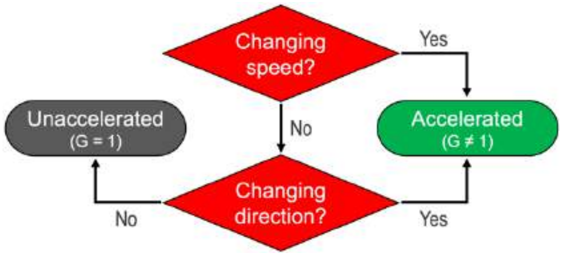
—the Physics Classroom

https://www.physicsclassroom.com[105]



We live in a world defined by three spatial dimensions and one time dimension. Objects move within this domain in two ways: they *translate* (change location); and they *rotate* (around some point or axis). The motion of an airplane is particularly complex because the translations and rotations are often coupled.[106]

In addition to translation and rotation, the motion of an airplane can be described as unaccelerated or accelerated.[107] If velocity remains constant, the airplane is in unaccelerated flight (G = 1); if velocity is changing, it is in accelerated flight (G ≠ 1). As a vector quantity, velocity has two parts: magnitude and direction. Acceleration occurs whenever one or both parts change. For example, speeding up or slowing down means you are experiencing acceleration. Curving the flight path—whether or not speed is changing—also means you are experiencing acceleration.



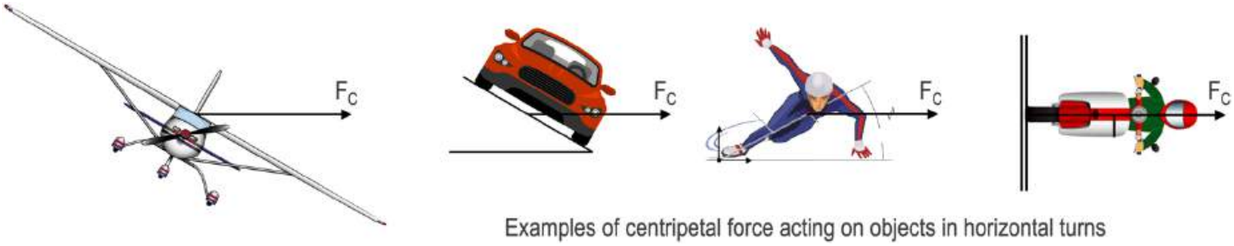
Examples of accelerated flight include climbing and descending turns, maneuvers during aerial combat, and aerobatics.[108] "An aircraft in accelerated (curved) flight—whether pulling up, pushing over, or turning—has a pitch rate."[109] Consequently, G-load is some value other than one.

Level turns just as well could be called horizontal loops. The FAA, for example, describes the orientation of eights across a road as "The **loops** should be across the road and the wind should be perpendicular to the **loops** [emphasis added]."[110] Similarly, while vertical circles are commonly called loops, they also could be called vertical turns.

Centripetal Force

A turn or loop or whatever label you want to give to the curving path "is only possible when there is a component of force directed towards the center of the circle about which the [object] is moving."[111] This component is called *centripetal force*.

During level turns, the horizontal component of lift is the centripetal force curving the flight path. Centripetal force acts not only on airplanes in level turns, but also on cars exiting curved freeway off-ramps, speed skaters turning on short tracks, and stunt motorcyclists riding the Wall of Death at carnivals.



Examples of centripetal force acting on objects in horizontal turns

There is nothing special about airplanes in this regard. So why does something as commonplace as centripetal force deserve sixteen mentions in the 2016 *Airplane Flying Handbook*? What *is* special about flying, though, is that it is not limited to level turns.

The Primary Controls

Control…is the ability of a pilot to change the airplane's flight conditions. It is brought about by the use of devices that alter the lift force on the surface to which they are attached.

—Theodore A. Talay

Introduction to the Aerodynamics of Flight[112]

Flying doesn't happen to us; it happens because of us. We interact with the airplane via the flight controls, and the inputs we make have performance consequences. Absent a complete understanding of the consequences of our inputs, we will be unable to apply the controls correctly, or to see the connections between the myriad forms of turning flight. This chapter addresses potential shortfalls in knowledge and skill regarding the proper use and function of the primary controls. It also establishes common ground for later discussions and training exercises.

Since flying is a three-dimensional activity, we should learn to interpret airplane motions relative to us sitting in the cockpit. This way, roll, yaw, and pitch will always look the same to us regardless of the airplane's attitude; thus, "All you need to remember is which way the controls work in relation to your body."[113] The consequences of our inputs are broken down into visual, aural, and kinesthetic cues, what is changing and how the changes manifest, and potential secondary effects.

Ailerons

The ailerons control the local angles of attack along the outer portion of the wings. Relative to the pilot, aileron inputs are left and right, and roll can be perceived with cues such as:

- Sight – looking outside, the nose and wingtips rotating head-to-hip.
- Sound – no change.
- Feel – either normal in the seat of the pants, or more pressure in the seat of the pants opposite to the direction of roll if trying to lean upright; changing control position/pressure.

We use ailerons primarily to control our bank angle relative to the horizon (roll angle when the airplane is vertical). The notable secondary effect is adverse yaw (yaw in the opposite direction of roll).

Rudder

The rudder controls the angle of attack of the fuselage.[114] Relative to the pilot, rudder inputs are left and right, and yaw can be perceived with cues such as:

- Sight – looking outside, the nose and wingtips sliding ear-to-ear.
- Sound – different type of sound in coordinated versus yawed flight.
- Feel – either balanced pressure in the seat of the pants, or unbalanced sideways pressure (left or right); changing control position/pressure.

Evolution of the Rudder

Replacing the fixed vertical rudder with a movable surface came to Orville Wright while lying awake one night in the fall of 1902. When he told Wilbur about it, Wilbur not only agreed, but further proposed that it be interconnected with their wing warping system to cancel what we now call adverse yaw. The problem of control in three axes at last had been solved.

—See *The Papers of Wilbur and Orville Wright*, Marvin W. McFarland (Editor), Vol. One 1899–1903 (McGraw-Hill, 2001), 269.

What we do with the rudder determines whether flight is coordinated, slipping, or skidding. Secondary effects can include proverse roll (i.e., roll in the same direction as yaw) and gyroscopic precession whose effect appears in pitch. Just like the 1903 Wright Flyer, rudder and ailerons are interconnected in some airplanes. When the pilot makes an aileron input in such airplanes, a bit of rudder simultaneously deflects in the same direction to offset adverse yaw.

The main reason airplanes have rudders has been known for more than a century:

Orville Wright, 1927: "The principal function of the rudder of an aeroplane is that of lateral equilibrium and not that of steering…"[115]

Wolfgang Langewiesche, 1944: "the rudder's essential function is to keep the airplane from yawing, to counteract all disturbing influences, whatever their source…"[116]

FAA, 2016: "The rudder does not turn the airplane."[117]

That one quarter of pilots surveyed would choose rudder when asked to identify the primary control used when turning an airplane is an indictment of the state of flight instruction.

Elevator

The elevator controls the angle of attack of the main wing. When we talk about AOA in the general sense, we are referring to the AOA of the main wing. Relative to the pilot, elevator inputs are fore and aft, and pitch can be perceived with cues such as:

- Sight – looking outside, the nose and wingtips rotating head-to-feet (or nose-to-toes).
- Sound – changes in wind noise.
- Feel – either normal in the seat of the pants, heavier/compressed into the seat, or lighter/stretched out of the seat; changing control position/pressure.

The consequence of elevator inputs can be measured by an AOA indicator installed in the airplane. Elevator inputs also register as changes in at least a couple of these parameters: airspeed, G-load, pitch attitude, flight path. Secondary effects can include changes in the engine effects (e.g., torque, P-factor, slipstream), gyroscopic precession whose effect appears in yaw, airplane rigging effects, rate of climb, and curiously, angle of bank.[118]

Developing EMT Lesson Plans

I was rummaging through the crammed bookcase at CP Aviation looking for reference materials. Just over an eighth of an inch thick, it was barely noticeable; the manual, however, offered two key insights as I lesson planned the EMT program. The *Pilot Proficiency Training Manual* by Bellanca Aircraft Corporation stated:[1]

> **Regardless of your attitude, the controls do not change their function**…. Think of their response in relation to your body, since your body's position in the airplane remains constant regardless of flight attitude. The elevator…moves the nose of the airplane toward your head or toward your feet…

While aileron and rudder inputs were described simply as "left" and "right," I asked myself, "Why not describe roll and yaw motions relative to the pilot's body as well?" I started delivering the EMT program in the summer of 1987, teaching trainees to see the consequences of their control inputs as follows: relative to you in the cockpit, pitch rotates the airplane head-to-feet, roll rotates it head-to-hip, and yaw slides it ear-to-ear.

Nearly three decades later, the FAA *Airplane Flying Handbook* incorporated similar language. Regardless of the airplane's attitude, the handbook describes pitch, roll, and yaw movements relative to the pilot as head-to-feet, head-to-hip, and shoulder-to-shoulder, respectively.[2]

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[1] Bellanca Aircraft Corporation, *Pilot Proficiency Training Manual*, 1978, 22.

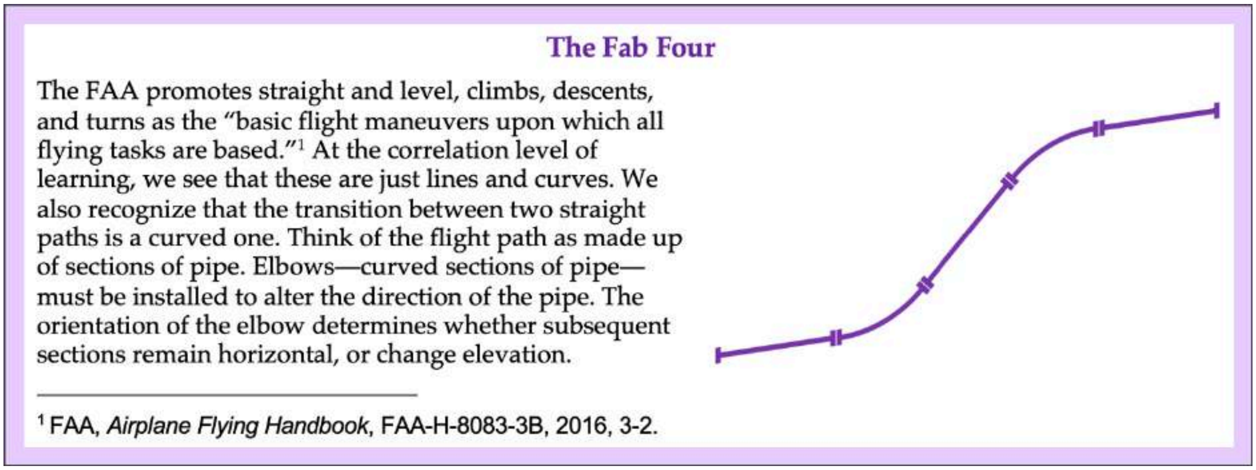
[2] FAA, *Airplane Flying Handbook*, FAA-H-8083-3B, 2016, 3-2 and 3-3.

Power

Power is our here-to-there control. We use power, for instance, to taxi from here to there, fly from here to there, climb (or descend) from here to there. Relative to the pilot, throttle inputs are open and close, and power can be perceived with cues such as:

- Sight – changes in altitude/rate of climb.
- Sound – changes in engine noise.
- Feel – balanced pressure in the seat of the pants, or unbalanced sideways pressure (left or right); acceleration fore or aft (i.e., changing pressure against the back of the seat).

The main consequence of throttle inputs is a change in rate of climb. Secondary effects can include changes in torque, P-factor, slipstream, and airspeed.



The Fab Four

The FAA promotes straight and level, climbs, descents, and turns as the "basic flight maneuvers upon which all flying tasks are based."[1] At the correlation level of learning, we see that these are just lines and curves. We also recognize that the transition between two straight paths is a curved one. Think of the flight path as made up of sections of pipe. Elbows—curved sections of pipe—must be installed to alter the direction of the pipe. The orientation of the elbow determines whether subsequent sections remain horizontal, or change elevation.

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[1] FAA, *Airplane Flying Handbook*, FAA-H-8083-3B, 2016, 3-2.

Summary

Ailerons control the local AOAs out near the wing tips; rudder controls the AOA of the fuselage; and elevator controls the AOA of the main wing; power moves us from one place to another. Each input we make can have one or more (ordinarily detrimental) secondary effects. The secondary effects might combine in some cases and offset in others. Maneuvering is a choreography of control inputs where we must mix the right proportions of roll, yaw, pitch, and power to achieve the desired performance.

Section 5

Turn Performance

Turning Flight

Turn performance *is the ability of an aircraft to change the direction of its motion in flight.*

—Robert L. Shaw

Fighter Combat Tactics and Maneuvering[119]

The designer-oriented approach to flight training asserts, "In order to master the art and science of flight, the pilot must develop a familiarity and working knowledge of the interplay of forces acting on the airplane."[120] While the concept of force might be useful for weight and balance calculations, it is of little practical value when flying. For instance, pilots don't say, "I need to pull some pounds" when they are itching to fly. They say, "I need to pull some Gs." Connecting flying to G-load instead of force has more practical value (refer to Appendix B to see how force is converted to G-load). Consider these advantages:

Intuitiveness—pulling on the elevator control can make you feel heavier (more G); pushing on it, lighter (less G).

Proprioception—not only can we sense the positions and motions of our limbs and joints in space, but this sense also allows us to respond to changes in G-load.

Instrumentation—G-meters can provide useful feedback and are independent of weight and attitude.

Performance—key performance diagrams not only show the link between G-load and parameters such as stall speed, bank angle, and turn rate and radius, but also can tie academic knowledge directly to actions and consequences.

Turning capability comes from excess G, and "Flight at more than 1 g is always associated with a pitch rate."[121] In level cruise flight, for example, increase the G and "the aircraft climbs (turns in the vertical). Increasing the bank with increased G will cause the aircraft to begin turning in the horizontal."[122] Thus, how we manipulate the elevator control determines the G that turns the airplane, whereas how we manipulate ailerons and rudder determines the geometric plane of the turn.[123]

Yaw Management

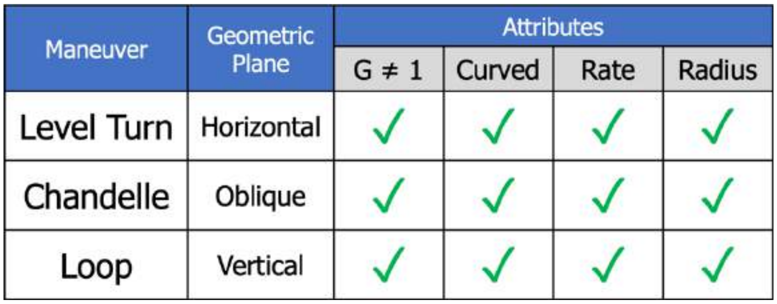
Turning flight is said to be coordinated when secondary yaw effects have been cancelled. This does not necessarily mean the rudder is neutral, only that it has been used properly to offset yaw from other sources. If yaw has not been cancelled, turning flight is said to be uncoordinated. We distinguish between two types of uncoordinated flight. Commonly:

> A **skid** is caused by using too much rudder in the desired direction of turn…. In a skid, turn radius will decrease and turn rate will increase.
>
> A **slip** is caused by insufficient rudder in the desired direction of turn…. In a slip, turn radius will increase and turn rate will decrease.[124]

For example, picture yourself established in a turn during a departure climb. In a right climbing turn, too much right rudder results in skidding; insufficient right rudder results in slipping. In a left climbing turn, on the other hand, insufficient right rudder now results in skidding; too much right rudder results in slipping. As stated before, rudder does not turn the airplane. "This is not a denial of the possibility of any 'flat turn,' or turn with the wings level, but a vigorous condemnation of all flat turns."[125]

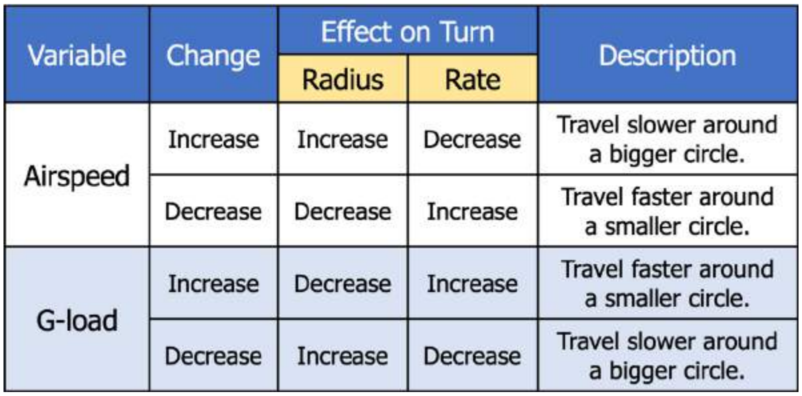
Common Attributes

All turns, regardless of their orientation, share common attributes. We have mentioned two of them repeatedly already: G-load and a curving flight path. The other two traits are turn rate and turn radius. A turning airplane revolves around some point at some rate, and at some distance. Since it is difficult to see invisible points in space, we often use ground references to help us maneuver in circles. Those references typically are found by sighting down one of the wings. Turns around a point, eights-on-pylons, and loops are good examples. The following table checks the boxes of traits shared by perhaps the three most well-known maneuvers in flying: level turn, chandelle, and loop.



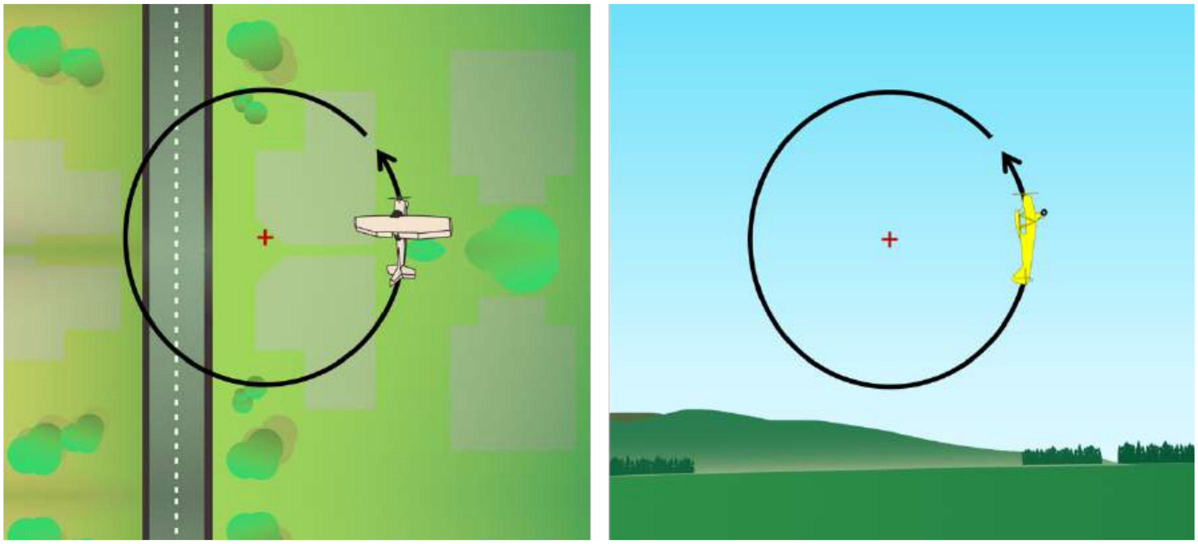
Maneuver	Geometric Plane	Attributes			
		$G \neq 1$	Curved	Rate	Radius
Level Turn	Horizontal	✓	✓	✓	✓
Chandelle	Oblique	✓	✓	✓	✓
Loop	Vertical	✓	✓	✓	✓

Turn rate and turn radius can be expressed in terms of G-load as well. For a fixed angle of bank (or pitch attitude in the vertical plane), the rate and radius vary with true airspeed and cockpit G as shown in the graphic.



Variable	Change	Effect on Turn		Description
		Radius	Rate	
Airspeed	Increase	Increase	Decrease	Travel slower around a bigger circle.
	Decrease	Decrease	Increase	Travel faster around a smaller circle.
G-load	Increase	Decrease	Increase	Travel faster around a smaller circle.
	Decrease	Increase	Decrease	Travel slower around a bigger circle.

Picture now an airplane flying in a circle. What you imagine depends on the point of view you choose. Looking down from above, for example, you could be watching an airplane perform a turn around a point. Looking from the ground toward the horizon, on the other hand, you could be watching an airplane perform a loop at an air show. The flight paths, driven by elevator inputs, are circles nonetheless.



Summary

We can change our direction of flight in a lot of different ways. The same characteristics found in level turns are present in all turns regardless of their orientation. As we have seen, "the level turn is only one method of achieving high-g turning flight…. An aircraft can also generate similar performance by flying maneuvers in which the altitude changes. Examples include the symmetric pull-up and the split-s, both of which are purely in a vertical plane."[126]

No matter the airplane's attitude, or the words used to describe its arcing motion, turn performance can be summed up thus: *Airspeed + G-load = Curved Flight*.[127] With this in mind, let's look at turning in the various geometric planes.

Horizontal Turns

The airplane is banked and back elevator pressure is applied.
—Federal Aviation Administration
Pilot's Handbook of Aeronautical Knowledge[128]

The catchphrase, *bank and yank* distills the turn process into its component parts (though catchy, in reality "yank" is far too strong a word for the pull, even during aerobatics). Here are a few examples showing how level turns have been described over the years:

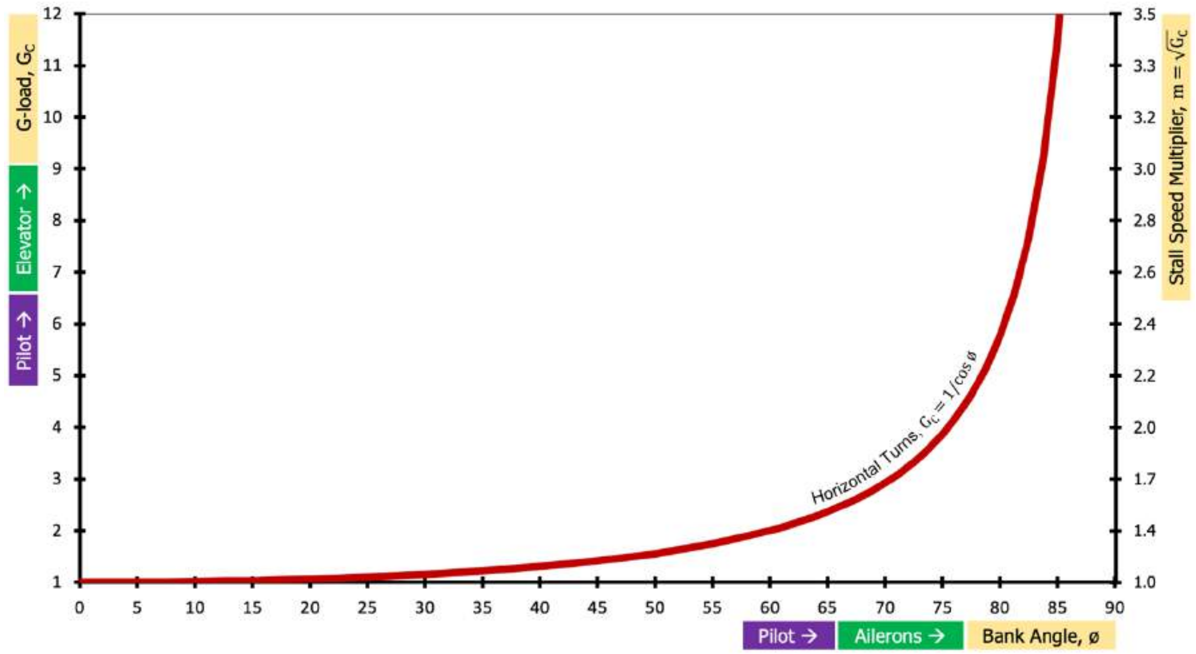
1941: The rules:
  (1) Ailerons: Just enough sidewise pressure on the stick to control the bank as desired.
  (2) Rudder: Neither Skid nor Slip…
  (3) Elevators: Use just enough back pressure on the stick to make the nose follow the horizon.[129]
1944: "An airplane is turned by laying it over on its side and lifting it around through back pressure on the stick."[130]
1985: "It is back pressure applied after the bank is established that makes the plane turn."[131]
1993: During a medium banked turn, "point out that once the proper bank is established the ailerons and rudder are 'neutralized' and the only pressure held is back pressure."[132] (Cueing opportunities like this are taken infrequently during primary training.)
2004: "The ailerons bank the wings" while the elevator "both sets the pitch attitude in the turn and 'pulls' the nose of the airplane around the turn."[133]

These descriptions are alluding to the underappreciated performance diagram, Bank Angle versus G-load (ø-G).

The ø-G Diagram

The standard diagram depicts bank angle along the horizontal axis, G-load along the vertical axis, and a curved line. Occasionally, the diagram will be modified with a second vertical axis and curved line representing the percent increase in stall speed.[134] We will enhance the standard ø-G diagram with detailed information that includes specific pilot actions and their consequences, the curve for horizontal turns, the stall speed multiplier, and applicable formulas.

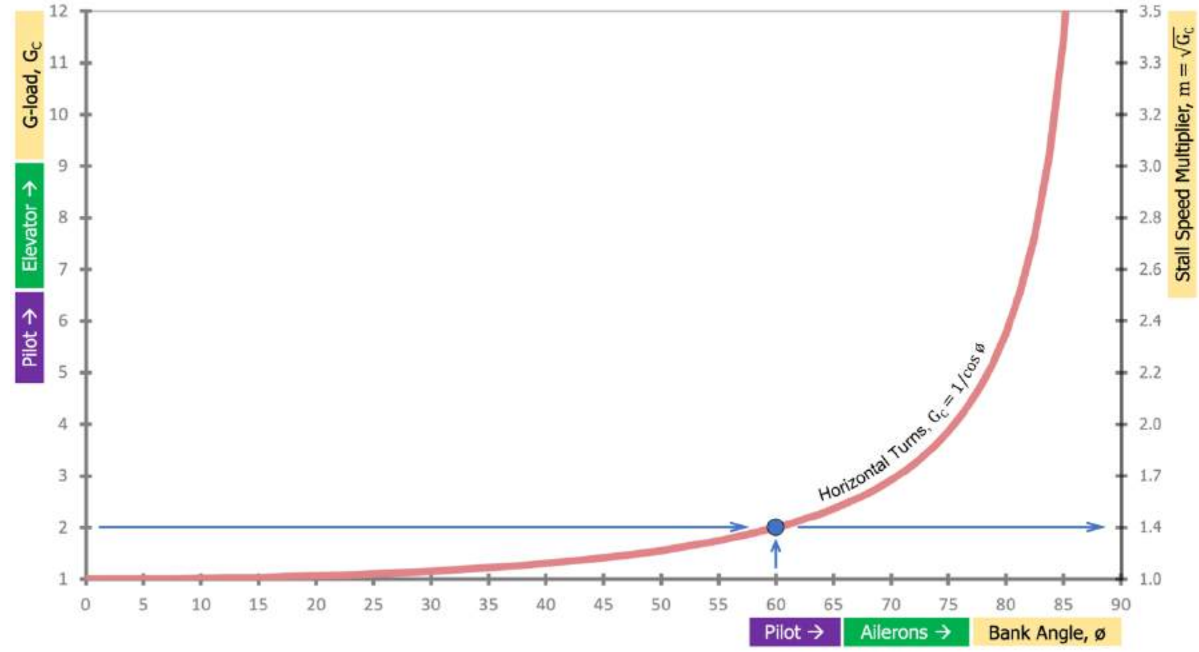
It is the pilot who manipulates the ailerons to set angles of bank. The pilot also manipulates the elevator to generate G-loads. Within energy and structural limitations, the consequence of the pilot finding the right combination of *bank and yank* to end up on the red curve is a turn in the horizontal. All the while, the pilot manipulates the rudder to maintain coordinated flight.



The diagram also reveals that "***for a constant-altitude turn, the required load factor goes up exponentially with bank angle.***"[135] The secret to "keeping a turn strictly level lies therefore entirely in the proportion of back pressure to bank."[136] Put another way, "For any given load factor, there exists one specific bank angle" for a steady, level turn, and vice versa.[137] The requirement is that G_C equal the inverse of the cosine of the bank angle (G_C = 1 / cos ø). This special relationship applies only for the case of steady level turns. Flight training spends a lot of time on the coordination of aileron and rudder inputs; when it comes to turning, however, we should be focusing on "the coordination of back pressure and bank."[138] While aileron and rudder coordination certainly is important, training that targets the proper matching of pitch and roll for level turns will increase awareness of turn dynamics and can reduce the likelihood of botching such maneuvers.

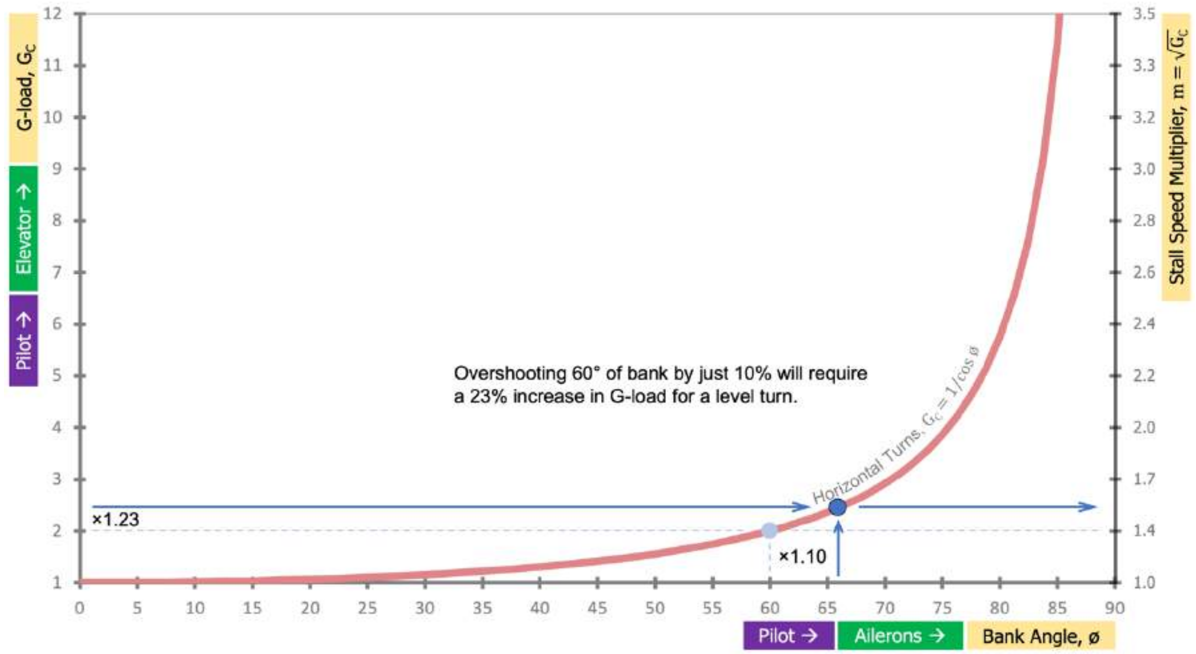
Adding the stall speed multiplier axis to the right side of diagram correlates stall speed with G-load from the outset. The multiplier is simply the square root of G-load (m = √G_C). It is the factor by which stall speed changes compared to the 1G stall speed (Vs at "x" G = m × Vs at 1G). Note, too, that stall speed varies with G-load, not bank angle.

Let's pick a point on the curve and see what we can glean. A steep turn at sixty degrees of bank is a popular choice.



At 60 degrees of bank, "the airplane requires a sustained 2G load by the pilot to remain in level flight."[139] The pilot rolls to 60 degrees of bank; the pilot pulls 2G. Further, the 2G pull must coincide with the 60-degree bank. More or less than 2G at 60 degrees of bank, or more or less than 60 degrees of bank at 2G, means the resulting turn will not be in the horizontal plane (the sustainability of the resulting unlevel turn is another matter). With a 2G pull, the stall speed will be 1.4 times greater than the 1G stall speed, regardless of the angle of bank. This allows us to plan the speed for the maneuver accordingly.

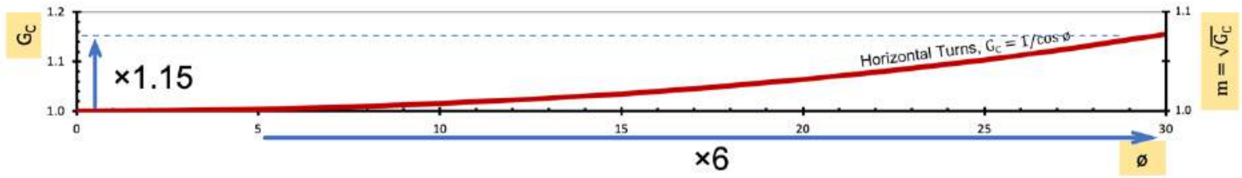
Let's say we inadvertently overbanked to 66 degrees. The required pull now increases to a touch more than 2.4G. So, a ten percent error in managing the angle of bank would necessitate a 23 percent increase in the G-load we would have to pull to remain in level flight. Stall speed would increase from a multiplier of 1.4 to nearly 1.6 times the 1G stall speed. This, coupled with the tendency of pilots to under-G during steep turns anyway, can lead to falling out of the horizontal into a descending spiral.



Overshooting 60° of bank by just 10% will require a 23% increase in G-load for a level turn.

Just Noticeable Difference

The ø-G diagram clearly delineates the roles of ailerons and elevator during level turns. Why, then, do so many pilots not recognize the elevator as the turn control? Everyday turns occur at shallow-to-medium angles of bank, where barely over 1G is required.[140] Let's zoom in to the lower left part of the ø-G diagram.



A six-fold increase in bank angle from five to 30 degrees, for instance, only demands a 15 percent increase in G-load to sustain a horizontal turn. Put another way, the difference in the pull required for a level turn at five degrees of bank and one at 15 degrees is just 0.04G; the difference in the pull required between 15 and 25 degrees is only 0.06G. At issue is a phenomenon called the *just noticeable difference*.

"The just noticeable difference (JND), also known as the difference threshold, is the minimum level of stimulation that a person can detect 50 percent of the time."[141] The average JND for a group of test subjects in a centrifuge-based simulator was at least 0.06G.[142] The experiment was conducted without outside visuals or cockpit instruments; hence, test subjects "could not relate to a visual reference for orientation."[143]

Given the numerous potential distractions when maneuvering a real airplane, the JND in G-load is likely even greater. Thus, pilots typically are unable to sense the subtle differences in G-load during shallow level turns, and possibly some medium turns. What is noticed during shallow turns, however, is a specious similarity between flying and driving: "turning the wheel turns the vehicle." Remember, 63 percent of pilots selected "ailerons" as the primary control used when turning an airplane. Other factors undoubtedly reinforcing this false connection are:

- The nearly imperceptible changes in G required for shallow turns;
- The obvious visual of even mildly banked attitudes;
- The limited understanding of the function of each primary control;
- The cursory exposure to the relationship between bank and G;
- The little-to-no deliberate attention given to G-cueing; and,
- The assumption that turns only occur in the horizontal.

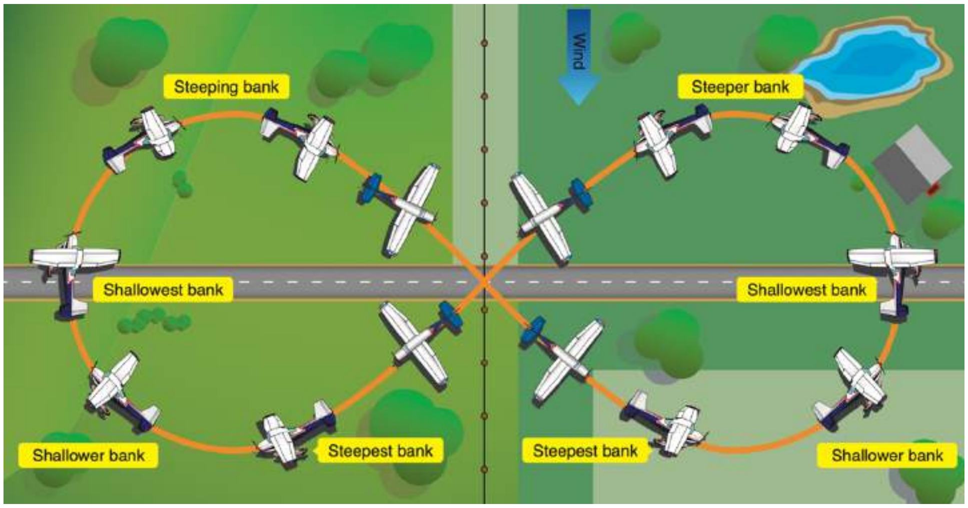
Pushing Learning

Let's take what we know and start reaching beyond rote learning to the understanding, application, and correlation levels. Think deeply about the following maneuvers. Play with a model airplane as you visualize, input by input, what is needed to accomplish them.

Eights Across a Road

Per the FAA, "This maneuver is a variation of eights along a road and involves the same principles and techniques. The primary difference is that at the completion of each loop of the figure eight, the airplane should cross an intersection of a specific ground reference point… The loops should be across the road and the wind should be perpendicular to the loops."[144]

The eight is made up of two joined circles flown in the horizontal plane. The linked circles are flown in opposite directions: one to the left, one to the right. It doesn't matter if the circles are described as "turns" or, as is the case here, "loops"—curving flight is curving flight. We must correct for wind drift to make the figure symmetrical. The diagram provided by the FAA only shows relative bank angles, but we know level turns need the right mix of bank *and* G. Consequently, we can summarize this eight more accurately as a variable bank, variable G maneuver. Think of it as "more bank, more G; less bank, less G." We continuously coordinate roll and pitch throughout—banking to compensate for wind drift, pulling to bend the flight path around each circle.

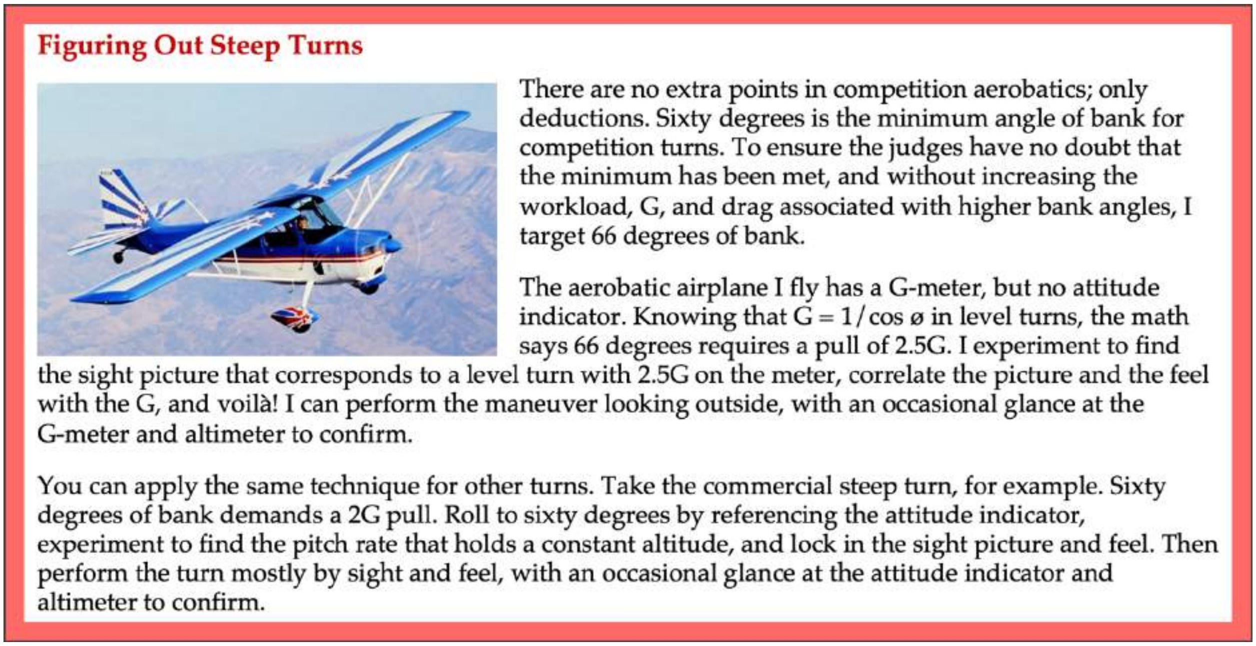


Aerobatic Competition Turn

Per International Aerobatic Club contest rules:

> In aerobatic competition, a turn is divided into three phases: 1) establishing the bank angle using a roll on heading; 2) the turn itself; and 3) a roll back to straight and level flight while maintaining heading…. Immediately after the desired bank angle is established, the heading change must begin. Throughout the turn, the established angle of bank and horizontal flight must be maintained…. Upon reaching the exit heading, the turn rate must stop followed immediately by a roll back to wings level…[145]

Roll and pitch are divorced in the competition turn; they are not blended as in normal turns. And their functions are clear: ailerons to bank and unbank, elevator to turn and to stop the turn. A variation of this maneuver is included in Section 6, "Training Exercises."



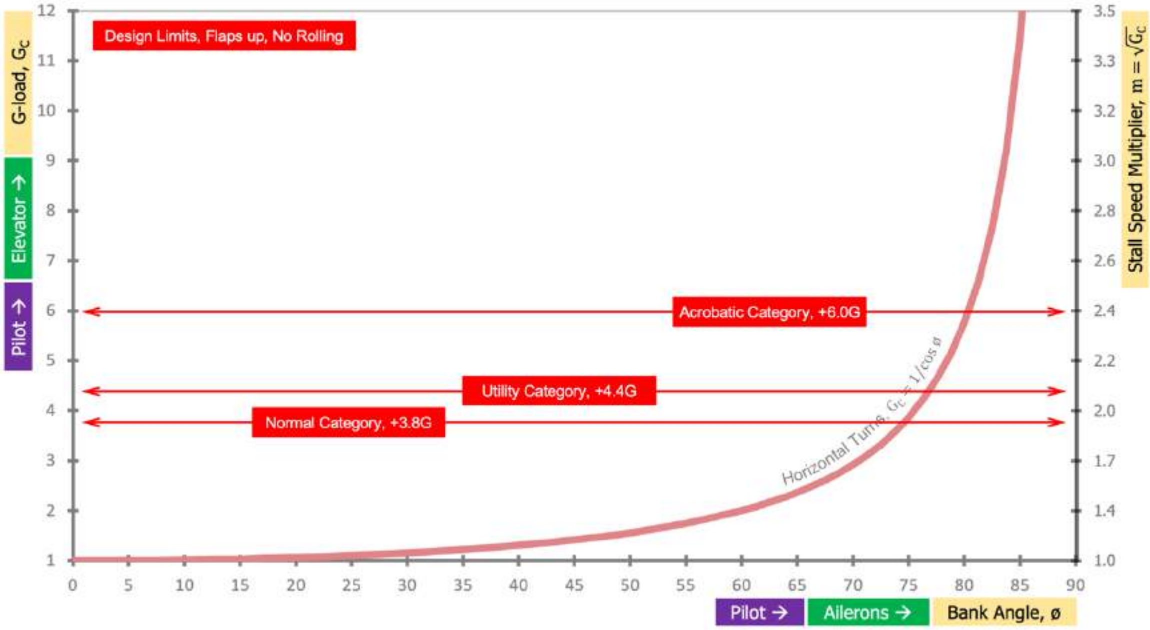
Figuring Out Steep Turns

There are no extra points in competition aerobatics; only deductions. Sixty degrees is the minimum angle of bank for competition turns. To ensure the judges have no doubt that the minimum has been met, and without increasing the workload, G, and drag associated with higher bank angles, I target 66 degrees of bank.

The aerobatic airplane I fly has a G-meter, but no attitude indicator. Knowing that $G = 1/\cos \o$ in level turns, the math says 66 degrees requires a pull of 2.5G. I experiment to find the sight picture that corresponds to a level turn with 2.5G on the meter, correlate the picture and the feel with the G, and voilà! I can perform the maneuver looking outside, with an occasional glance at the G-meter and altimeter to confirm.

You can apply the same technique for other turns. Take the commercial steep turn, for example. Sixty degrees of bank demands a 2G pull. Roll to sixty degrees by referencing the attitude indicator, experiment to find the pitch rate that holds a constant altitude, and lock in the sight picture and feel. Then perform the turn mostly by sight and feel, with an occasional glance at the attitude indicator and altimeter to confirm.

Before we leave horizontal turns, let's enhance our ø-G diagram one step further. We have connected G and bank for level turns. We have also connected G and stall speed. Let's add another layer of relevant operational information by superimposing airplane design limits for the flaps up, no rolling case.



Looking purely in terms of the structural implications, here are the approximate maximum angles of bank that could be available for steady, level turning in each category:

> Normal – 75 degrees of bank at 3.8G, with a stall speed 1.9 times the 1G stall speed.
> Utility – 77 degrees at 4.4G, with a stall speed 2.1 times higher.
> Acrobatic – 80 degrees at 6.0G, with a stall speed 2.4 times higher.

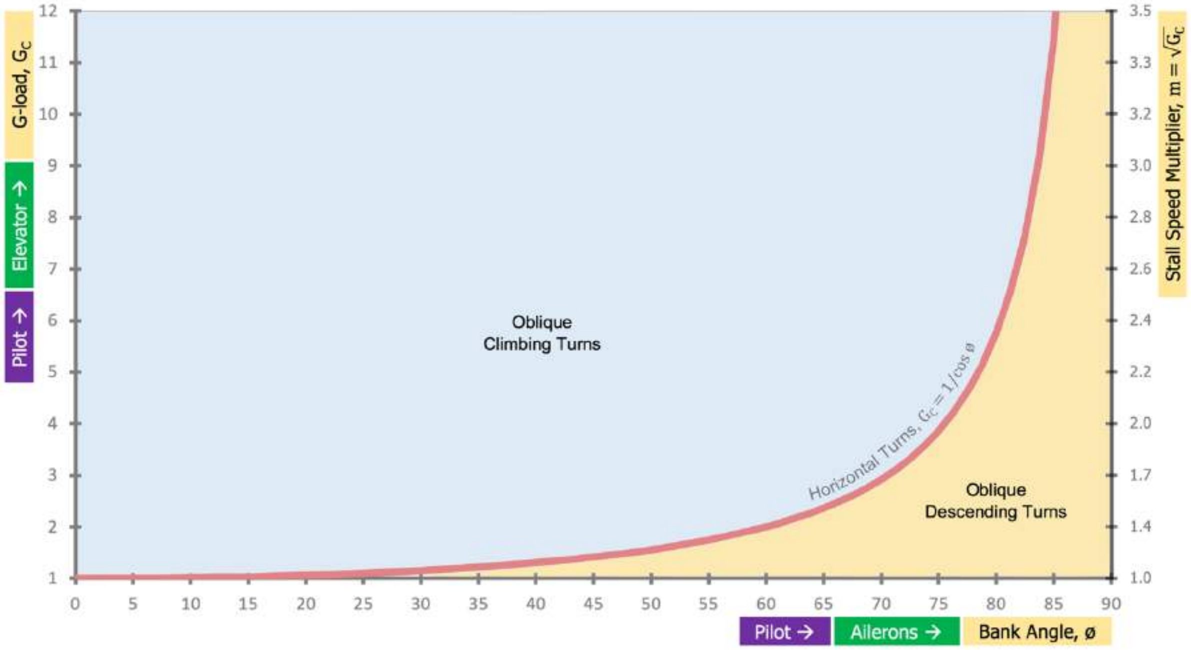
This does not imply that bank angle is limited by structural design, only that we would not be able to perform level turns beyond these angles of bank without exceeding design limits. Moreover, it is possible to exceed design limits at any angle of bank.

Ok, time to move into the oblique planes.

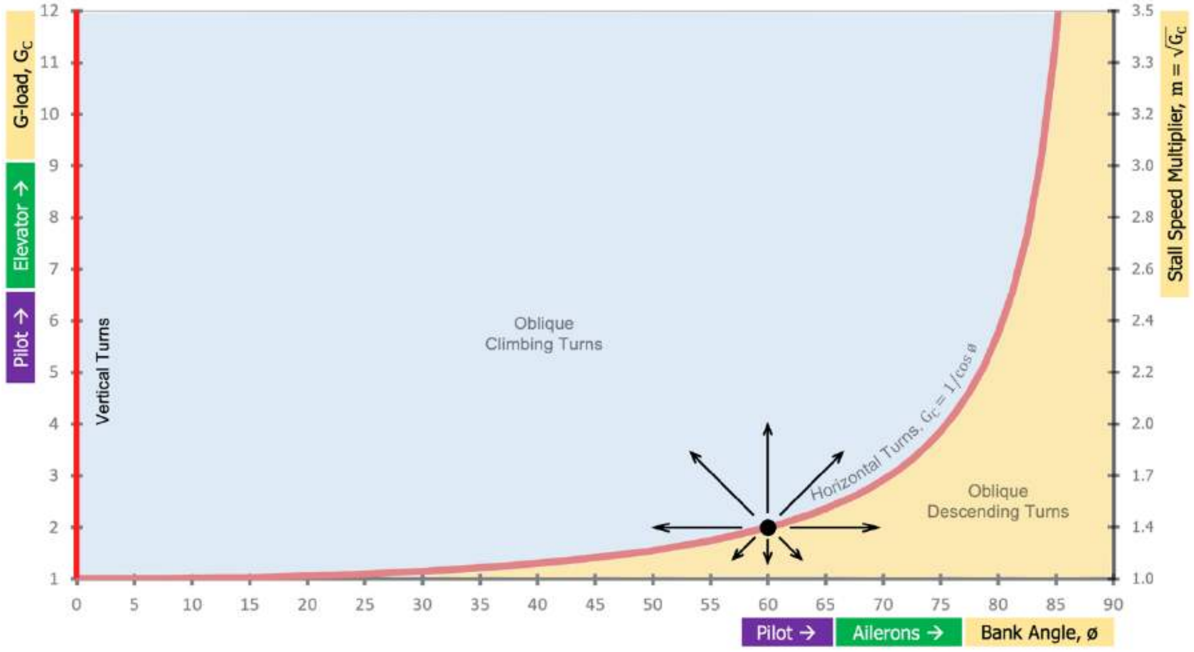
Oblique Turns

> *A slice back is a maximum performance descending turn performed in the oblique.*
> *The lift vector and velocity vector are below the horizon throughout the maneuver.*
>
> —Michael Vaccaro
>
> *RV-Type Training Guide*[146]

The red curve on the ø-G diagram represents horizontal turns per the special relationship, $G_C = 1/\cos ø$. But what if our combination of roll and pitch places us above and to the left of the curve, or below and right of it? These areas of the diagram represent oblique turns—somewhere between the horizontal and vertical planes. Oblique turns are a staple of flying, and changing altitude is a key trait. In the traffic pattern, for example, the climbing turn from the departure leg to the crosswind leg, and the descending turn from base to final are oblique turns.



Imagine an airplane in a stabilized level turn. Bank angle, G-load, airspeed, and altitude are constant. We are on the curve at 60 degrees of bank and 2G. What would be the performance consequence if we tinkered with the amounts of bank and pull? Reducing bank angle, increasing G-load, or a combination of the two would start a climbing turn. In contrast, increasing bank angle, reducing G-load, or a combination would trigger a descending turn. A couple of other permutations are possible as well.



Pushing Learning

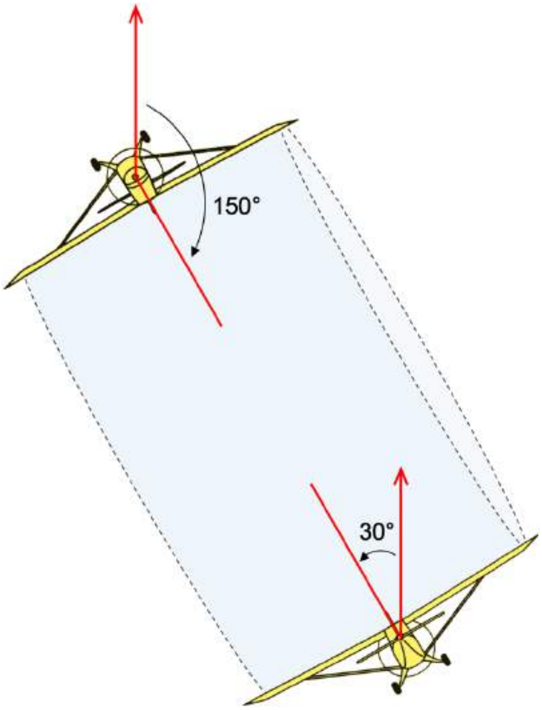
Time again to push our learning. Think deeply about the oblique turns that follow. Play with a model airplane as you visualize, input by input, what is needed to accomplish them.

Chandelle

Per the FAA, "After the appropriate bank is established, a climbing turn should be started by smoothly applying back-elevator pressure…"[147] This is *bank and yank* (again, the actual pull is far smoother and softer than "yank" implies). The chandelle is essentially a climbing turn with 180 degrees of heading change using ground references. The specifics can be broken down into three parts accomplished in coordinated flight:

1. Set the bank angle – on heading, roll to 30 degrees of bank.
2. First 90 degrees of heading change – constant bank, variable pitch. Maintain 30 degrees of bank as you smoothly pull the nose up and over to your 90-degree ground reference.
3. Second 90 degrees of heading change – constant pitch, variable bank. Maintain the nose-up pitch attitude as you slowly roll to wings level by the time you reach the 180-degree ground reference. Properly executed, the airplane ends up in slow flight 180 degrees from the original heading.

Continuous interaction in roll and pitch are required to "maintain bank" and "maintain pitch" in parts two and three. The FAA notes, "Although the degree of bank is fixed during this climbing turn, it…actually will tend to increase if allowed to do so as the maneuver continues."[148] Changes in bank angle are a secondary effect of pitching out of the horizontal plane. We can highlight this unusual effect with a simple demonstration.



Picture an airplane at 30 degrees of bank with plenty of energy. Instead of performing a chandelle, the pilot now pulls straight back on the elevator control into a tilted loop. Looking over the nose, the pilot sees that the angle of bank has steepened to 150 degrees at the top—it has increased by 120 degrees since the start! By the end of the tilted loop, the pilots sees that the bank angle has shallowed to 30 degrees—it has decreased by 120 degrees since the top. Bank angle inherently tends to increase during climbing turns and decrease during descending turns. Thus, holding a constant angle of bank usually requires a slight amount of roll opposite the direction of an oblique climbing turn, but with the direction of an oblique descending turn.

<u>Steep Spiral</u>

Per the FAA, "Once the proper airspeed is attained, the pitch should be lowered and the airplane rolled to the desired bank angle…"[149] This is another example referencing the coordination of pitch and roll actions during turning flight. Just like turns around a point, steep spirals should be corrected for wind drift relative to a ground reference. It is a descending oblique turn of constant radius and speed. Like the eights across a road mentioned in the previous section, this is a variable bank, variable G series of turns: "The pilot should anticipate pitch corrections as the bank angle is varied throughout the maneuver."[150] The flight path resembles the coils of a spring.

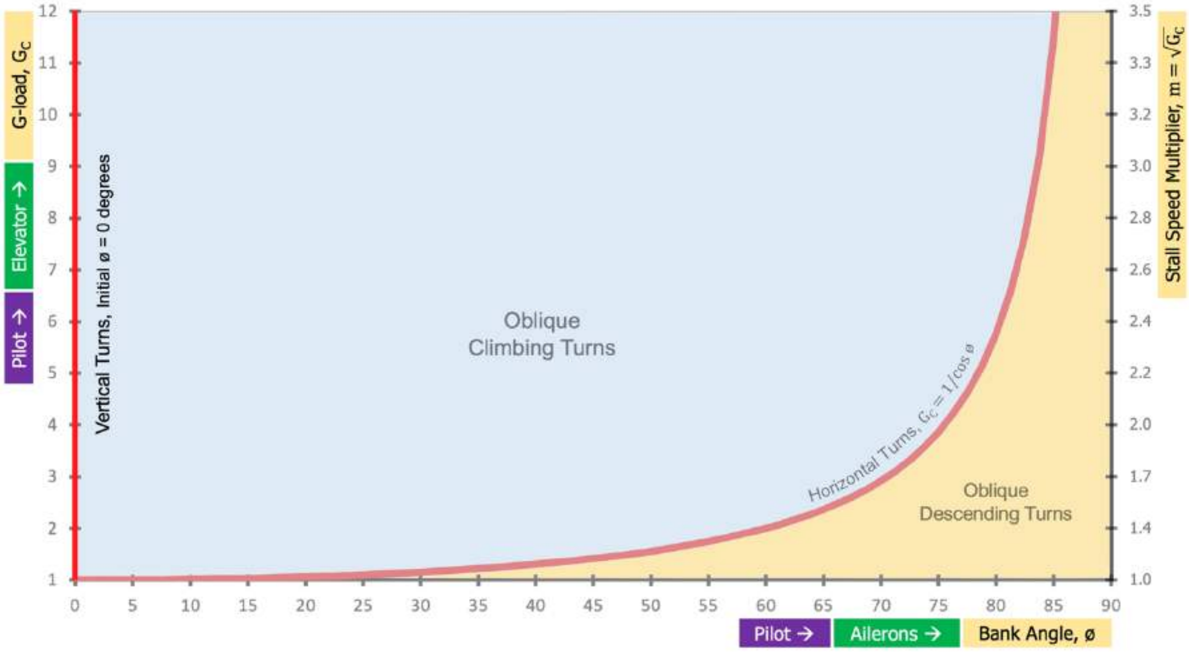
On to the vertical plane next.

Vertical Turns

> *While referred to as a* loop, *this maneuver is nothing more than a turn in a vertical dimension.*
>
> —Mark Danielson
>
> *Flight Training magazine*[151]

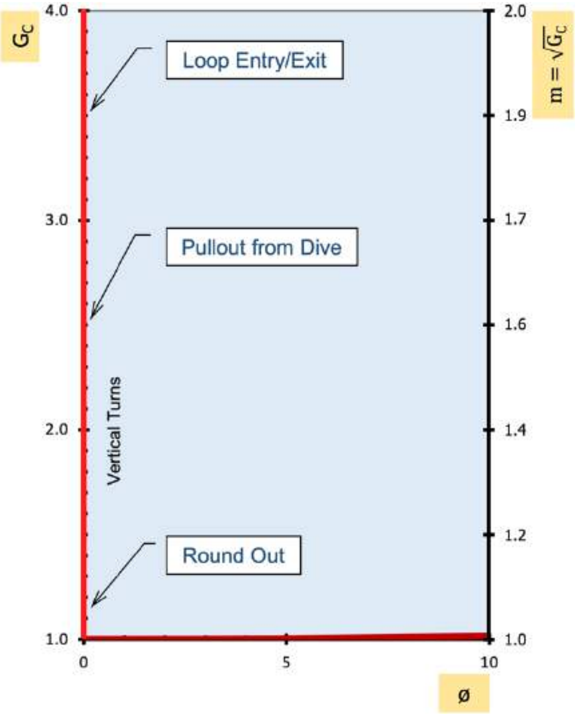
Pilots understand the connection between climbing, descending, and level turns; however, some seem reluctant to see looping maneuvers as close relatives of these other turns even though they share the same DNA. The full loop and the 360-degree aerobatic turn, for instance, begin and end where they started. The difference is that the airplane experiences variable G, bank, speed, and altitude during the loop, but constant G, bank, speed, and altitude during the level turn. The oblique chandelle and the vertical Immelmann are 180-degree climbing turnarounds that end in slow flight. The difference: roll and pitch are blended during the chandelle to maintain upright flight, whereas they are separate actions in the Immelmann—pitch into a half loop, then half roll upright at the top.

"Everything that is true…of the curving of the flight path sideways, is true also of the pull-out from the dive, the flare-out from the glide, the pull-up into a loop—in short, of any curving of the flight path upward."[152] Suppose all you know is that an airplane is experiencing 2G. Absent additional information, the only conclusion you can reach is that the airplane is in turning flight somewhere in space. However, "Unlike a purely horizontal turn, your turn performance in a purely vertical turn is affected differently depending upon where you are in the turn."[153] It should come as no surprise that we can depict vertical turns on the ø-G diagram, which begin with an initial bank angle of zero degrees.



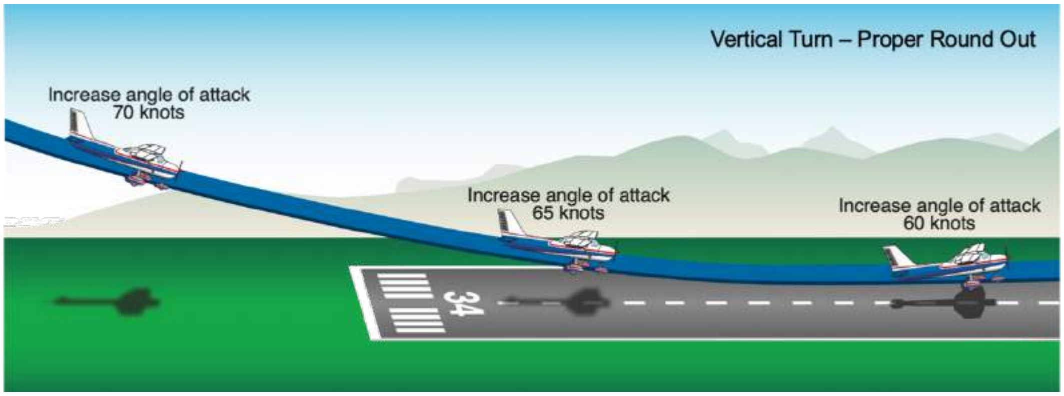
Pushing Learning

Time to advance our learning once again. As before, think deeply about the maneuvers discussed below. Play with a model airplane as you visualize what is needed to accomplish them. To facilitate the discussion, let’s zoom in to the lower left part of the ø-G diagram.



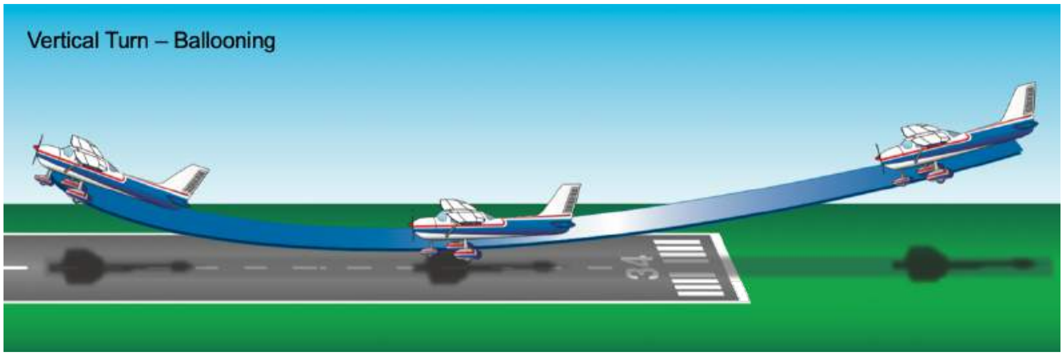
Round Out

Per the FAA, “The round out is a slow, smooth transition from a normal approach attitude to a landing attitude, gradually rounding out the flightpath to one that is parallel with, and within a very few inches above, the runway…. back-elevator pressure is gradually applied to slowly increase the pitch attitude and angle of attack (AOA).”[154] Properly rounding out for landing is about vertical turn management, i.e., managing pitch.[155]



Failure to round out at all can result in a hard or bounced landing. More common, however, is the “tendency to increase the pitch attitude and AOA too rapidly. This not only stops the descent, but actually starts the airplane climbing.”[156] Factors leading to problems with the round out include ground shyness, tension on the controls, looking in the wrong place, and misjudging the height above the ground.

Recall the discussion about just noticeable difference in the article on horizontal turns. The inability to sense the subtle changes in G needed during the round out further compounds the degree of difficulty. Consequently, the round out can become a balloon or porpoise if the pilot over-controls pitch.[157]



Pullout from a Dive

"The pull-up you may find yourself in during a nose-low unusual-attitude recovery is a vertical turn."[158] We find ourselves in nose-low attitudes after recovering from spins and spiral dives, as well as many stalls. The final step in the recovery process in these cases involves a vertical turn to straight and level flight. Not with any old pull on the elevator, but a deliberate one that takes into account the relationship between the G-load we will impose and the aerodynamic and structural limits of the airplane.

Imagine performing a routine, wings-level, power off stall. We've reattached the airflow, and the nose is below the horizon. Literally yanking back on the elevator triggers a secondary stall even though the nose is still below the horizon. Aerodynamically, the airplane cannot tolerate the G we tried to pull. Regarding G-load and stalls, lower speeds require lower Gs; higher speeds can tolerate higher Gs up to the design limit.

Now imagine we have just recovered from a spin or spiral dive. The nose attitude is well below the horizon. Speed is increasing and is above the level flight trim speed. In this scenario, we might have to apply forward elevator pressure to prevent the trim from imposing unnecessary G-loads. The target should be two to 2.5G en route to level flight, i.e., "make it feel like a steep turn." Then hold the airplane in level flight and retrim as needed.

G-cueing

A study on the effects of G-cueing found "that pilots without previous G-exposure tend to overestimate G-levels based on their seat-of-the-pants, resulting in performance below the target G-level."[1] In other words, our natural tendency is to under-G our pulls (assuming we are not adrenalized and elevator trim effects are not a factor). Anecdotally, I have seen this regularly during steep turns, but especially when trainees are learning to do loops. The target on loop entry and exit is 3.5G. It's not uncommon for trainees to under-G their first several pulls by one-half to as much as one full G. This is more pronounced when pulling into the sky on entry; less so when pointing toward the ground during the exit.

The good news about specific G-cueing training: with minimal training, performance improves rapidly up to the target. The bad news: like all of our flying skills, it is perishable. The study found that "a retest after six months showed that this improvement did not endure."[2] Not only is G-cueing important for routine flight operations, but it also is critical during recoveries from upsets. Exercises focused on developing the kinesthetic cues associated with G-load (e.g., seat-of-the-pants feel, control pressure feel) can help. Level steep turns at 60 degrees of bank and 2G, and descending spirals are two examples. Also be aware that compared to centrifuge-based simulation and structured in-airplane training, "flight simulators without G-cueing capabilities can elicit unrepresentative upset recovery behavior, with unrealistic small altitude-loss and overstressing of the simulated aircraft."[3]

---

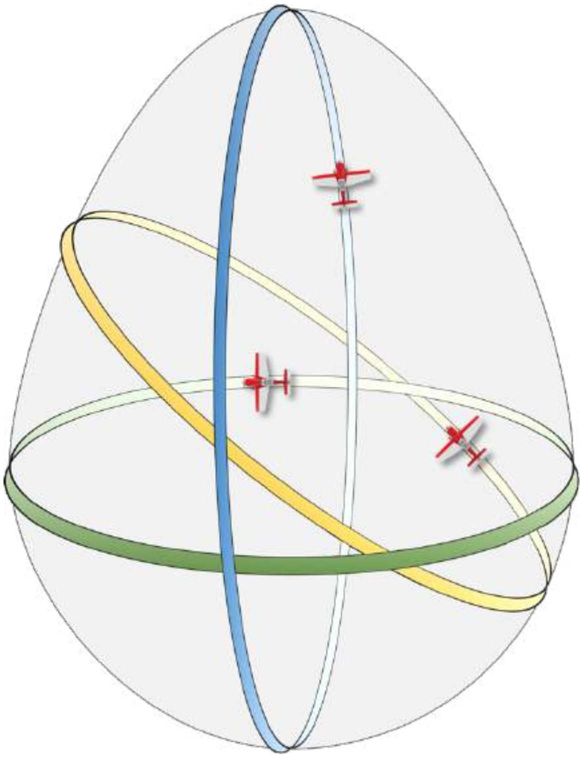
[1] W.D. Ledegang, E.L. Groen, and M. Wentink, *Effect of G-cueing on Pilot Performance in Centrifuge-Based Simulation of Unusual Attitude Recovery*, AIAA 2011-6701, AIAA Modeling and Simulation Technologies Conference, August 8–11, 2011, 1.

[2] Ibid.

[3] Ibid, 11.

Now that we've touched on turning flight in various geometric planes, we can conceptualize it as a three-dimensional, egg-shaped sphere called the "Energy Maneuverability Egg."[159]

Let's talk about accelerated stalls for a moment.



Accelerated Stalls

> *Under pressure the best of us sometimes make bad turns.*
>
> —Wolfgang Langewiesche
>
> *Stick and Rudder*[160]

Why does the wing stall?

Because the wing has exceeded its critical angle of attack.

How does the wing stall?

By pulling aft on the elevator control, the pilot causes AOA to increase enough to exceed the critical value.

When does the wing stall?

Whenever the pilot causes airspeed and G-load to converge on the airplane's stall curve. Stall curves are part of V-G diagrams and represent the aerodynamic limit of the wing.[161]

What is an accelerated stall?

A stall that usually occurs "at more than 1 G, similar to what is experienced in a steep turn or a pull up."[162]

What is the relationship between stall speed and G-load?

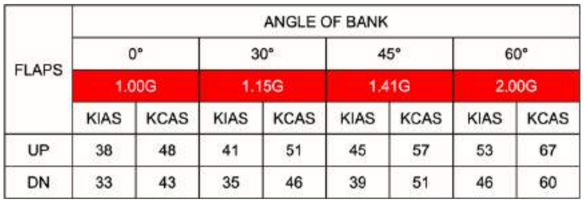
All airplanes "experience an increase in stall speed with an increase in load factor…"[163] Turns, whether horizontal, oblique, or vertical, "load the wings and will increase the stall speed…"[164] The stall speed increases by the stall speed multiplier shown on our ø-G diagram ($m = \sqrt{G_C}$). For example, if the 1G stall speed is Vs, the 2G stall speed multiplier is 1.4 (i.e., $\sqrt{2}$); hence, the accelerated stall speed is 1.4Vs.

Why does stall speed vary with bank angle?

It really doesn't. Although flight manuals might include stall speeds at different bank angles for a given weight and center of gravity, realize:

1. The information is presented in the context of common level turns performed by pilots;
2. Bank angle is a proxy for G-load; and
3. Stall speed increases because the G-load required for the assumed-level turn increases as angle of bank increases.

Here are power-off stall speeds for a generic airplane. To expand the concept beyond bank angle, the corresponding G-load has been included.



FLAPS	ANGLE OF BANK							
	0°		30°		45°		60°	
	1.00G		1.15G		1.41G		2.00G	
	KIAS	KCAS	KIAS	KCAS	KIAS	KCAS	KIAS	KCAS
UP	38	48	41	51	45	57	53	67
DN	33	43	35	46	39	51	46	60

> This airplane will stall if we were to attempt a flaps-up turn at 57 KCAS by rolling to 45 degrees of bank and pulling 1.4G. But this airplane will stall any time 57 KIAS and 1.4G coincide—not just in a turn at 45 degrees of bank. For instance, it will stall if we were to pull 1.4G at 57 KCAS during the round out for landing.

What do certification standards say about performing accelerated stalls during flight testing?

> "Establish and maintain a coordinated turn in a 30 degree bank. Reduce speed by steadily and progressively tightening the turn with the elevator until the airplane is stalled…"[165]

Witness to Fatal LOC-I

The Berkut abruptly rolled underneath and around to upright, and vanished below the trees. The debris field in the riverbed was 210 feet long. The air show pilot—an American Airlines pilot and former Navy test pilot—was fatally injured.

It was a perfect SoCal summer afternoon. Sitting on the flatbed trailer at show center, I had just called the maneuver to the announcer and was watching the airplane come around. The pilot was nearly finished with his routine, the steeply banked Berkut turning hard and fast practically at eye level. In an instant the nose twitched, the airplane departed controlled flight, and the pilot died.

I had seen the nose of the Berkut bobbing in and out of stall during a couple of prior maneuvers as well, and had wondered, "Why so many Gs?" I had been teaching the EMT program at CP Aviation for eight years by then; presented safety programs across the country; written articles for aviation magazines. But this was the first time I had witnessed a fatal loss of control.

Let's review what we've learned about turning flight.

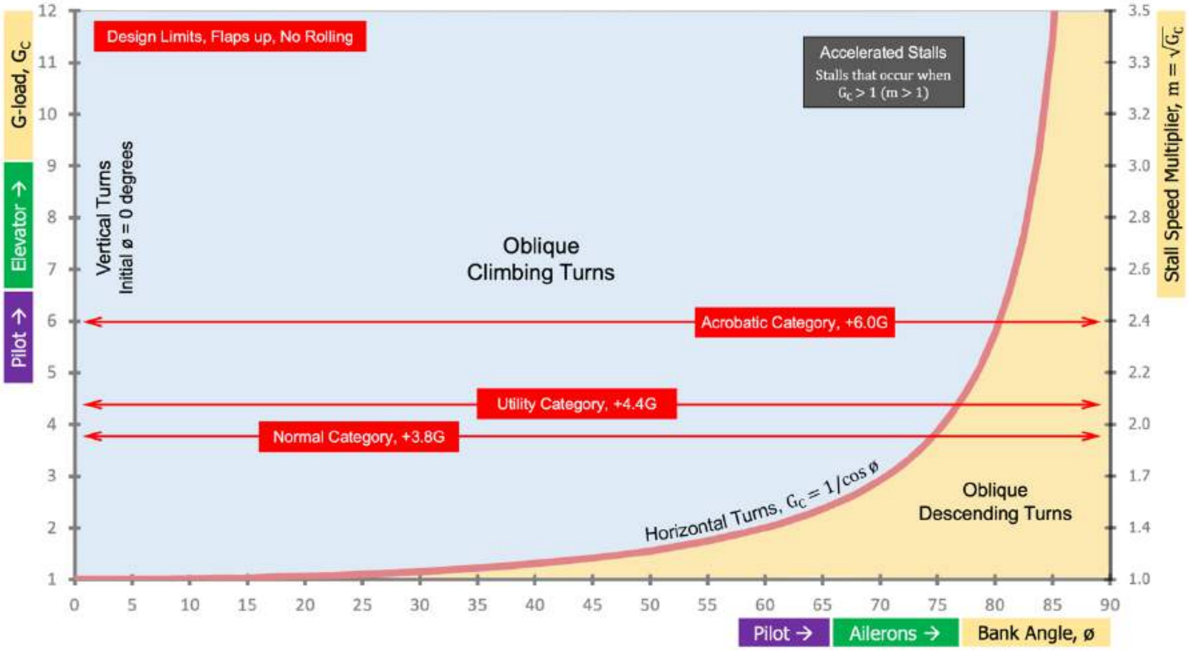
Review

The elevator is used to turn the plane.

—Bill Thomas
Fly for Fun[166]

Accordingly, “rudder and aileron have nothing to do with creating lift or turning an airplane. They are used to change the plane of motion.”[167] We now see that level turns and pullups are similar in that “the aircraft experiences an increased load factor and a steady pitch rate.”[168] And we recognize that a loop “is basically a 360° ‘turn’ in a vertical plane…”[169] The pilot controls pitch, which determines the G-load that bends the flight path into a circle. In the horizontal, each angle of bank must be matched with exactly the right G-load, and vice versa. In the oblique and vertical planes, on the other hand, turning G is largely at the pilot’s discretion.

Properly used as a training aid, a lot of operationally useful information can be extracted from the ø-G diagram.



Any competent instructor should be able to introduce trainees to the basic form of the diagram. The instructor also should be able to:

- Build on the basic diagram as training progresses by adding new layers of pertinent information;
- Connect the consequences of elevator inputs to G-loads, stall speeds, design limits, and turning flight;
- Emphasize the coordination of pitch and roll needed for the special case of level turns;

- Present turning flight in terms of horizontal, oblique, and vertical planes;
- Make the academic discussion relevant by tying it to the performance of flight maneuvers; and,
- Include G-cueing as part of turn practice.

A deeper dive into turn performance in three dimensions, coupled with deliberate G-cueing, can minimize false connections between aileron inputs and turning flight. Ditto false connections between rudder inputs and turns. Improving awareness of all the things directly affected by our elevator inputs is the first step toward avoiding a loss of control. Points to reflect on regarding elevator inputs:

Angle of Attack: Are we stalled or unstalled; what is our margin to the wing's critical angle of attack?
Airspeed: Are we fast or slow; are we operating at an appropriate speed?
G-load: Is our flight path straight or curving; what is our margin to aerodynamic and structural limits?

Pilots who maneuver in air combat and air show environments learn to envision turning flight in the horizontal, oblique, and vertical planes; we should develop that ability as well.[170]

Thought Experiments

Challenge your learning by puzzling out the two problems on the next page. Solutions are provided in Appendix A.

Traffic Pattern

Imagine doing one hop around a left-hand rectangular traffic pattern. The pattern begins at the start of the takeoff roll and ends at the end of the landing roll. Assume the airplane flies at constant speed from liftoff to touchdown; it reaches pattern altitude the moment it commences the turn to downwind; and it begins descending the moment it exits the turn to base. Ignore the vertical bits where the airplane transitions to pattern altitude, and to the descent for landing.

Fill in the table segment by segment all the way around the pattern. Drawing a sketch first might help.

Segment		Flight Path[1]	Accelerated[2]
#	Name		

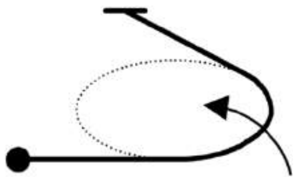
[1] Flight Path Key: SL = Straight Level; SC = Straight Climb; SD = Straight Descent; TH = Turn Horizontal; TO = Turn Oblique; TV = Turn Vertical.

[2] Accelerated Key: Yes; No

Rolling Turn

Per International Aerobatic Club contest rules, "The rolling turn is a figure that combines a turn of a prescribed amount with a roll or rolls integrated throughout the turn."[171]

In terms of difficulty, rolling turns are to competition aerobatics what eights-on-pylons are to commercial flight training. Altitude, roll rate, and pitch rate must remain constant throughout the maneuver, with the banking and turning starting and ending at the same time.



Using a model airplane (or your hand), discover how the following rolling turn is done: complete a full roll to the left while simultaneously changing the heading 90 degrees to the left. Move the model airplane only in response to your simulated roll and pitch inputs.

Section 6

The Pilot-in-Control

Excellence in Airmanship

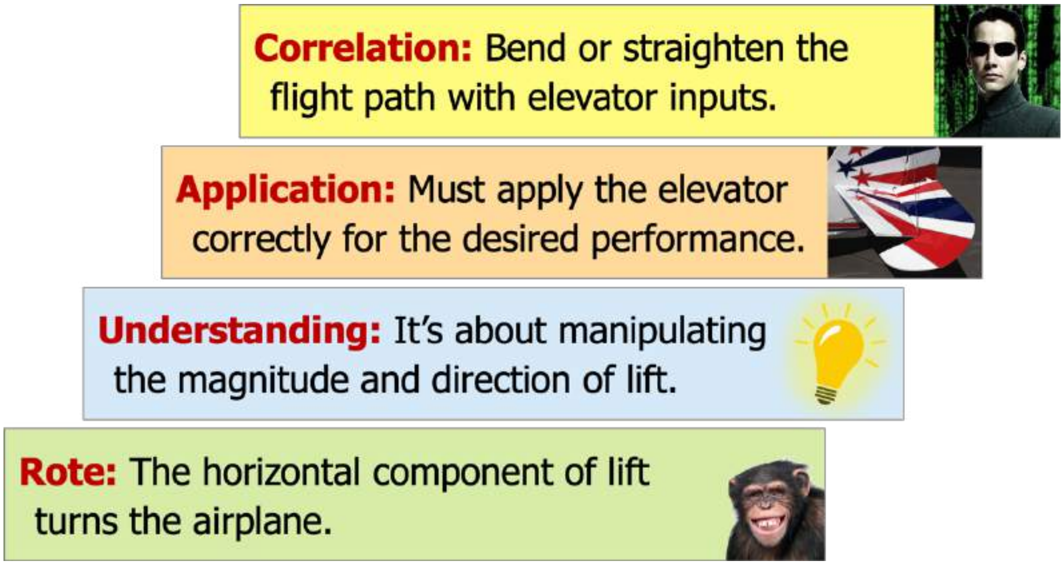
> *To teach more about flying than how to steer an airplane; to take time with the students;*
> *to offer them the priceless thing that is the ability to fly.*
>
> —Richard Bach
>
> *School for Perfection*[172]

We often think of the Wright brothers' achievement in terms of powered flight. But the Wrights realized that control was the central problem they had to solve for airplanes to be viable. Controllable flight is their true legacy, and their vision forever changed the world. Teaching pilots the proper way to control their airplanes must be our top priority; otherwise, *Aviate–Navigate–Communicate* becomes moot. Everything hinges on the pilot's ability to fly the airplane.

Achieving Correlation

Training for control must be frequent, focused, and deliberate. It must go beyond the rote level. And as it relates to loss of control, training must include awareness, prevention, and recovery strategies. Continual awareness of the consequences of pulling aft on the elevator control, for instance, can mitigate the risk of a loss of control. Preventing loss of control by aborting botched maneuvers early is simple: "Get rid of the back pressure, and you get rid of the turning; but you also get rid of all those other disadvantages [such as nearness to the stall and G-load]."[173]

If we represent the rote level of learning as monkey-see, monkey-do, think of the correlation level of learning as the character Neo in *The Matrix* movies. Over time, not only is Neo able to see the underlying computer code that generates the virtual world in which he operates, but he also learns how to manipulate the code to change outcomes in that world. Thus, the graphic below shows one way of thinking about the levels of learning vis-à-vis *Learn to Turn*.



Correlation: Bend or straighten the flight path with elevator inputs.

Application: Must apply the elevator correctly for the desired performance.

Understanding: It's about manipulating the magnitude and direction of lift.

Rote: The horizontal component of lift turns the airplane.

Learning to fly is like learning to code. Lines and circles are to pilots what ones and zeroes are to coders. The primary flight controls are our keyboard; roll, yaw, pitch, and power, our coding language. Provided our inputs are correct, the airplane performs the way we intend it to. Competently piloting an airplane is rooted in five primary actions:

1. Controlling roll with ailerons;
2. Controlling yaw with rudder;
3. Controlling the wing's angle of attack with elevator;
4. Controlling altitude with power; and,
5. Maintaining a cerebral sense of our place in the operating environment:
    a. What do I want to accomplish, what's the big picture?
    b. What are the angles, rates, and speeds of the airplane right now, how well is my flight path conforming to what I want right now, and how well will it be conforming in the immediate future?[174]

To reduce the likelihood of a loss of control, as well as to have a richer, more rewarding flying experience, know the proper function and use of the primary controls; interpret aircraft motions relative to you sitting in the airplane; systematically develop and heed the relevant cues; visualize turning flight in three dimensions; and be a lifelong student—learn, do, fly, repeat.

Challenging the Status Quo

The concepts that have been presented here are not new. What is new, however, is the appeal to make them staples of flight training. Barriers to change—driven by fixed mindsets, institutional inertia, and entrenched methods—are inevitable. But change will be required to make a real dent in the persistent problem of fatal loss of control. "Getting students done" and "getting students trained right" are not mutually exclusive objectives.

Learn to Turn is not intended to be another new training module heaped on top of the staggering amount of information pilots already need to learn. Rather, it should be integrated into existing training by replacing the incomplete and inaccurate information that has been imposed on general aviation pilots for generations. Be forewarned: it might require some unlearning and shifting from so-called conventional wisdom. The conscientious aviation educator, of course, will find ways to make this happen.

Recognize, too, that "Pilot conduct impacts the entire aviation community, including its safety culture."[175] This is our community, and it's up to us to take charge of our training. Question, probe, strive for excellence. Whether a trainee or an educator, weave *Learn to Turn* concepts and techniques into your flying. If you are a trainee, assume nothing. Push your instructor to push you to higher levels of knowledge and experience. If you are an instructor, it is your responsibility to act in the best interests of your trainees. This includes growing as an aviation educator through continuous professional development.

The next two articles wrap up *Learn to Turn* by offering insights into how to train, as well as exercises to improve control awareness and discipline. Once you've completed the program, don't forget to take the survey at https://www.CommunityAviation.com/Learn-to-Turn.

Stay aware. Stay proficient. And be safe!

The Training Mindset

> *Frightened human beings will only do what they're trained to do….*
> *You don't rise to the occasion. You sink to the level of your training.*
>
> —Lt. Col. Dave Grossman
>
> *Marine Corps News*[176]

Training can be as much art as science, but the science certainly can guide us. Performing well under stress requires focus, confidence, and commitment. All of us can have a bad day flying; even so, "it is unacceptable not to train, not to try to get better, not to use the resources available to make sure that what caused that bad day never happens to you again."[177]

Lifelong Learning

Asked why he continues to practice at 91 years old, renowned cellist Pablo Casals replied, "Because I am making progress."[1]

---

[1] Norman Doidge, M.D., *The Brain That Changes Itself* (New York: the Penguin Group, 2007), 257.

Training time is finite. Consequently, we need to realize that "'all training has an opportunity cost.'"[178] Hence, training should focus on building the basics "to a useable level, increase the toughness and realness of conditions, pressure test it and see what holds up and what doesn't, then work back through the basics again building them to a higher level."[179] In the scheme of *Aviate-Navigate-Communicate*, for example, poorly executed turns and fumbled radio calls on the same flight do not deserve equal remedial training time. Improve the stick and rudder skills first, then increase the difficulty by reintroducing communication skills.

Deep Practice

The single most important factor in learning a physical skill is practice; however, "the practice cannot be random," and we "must be focused, the practice must have planned content, and this content must be organized."[180] As we practice a particular motor skill, we "eventually learn to eliminate extraneous movement and to effectively coordinate muscles to act as a single functional unit."[181]

As we improve, executing the complex motor patterns involved in flying becomes smoother, quicker, more effortless.[182] Equally as important, we start to relax. The more highly developed our stick and rudder skills, the more mental energy we can devote to other critical tasks such as situational awareness, risk management, and aeronautical decision making. In fact, overlearning the basics "helps to reduce the likelihood that performance will be interfered with by anxiety and/or emotional arousal."[183]

Deep Practice in the Blue Box

Patented in 1929, the Link trainer "permitted pilots to practice more deeply, to stop, struggle, make errors, and learn from them. During a few hours in a Link trainer, a pilot could 'take off' and 'land' a dozen times on instruments. He could dive, stall, and recover, spending hours inhabiting the sweet spot at the edge of his capabilities in ways he could never risk in an actual plane."[1]

General aviation pilots today can practice deeply on a home PC, or in a sophisticated motion simulator at a flight training center.

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[1] Daniel Coyle, *The Talent Code* (Bantam Books, 2009), 24; photo source Bzuk/Wikimedia.

Regarding the structure of practice sessions, quality always beats quantity. "Quality requires motivation, whereas quantity reflects rote."[184] Follow these three rules to practice deeply:[185]

1. Chunk it – Absorb the whole, but then break it down into its component parts; slow the process down as well.
2. Repeat it – Repetition is essential. Further, perishable skills need to be practiced regularly; fix any problems by returning to the basics.
3. Feel it – Learn to know when it feels right and when it feels wrong.

If properly managing roll, yaw, pitch, power, straight lines, and curves are the basic skills, advanced skills are "nothing more than the ability to perform the basics under extremely tough conditions."[186] Without eventually practicing our stick and rudder skills "in the same context, conditions and environment in which [they'll] be used, you have no proof that you'll perform the skill[s] well…"[187] Once the basics have been developed, the experience needs to be ratcheted up by adding "realistic decision making to the instructional setting" in the "fluid, reactive, spontaneous, stressful environment" of flight.[188] This is called scenario-based training. More to the point, this is loss of control survival training.

Mental Practice

Research has shown that "mental practice combined with physical training is better than physical training alone."[189] In fact, "a training schedule of 25 percent physical training and 75 percent mental training is more effective than 100 percent physical training."[190] Mental practice has also been found to be "more effective in early stages of learning as it facilitates symbolic organisation."[191]

Also referred to as imagery, mental training uses "all the senses to develop an experience in one's mind."[192] More than simple visualization, it is "'tactile, auditory, emotional and muscular.'"[193] Think of it as your own virtual reality, and "the closer one can come to simulating an actual situation, the greater his chances are of developing the skill to perform in that situation."[194]

Practicing Smarter

The training regimens of two top competition aerobatic pilots reinforces the role mental training played in their success. They are two of fewer than 50 pilots who have earned the IAC *All Ten* aerobatic achievement award. Vicki Cruse was a former US Unlimited Aerobatic Champion and four-time member of the US Unlimited Aerobatic Team. Dan Matejczyk had a dominant, two-year run in the Advanced category in California, including back-to-back contests where he broke the 90 percent barrier.[1]

Dividing practice time

Vicki: *I'd say I spend almost twice as much time working out all of the mental things than I do actually flying. I always know what I am going to fly before I go out to practice.*

Dan: *I estimate at least 80 percent mental work, 20 percent actual flying. This mental work does not include informal thinking while driving or time preparing the plane or doing maintenance.*

Taking notes

Vicki: *I now have two small notebooks that I take with me to training camps and contests. In them I have notes from every coaching session with everything from entry speeds, figure techniques, and things learned from specific sequences. When old habits creep back in, I can go look to see how I fixed them previously.*

Dan: *I have notes on virtually every practice flight I ever flew. I think the main purpose and value are to close the loop between the physical flying and the perception and understanding of flying.*

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[1] Rich Stowell, "Design Limits – G's break airplanes, skill wins contests," *Sport Aerobatics*, May 2009, 9–10.

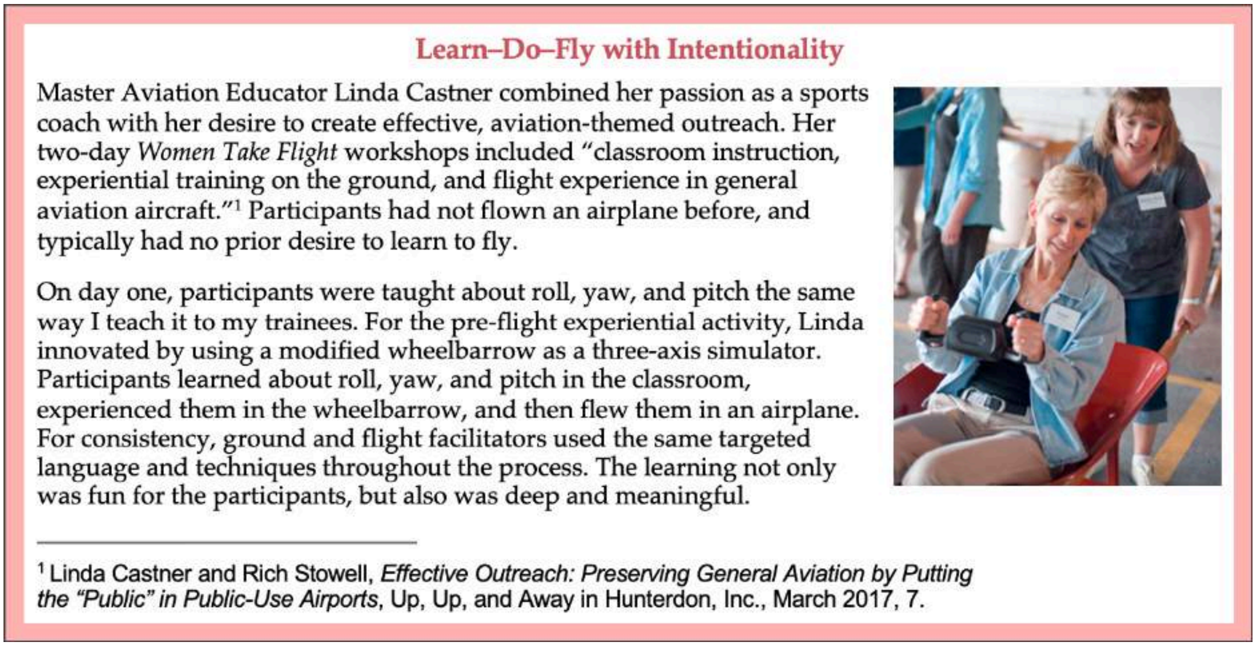
Stable, safe environments where we can train deeply include mental practice at home and procedural practice with a flight simulator. Dynamic, more stressful training environments include scenario-based flight simulation and actual flying.

The Instructor-as-Coach

"The essence of coaching lies in helping others and unlocking their potential."[195] Steps that not only create confidence in a skill, but also motivate trainees to learn and practice include:[196]

- Creating the need to learn the skill;
- Convincing trainees they can learn the skill quickly;
- Creating an environment where trainees observe the skill working; and,
- Providing trainees with firsthand experience that demonstrates a high potential for success.

Remember, "It is easy to design a…scenario that makes every trainee look like an idiot, but all that proves is that the trainers are jerks."[197] Professional aviation educators act in the best interests of their trainees. The exceptional ones are distinguished by "their ability to motivate and train students to perform a specific skill in a specific environment."[198]



Learn–Do–Fly with Intentionality

Master Aviation Educator Linda Castner combined her passion as a sports coach with her desire to create effective, aviation-themed outreach. Her two-day *Women Take Flight* workshops included "classroom instruction, experiential training on the ground, and flight experience in general aviation aircraft."[1] Participants had not flown an airplane before, and typically had no prior desire to learn to fly.

On day one, participants were taught about roll, yaw, and pitch the same way I teach it to my trainees. For the pre-flight experiential activity, Linda innovated by using a modified wheelbarrow as a three-axis simulator. Participants learned about roll, yaw, and pitch in the classroom, experienced them in the wheelbarrow, and then flew them in an airplane. For consistency, ground and flight facilitators used the same targeted language and techniques throughout the process. The learning not only was fun for the participants, but also was deep and meaningful.

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[1] Linda Castner and Rich Stowell, *Effective Outreach: Preserving General Aviation by Putting the "Public" in Public-Use Airports*, Up, Up, and Away in Hunterdon, Inc., March 2017, 7.

Incorporate the above concepts into your training sessions, starting with the exercises described next.

Training Exercises

TO BUILD HARD SKILLS, WORK LIKE A CAREFUL CARPENTER

—Dan Coyle

The Little Book of Talent[199]

For more than 30 years, these and other exercises have been taught to pilots from around the world. This includes nearly a quarter century providing recurrent training to government pilots representing fish and wildlife and national park services, as well as law enforcement agencies. The typical flight profile of these government pilots involves maneuvering around objects on the ground while low and slow, and often in challenging environments. Armed with a training mindset, try the exercises yourself. Think in terms of the *Learn-Do-Fly* framework:

LEARN: Absorb the lesson plans. Relate them to the rest of the *Learn to Turn* content.

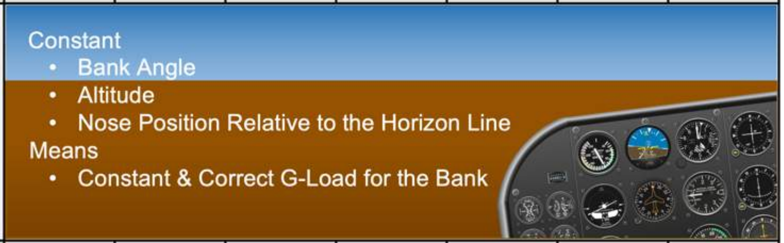
DO: Go through the motions before jumping in the airplane to fly. Sit in a chair or the airplane and imagine performing the maneuver(s): what does it feel like? sound like? Recall even the smell of the cockpit. If you have access to a flight simulation training device, use it. Keep in mind, though, that most of these devices lack seat-of-the-pants G-cueing capability—you will need to fly the airplane to develop that cue.

FLY: Pay attention to the details. Pick up on as many cues as possible as you fly the maneuver(s). Chunk it, repeat it, feel it. Connect the physical experience with the academics and the simulation. When done flying, take a few moments to debrief yourself. Pinpoint areas that need additional work and determine how you will resolve any questions or problems at the *Learn* and *Do* stages. Then repeat the process.

Practice the exercises at a safe altitude. Before starting any of them, be sure to clear the area, configure the airplane properly, and select your ground references. Spend the bulk of the time looking outside as you manipulate the controls to achieve the different pitch and bank attitudes. Glance only occasionally at the relevant instruments. Unless otherwise noted, power will be set for level, slow–to-medium cruise flight; it will not have to be changed during the maneuvers. Naturally, adjust the power as necessary should you have to abort or recover from a botched maneuver.

If any of the concepts are unclear, or you are uncomfortable at all with any aspect described below, consult with a competent flight instructor. Above all, relax and enjoy this deeper exploration of actions, consequences, and turning flight. For the level turn exercises, use the table below to facilitate building the connections between bank angle, G-load, and stall speed.

LEVEL TURNS: Connecting Bank Angle, G-load, Stall Speed per the ø-G Diagram

ø	0°	10°	20°	30°	40°	50°	60°
Sight Picture	Constant • Bank Angle • Altitude • Nose Position Relative to the Horizon Line Means • Constant & Correct G-Load for the Bank						
G_C $(= 1/\cos ø)$	1.00	1.02	1.06	1.15	1.30	1.56	2.00
m $(= \sqrt{G_C})$	1.00	1.01	1.03	1.07	1.14	1.25	1.41
Stall Speed (= mVs, CAS)	1.00Vs	1.01Vs	1.03Vs	1.07Vs	1.14Vs	1.25Vs	1.41Vs
Awareness	Likely unable to feel differences in G-load due to JND				Tendency may be to under-G as bank angle approaches 60°		

Don’t forget to take the survey at https://www.CommunityAviation.com/Learn-to-Turn

Control Awareness Exercises

1. Dutch Rolls[200]

Essence: Rock the wings left and right while on a constant heading

Plane: Horizontal

Objectives:

- Experience banking without turning
- Learn to coordinate aileron and rudder inputs
- Develop visual and kinesthetic cues for roll and yaw
  - See head-to-hip movements relative to the pilot
  - Feel not only the differences between aileron and rudder control pressures, but also their displacements (i.e., how far you are moving them)
  - See and feel the difference between coordinated and uncoordinated flight

Applicability:

- Banking into and out of turns in horizontal and oblique planes
- Recovering from spirals and other overbanked attitudes
- Correcting deviations in bank caused by turbulent air

Actions and consequences: The pilot applies the ailerons; the airplane rolls. The airplane also yaws, requiring corrective action with the rudder.

Takeaway: Coordinated banking requires linking our aileron and rudder inputs together—same time, same direction.

Performance:

- Establish level, trimmed flight in a slow cruise configuration
- Select a prominent reference over the nose for heading
- Smoothly and continuously rock the wings left and right, while remaining on heading
  - Apply aileron and rudder inputs simultaneously—left aileron and left rudder together, and so on
  - Apply more aileron than rudder
- Looking in one direction at a time, rock the wings a few times:
  - Over the nose—minimize deviations of the nose relative to the heading reference
  - Straight out at the left wingtip—move the wingtip in a line head-to-hip
  - Straight out at the right wingtip—move the wingtip in a line head-to-hip
- Strive for symmetry in the angles of bank, e.g., 30 degrees of bank left and right

Tips:

- Don't overdo this exercise, as it can trigger motion sickness
- Ignore the slip-skid ball, as it lags during this dynamic rolling exercise
- Look outside; see and feel your way to coordinated rolling
- Start with a comfortable roll rate and angle of bank each way; increase the rate and angle as you improve
- Move the stick/yoke farther in roll than you think
- Be aware of the tendency to lean the body upright when banking; relax and sit with the airplane
- Don't fight one leg against the other on the rudder pedals; relax, make fluid movements as if you are strolling
- Focus more on the aileron input than the rudder input

(continued)

Common errors:

- Not deflecting the ailerons enough side-to-side
- Getting out of synch with the rudder inputs, or applying too much or too little rudder with the ailerons
    - The consequence of mismanaging the rudder will be seen as the nose or wingtip slewing back and forth in a *U* shape, and possibly felt as side-to-side imbalance in the seat-of-the-pants.
- Lacking symmetry in bank angle when looking at the wingtip—roll the wingtip the same distance above and below the horizon line
- Inadvertently pitching as you roll
- Being tense on the controls—relax, allow the inputs to happen

Variations:

- Take your feet off the rudder pedals
    - Smoothly bank left and right once or twice
    - See the adverse yaw as an ear-to-ear movement
    - Feel (and in some airplanes, hear) the adverse yaw
- Perform Dutch rolls in slow flight, or while climbing out to the practice area
    - This introduces engine effects into the mix, requiring slightly different amounts of left and right rudder as the engine effects add to, or subtract from adverse yaw
- Vary the roll rates and bank angles

* *

2. Undulating Turns

Essence: Play with the elevator to see its effect on turning flight while holding a constant bank angle

Plane: Horizontal with minor excursions into the oblique

Objectives:

- Experience the effect elevator has on flight path
- Find the right match between pitch and bank vis-à-vis the ø-G curve for horizontal turns
- Develop visual and kinesthetic cues for pitch
    - See head-to-feet movements relative to the pilot
    - Feel not only the subtle changes in control pressures, but also their displacements
    - Possibly feel changes in G-load (depends on Just Noticeable Difference)

Applicability: Performing normal level turns

Actions and consequences: The pilot varies elevator inputs while turning; the plane of the turn changes. Secondary effects may be evident, requiring corrective aileron and rudder actions.

Takeaway: Use the elevator to manage the shape, type, and quality of turning flight

Performance:

- Establish level, trimmed flight in a slow cruise configuration
- Trim the airplane slightly nose down, but remain in level flight
- Establish a level, coordinated turn of medium bank
- Note the amount of aft elevator needed for the nose of the airplane to track parallel to the horizon line
- Smoothly apply more aft elevator than necessary, allowing the nose to rise
    - Note the initiation of an oblique climbing turn
- Adjust elevator pressure to reacquire the level turn
- Release some aft elevator, allowing the nose to drop
    - Note the initiation of an oblique descending turn
- Smoothly apply enough aft elevator pressure to reacquire the level turn
- Repeat the climbing and descending turn elements
- Return to wings level

Tips:

- Look outside; see and feel your way to coordinated turning
- Glance at the slip/skid ball only if necessary
- Think "Dutch roll" when banking
- Be aware of the tendency to lean the body away from the turn; relax and sit with the airplane

Common errors:

- Improperly coordinating aileron and rudder while banking
- Improperly coordinating aileron and elevator while turning
- Allowing bank angle to vary during the turns
- Being tense on the controls—relax, allow the inputs to happen

* *

3. Sine Waves

Essence: Pull into a climb, then push into a descent

Plane: Vertical

Objectives:

- Experience turns in the vertical plane
- Learn to coordinate elevator and rudder inputs
- Manage G-load, speed, and proximity to the stall
- Develop visual and kinesthetic cues for pitch
    - See head-to-feet movements relative to the pilot
    - Feel not only the differences in control pressures, but also their displacements
    - Feel changes in G-load
    - See and feel the difference between coordinated and uncoordinated flight

Applicability:

- Performing normal climbs and descents
- Reacting to an engine failure during climbout
- Recovering from stalls
- Rounding out for landing

Actions and consequences: The pilot makes pitch inputs in wings-level flight; the flight path curves in the vertical plane. The airplane also yaws, requiring corrective action with the rudder.

Takeaway: Use the elevator to bend or straighten your flight path

Performance:

- Establish level, trimmed flight in a medium-slow cruise configuration (reference: Vcruise)
- Select a prominent reference over the nose for heading
- Holding the heading, smoothly but positively pull into a climb attitude
    - Stop 20–30 degrees nose up
    - Acknowledge the increase in G as you bend the flight path upward, and the unloading of G as you set and hold the climb attitude
    - Adjust rudder as needed to cancel yaw as speed decays
    - Adjust elevator as needed to hold the climbing line as speed decays
- At (Vx plus 5) on the airspeed indicator, smoothly push over to a descent attitude on heading
    - Maintain positive G during the push over; you should not come out of your seat
    - Stop 20–30 degrees nose down (mirror image of the climb attitude)
    - Acknowledge the reduction in G as you bend the flight path downward, and the G as you set and hold the descent attitude
    - Adjust rudder as needed to cancel yaw as speed increases
    - Adjust elevator as needed to hold the descending line as speed increases
- At (Vcruise minus 5), smoothly yet positively pull to level flight on heading

Tips:

- Look outside; see and feel your way to coordinated climbs and descents
- Glance at the slip/skid ball only if necessary
- When transitioning from the curves to the straight lines, set the lines with a small but positive movement of the elevator control
- Make the pullup and pullout feel like a steep turn; maintain positive G during the push over.

(continued)

Common Errors:

- Pulling too softly, but pushing too hard
- Not holding the climbing and descending attitudes until the appropriate time
- Inadvertently rolling or yawing as you pitch
- Not canceling the yaw, especially through the apex of the wave
- Being tense on the controls—relax, allow the inputs to happen

Variations:

- Perform the wave looking only at one wingtip
- Take your feet off the rudder pedals and perform the wave
  - See the yaw effects as an ear-to-ear movement
  - Feel (and in some airplanes, hear) the yaw as it changes
- Simulate an engine failure during a Vx climb
  - At altitude, establish a wings-level climb at Vx
  - Reduce power to idle
  - Push over and set the best glide attitude, while keeping the wings level and yaw cancelled
- Simulate the round out for landing
  - In the normal landing configuration at altitude, establish a power off descent at the normal final approach speed
  - Fifty feet above a target altitude, begin the round out
  - Have the round out completed and the landing attitude set by the time the target altitude is reached
  - Bleed off speed at the target altitude until stall warning (like an approach-to-landing stall)
- Combine the simulated engine failure during a Vx climb and the simulated round out for landing into one exercise
- Try an (almost) Square Wave
  - Pull and set a climbing attitude, hold it for a two count
  - Push and set a level, slow flight attitude, hold it for a two count
  - Push and set a descending attitude, hold it for a two count
  - Pull and set level flight

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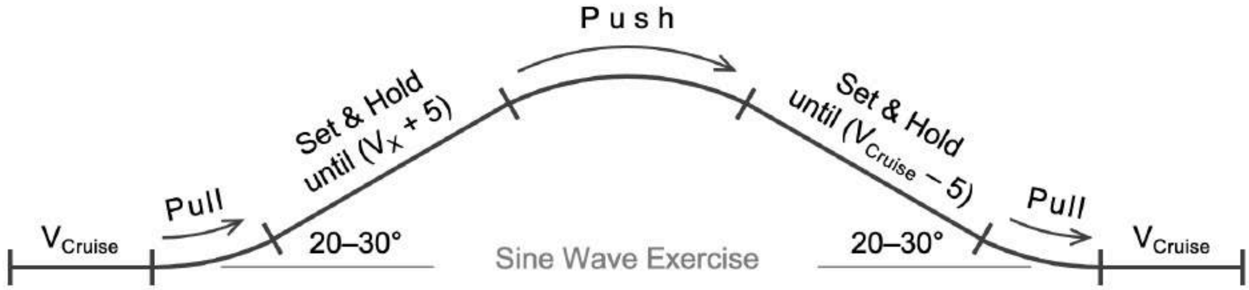

Sine Wave Exercise

Control Discipline Exercise

Acro-Style Turns

Essence: Separate the banking piece from the turning piece during level turns

Plane: Horizontal

Objectives:

- Experience the effect elevator has on flight path
- Learn to separate roll inputs from pitch inputs
- Find the proper match between G and bank vis-à-vis the ø-G curve for horizontal turns
- Improve precision and discipline with your control movements
- Develop visual and kinesthetic cues
  - See head-to-hip motion while rolling; head-to-feet motion while pitching
  - Feel not only the changes in control pressures, but also their displacements
  - Feel changes in G-load and correlate the required G with the sight picture for level turning at the given bank angle

Applicability:

- Performing normal level turns
- Learning steep turns
- Recovering from spirals and other overbanked attitudes

Actions and consequences: The pilot applies coordinated aileron and rudder inputs; the airplane Dutch rolls. The pilot neutralizes aileron and rudder inputs; the airplane instantly stops rolling. The pilot pulls the elevator control aft; the airplane turns. Provided the G-load equals the inverse of the cosine of the bank angle, the turn occurs in the horizontal plane. The pilot unloads the added G; the airplane instantly stops turning.

Takeaways:

- Ailerons roll the airplane
- Elevator bends or straightens the flight path
- Rudder maintains coordinated flight

Performance:

- Establish level, trimmed flight in a medium-slow cruise configuration
- Select two prominent references for headings: one over the nose; one at 90 degrees by sighting beyond the left or right wingtip
- Apply inputs in this sequence:
  Roll – Stop – Turn – Stop – Roll – Stop
  - Roll: Dutch roll to establish a bank angle of 45 degrees
  - Stop: instantaneously neutralize aileron and rudder inputs
  - Turn: pull straight back on the elevator control enough for the nose of the airplane to track parallel to the horizon line
  - Stop: at the 90-degree reference point, instantaneously release all the aft elevator to stop the turn (i.e., unload the turning G)
  - Roll: Dutch roll to wings level
  - Stop: instantaneously neutralize aileron and rudder inputs for wings level flight
- Procedural note: each “Stop” is a positive movement of the control(s) to neutral before making the next input(s) in the sequence

(continued)

Tips:

- Look outside; see and feel your way through the banking and the turning
- Think "Dutch roll" when banking
- Use faster roll rates than normal when banking
- Glance at the slip/skid ball only if necessary
- Ignore the directional gyro and compass
- Be aware of the tendency to lean the body away from the turn; relax and sit with the airplane

Common errors:

- Blending bank and turn inputs instead of separating them
- Starting the turn before stopping the roll completely
- Forgetting to neutralize the rudder when neutralizing the ailerons; thus, skidding the turn
- Forgetting to stop pulling before rolling to wings level at the end of the maneuver
- Improperly coordinating aileron and rudder while banking
- Mismanaging the amount of pull needed for the level turn
- Allowing bank angle to vary during the turn
- Being tense on the controls—relax, allow the inputs to happen

Variations:

- Link two Acro-Style Turns together to return to the original heading
- Steepen the bank angle (up to 60 degrees)
- Increase the heading change to 180 degrees

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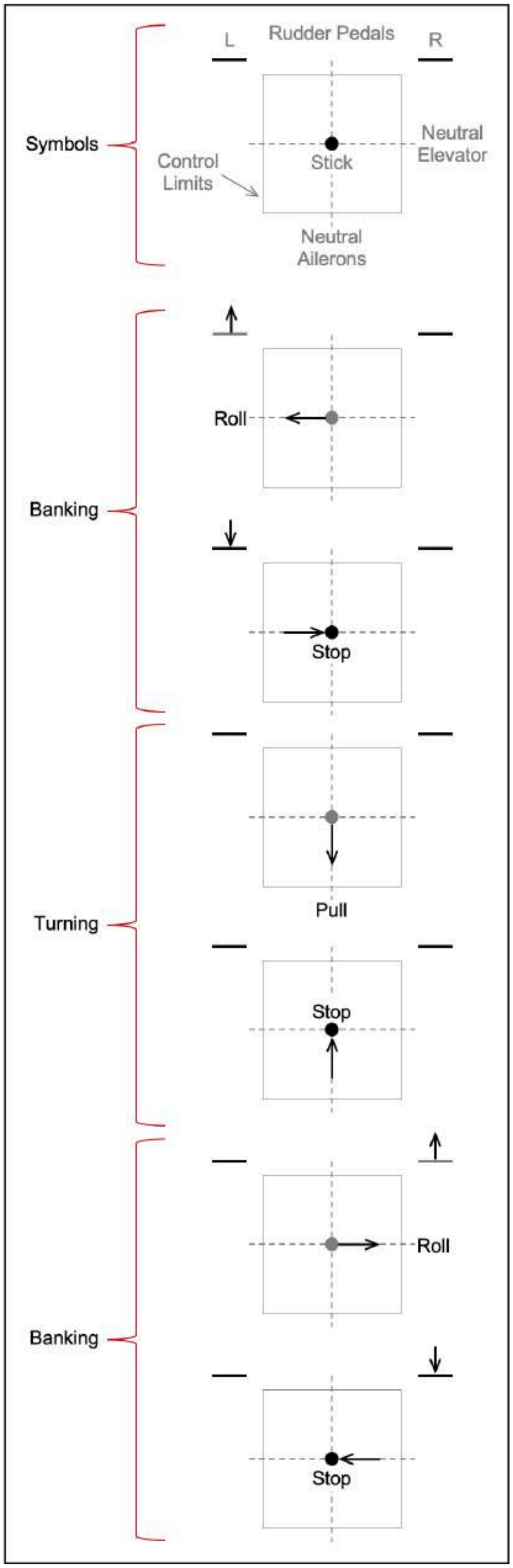


Section 7

Back Matter

Appendix A

Solutions to Thought Experiments

Section 2 – Bottom Line Up Front

Knife Edge Flight

With the airplane banked at 90 degrees, what must the pilot do to continue along an essentially straight flight path? To preserve the flight path, the pilot must apply enough forward elevator to reach the zero-lift angle of attack of the wing. Otherwise, the airplane will have a net horizontal component of lift that will force it to turn. The rudder is not part of this aspect of knife-edge flight. Instead, the rudder controls the angle of attack of the fuselage; it is used to generate lift on the fuselage to offset the weight of the airplane.

Section 5 – Review

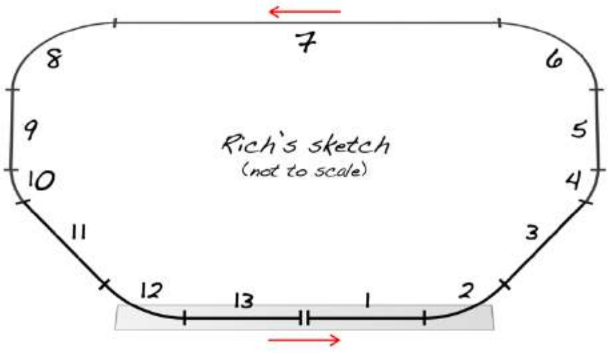
This is how I worked through the Traffic Pattern and Rolling Turn challenges. Your process may have been different, yet the solutions should have elements in common.

Traffic Pattern

Segment		Flight Path[1]	Accelerated[2]
#	Name		
1	Takeoff Roll	SL	Yes
2	Rotation	TV	Yes
3	Departure Leg	SC	No
4	X-wind Turn	TO	Yes
5	X-wind Leg	SC	No
6	Downwind Turn	TH	Yes
7	Downwind Leg	SL	No
8	Base Turn	TH	Yes
9	Base Leg	SD	No
10	Final Turn	TO	Yes
11	Final Leg	SD	No
12	Round Out	TV	Yes
13	Landing Roll	SL	Yes

[1] Flight Path Key: SL = Straight Level; SC = Straight Climb; SD = Straight Descent; TH = Turn Horizontal; TO = Turn Oblique; TV = Turn Vertical.

[2] Accelerated Key: Yes; No



Rolling Turn

Here's what we already know:

- The maneuver occurs in the horizontal plane;
- Roll left 360 degrees, turn left 90 degrees;
- Roll and turn begin and end at the same time;
- Roll and turn must be blended throughout; hence, it's a variable bank, variable G maneuver; and,
- *Bank and yank* serves as a general reminder of the control actions.

The rolling turn, like commercial maneuvers, is a ground reference maneuver. As such, let's choose three reference points on the horizon (or in our simulation, points on the walls in the room):

1. A point in front of us as our starting heading;
2. A point off the left wing as our ending heading; and,
3. A point halfway between 1 and 2.

We could select other references in between points 1 and 2, and 2 and 3, but these points will do for this exercise. We can deduce the following based on what we now know:

Point 1 – Bank angle is zero degrees (level upright), heading change is zero degrees.
Point 2 – Bank angle is 180 degrees (level inverted), heading change is 45 degrees.
Point 3 – Bank angle is zero degrees (level upright), heading change is 90 degrees.

Slow the maneuver down. Play with roll and pitch inputs bit by bit at first. Exaggerate if that helps before trying to put it all together into one smooth, continuous maneuver. Looking over at point 2, begin rolling the airplane to the left and pulling the nose toward that point. Adjust roll and pitch rates as needed until the nose points at the reference. The airplane should be in level, inverted flight here.

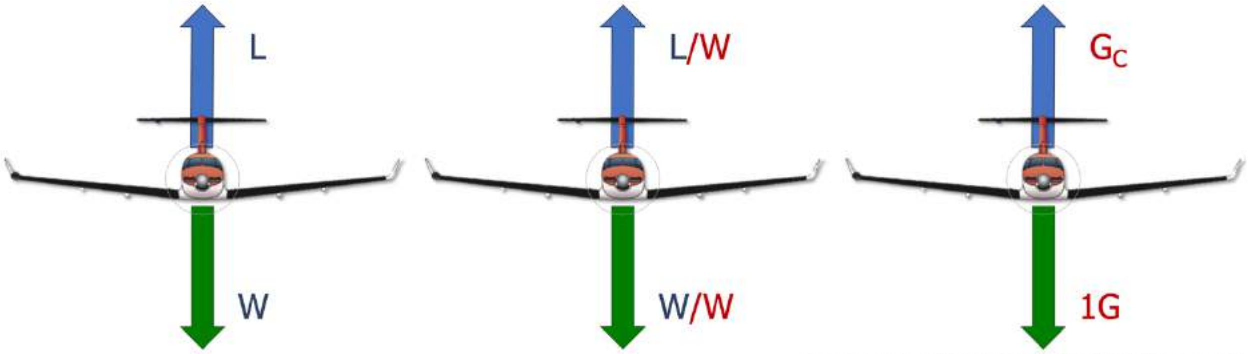
Look over at point 3. The angle of bank must change from 180 degrees back to zero degrees by the time we reach point 3. But how do we get the nose from point 2 to point 3 now? Pulling on the elevator won't make that happen. But pushing will! Push the nose of the airplane from point 2 to point 3 as the left roll proceeds. Arrive at point 3 with the wings level.

Even though *Learn to Turn* focused on positive G flight, the correlation level of learning allows us to see that pushing, that negative G also is possible and in fact, necessary to complete this rolling turn. We can divide the maneuver into two halves and summarize the key actions:

First half – roll and pull from point 1 to point 2.
Second half – roll and push from point 2 to point 3.

Appendix B

Converting Forces to G-loads



Lift and Weight forces converted to G-loads by dividing by Weight

Endnotes

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1. Earl F. Weener, *NTSB to Hold Forum Addressing Inflight Loss of Control in Fixed-Wing General Aviation Aircraft*, NTSB News Release, September 8, 2015, http://www.ntsb.gov/news/press-releases/Pages/PR20150908.aspx.
2. Wolfgang Langewiesche, *Stick and Rudder* (New York: McGraw-Hill, 1944), 190.
3. Ibid.
4. FAA, *GAJSC Accident Data Set*, http://www.safepilots.org/documents/GAJSC_Accident_Data_Set.pdf.
5. FSF Editorial Staff, "Safety Innovations, Solutions Show Contemporary Relevance," *Flight Safety Digest*, Flight Safety Foundation Aug–Sep 2002, 18 (quoting from Skygod.com in 2002).
6. AOPA, *The Flight Training Experience: A Survey of Students, Pilots, and Instructors*, Aircraft Owners and Pilots Association, October 2010, 37.
7. Ibid., 16.
8. ICAO, *Manual on Aeroplane Upset Prevention and Recovery Training*, First Edition 2014, x.
9. Community Aviation connects learners with subject matter experts in all areas of aviation and promotes a training framework called *Learn–Do–Fly*. See https://www.communityaviation.com/about.
10. ICAO, x.
11. ICAO, viii.
12. FAA, *Acceleration in Aviation: G-Force* (Publication AM-400-09/14), 2.
13. Tony Kern, *Blue Threat–Why to Err is Inhuman* (Colorado Springs: Pygmy Books, 2009), 52.
14. FAA, *Aviation Instructor's Handbook*, FAA-H-8083-9A, 2008, G-4.
15. Kendra Cherry, "Just Noticeable Difference (JND) in Psychology," *Verywell Mind*, reviewed by Amy Morin, LCSW on April 30, 2020, https://www.verywellmind.com/what-is-the-just-noticeable-difference-2795306.
16. ICAO, xii.
17. USAF Test Pilot School, *Performance Flight Test Phase* (CA: Edwards AFB, 1998), 9.52.
18. ICAO, xiii.
19. Proprioception (n.d.), *The American Heritage® Medical Dictionary*, 2007. Retrieved June 28, 2021 from https://medical-dictionary.thefreedictionary.com/proprioception.
20. See Merriam-Webster Dictionary, https://www.merriam-webster.com/dictionary/primary, Entry 1, 2a and 2b, accessed April 27, 2021.
21. FAA, *Aviation Instructor's Handbook*, G-6.
22. Darrol Stinton, *Flying Qualities and Flight Testing of the Airplane* (Reston, VA and Oxford, UK: AIAA, 1996), 107.
23. FAA, *Aviation Instructor's Handbook*, G-7.
24. Mica R. Endsley, Ph.D., Daniel J. Garland, Ph.D., et al., *Situation Awareness in General Aviation Pilots*, SATECH-00-01, January 2000, 1.
25. Sammy Mason (n.d.), *S.A.F.E. Flight Instruction Manual*, 2.
26. The author surveyed nearly 900 pilots during several safety seminars/webinars.
27. FAA, *Aviation Instructor's Handbook*, 2-13.
28. Langewiesche, 225-226.
29. AOPA Air Safety Foundation, *Maneuvering Flight – Hazardous to Your Health?* Safety Advisor, Operations & Proficiency No. 8, 2005, 2.
30. ICAS (n.d.), *Air Show Performers Safety Manual*, 17.
31. Langewiesche, 211.
32. USAF Test Pilot School, 9.47–9.55.
33. FAA, *Airplane Flying Handbook*, FAA-H-8083-3A, 2004, 3-7.
34. FAA, *Airplane Flying Handbook*, 2004, 9-4; FAA, *Airplane Flying Handbook*, FAA-H-8083-3B, 2016, 9-6.
35. FAA, *Airplane Flying Handbook*, 2016, 6-16.
36. FAA, *Airplane Flying Handbook*, 2004, 6-14.
37. Ibid, 8-6.
38. Langewiesche, 202.
39. John T. Lowry, *Performance of Light Aircraft* (Reston, VA: AIAA, 1999), 245.
40. *Pilot Training Reform Symposium Preliminary Report*, Society of Aviation and Flight Educators, Inc., June 6, 2011, 29. The symposium defined curricula as the "'how, when, and where' of pilot training and includes syllabi, training vehicles, setting, and other elements of the delivery system."
41. Robert L. Cohn, *They Called It Pilot Error, True Stories Behind General Aviation Accidents*, (Tab Books, a Division of McGraw-Hill, 1994), 131.
42. Kern, 23.
43. FAA, *GAJSC Accident Data Set*.

---

44. Ibid.
45. Ibid.
46. FAA, *Pilot's Handbook of Aeronautical Knowledge*, FAA-H-8083-25A, 2008, 17-2.
47. See https://www.youtube.com/playlist?list=PL5aVmmm4Qt9Et0rBM7CwXdX5C9o2jxudh.
48. Weener, http://www.ntsb.gov/news/press-releases/Pages/PR20150908.aspx.
49. Langewiesche, 190.
50. Brent W. Silver, *Statistical Analysis of General Aviation Stall Spin Accidents*, SAE 760480 (SAE, 1976), 5.
51. *Pilot's Handbook of Aeronautical Knowledge*, EA-AC 61-23B (Basin, WY: Aviation Maintenance Publishers, Inc., revised 1980), 30–31.
52. AOPA Air Safety Foundation, 1, 5.
53. Langewiesche, 345.
54. See for example, *Flight Training Handbook*, AC 61-21A, revised 1980, 62; *Pilot's Handbook of Aeronautical Knowledge*, 1980, 31; *Airplane Flying Handbook*, 2004, 3-7 & 3-8; *Pilot's Handbook of Aeronautical Knowledge*, 2008, 4-19.
55. FAA, *Airplane Flying Handbook*, 2016, 9-7, 3-11, 3-12.
56. Dr. David Hunter, *A Guide for the Conduct of Biennial Flight Reviews*, FAA, Draft May 1999, 7.
57. Trevor Thrasher, "Stress Proofing Skills," *Breach Bang Clear*, July 31, 2017, accessed April 26, 2021 at https://www.breachbangclear.com/stress-proofing-skills/.
58. See Jerry M. Childs, William D. Spears, and Wallace W. Prophet, *Private Pilot Flight Skill Retention 8, 16, and 24 Months Following Certification*, Embry-Riddle Aeronautical University, July 1983, and Hunter, *A Guide for the Conduct of Biennial Flight Reviews*. Though the pilots were considered "relatively inexperienced," they were likely at or near the peak of their proficiency when the study commenced, i.e., at the time of their private pilot checkrides.
59. Hunter, 8. The composite ranking was the average rank of the error rate at 24 months, the increment in the error rate from the checkride to the 16-month check, and the increment in the error rate from the checkride to the 24-month check. The composite was used since it represented more aspects of performance. All checks were done relative to private pilot checkride performance.
60. Childs, Spears, and Prophet, 33.
61. Ibid., 36.
62. Langewiesche, 190; Bill Thomas, *Fly for Fun*, 1985, 12.
63. See Kern, 57.
64. Juan R. Merkt, *Flight Energy Management Training* (Journal of Aviation Technology and Engineering, 3:1, 2013), 34.
65. FAA, *Pilot's Handbook of Aeronautical Knowledge*, 2008, 17-2.
66. Lt. Col. Dave Grossman with Loren W. Christensen, *On Combat* (Warrior Science Publications, Third Edition, 2008), 212.
67. FSF Editorial Staff, "Safety Innovations," 18.
68. FAA, *Pilot's Handbook of Aeronautical Knowledge*," 17-2; FAA, *2010 FAASTeam Safety Stand Down*, https://www.faasafety.gov/files/notices/2010/May/FAA_Safety_Stand_Down_Brochure.pdf.
69. Michael A. Kellar, Raymond A. Folen, et al., *Autogenic-Feedback Training Improves Pilot Performance During Emergency Flying Conditions*, NASA Technical Memorandum 104005 (Ames Research Center, Moffett Filed, CA, March 1993), 1.
70. ICAO, 1-2.
71. ICAS, 7.
72. *Pilot's Handbook of Aeronautical Knowledge*, revised 1980, 24; FAA, *Pilot's Handbook of Aeronautical Knowledge*, 2008, 4-19; FAA, *Airplane Flying Handbook*, 2016, 4-2.
73. Jeff Scott, *Bank Angle and G's*, Aerospaceweb.org, October 19, 2003, http://www.aerospaceweb.org/question/performance/q0146.shtml.
74. FAA, *Airplane Flying Handbook*," 2016, 3-11; for similar examples, see FAA, *Airplane Flying Handbook*, 2004, 3-8 and FAA, *Flight Training Handbook*, revised 1980, 62.
75. FAA, *Airplane Flying Handbook*, 2016, 3-4.
76. See FAA, *Pilot's Handbook of Aeronautical Knowledge*, 2016, 5-34 and 2008, 4-29.
77. FAA, *Airplane Flying Handbook*, 2004, 9-2.
78. FAA, *Airplane Flying Handbook*, 2016, 9-2.
79. Lowry, 245.
80. FAA, *Pilot's Handbook of Aeronautical Knowledge*," 2016, 5-34.
81. Ibid., 3-11.
82. David F. Anderson and Scott Eberhardt, *Understanding Flight* (NY: McGraw-Hill, 2001), 7.
83. H.C. "Skip" Smith, *The Illustrated Guide to Aerodynamics* (Blue Ridge Summit, PA: Tab Books, 1992), 183.
84. Dave Higdon, "Turn Fundamentals," *Aviation Safety*, June 2016, 9.
85. US Department of Commerce, "Civil Pilot Training Manual," *Civil Aeronautics Bulletin No. 23*, 1941, 130.

---

86. Langewiesche, 198.
87. Thomas, 12.
88. *Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes*, 14 C.F.R. § 23.203 (1993), 163.
89. FAA, *Airplane Flying Handbook*, 2004, 3-7.
90. FAA, *Airplane Flying Handbook*, 2004, 9-4 and 2016, 9-6.
91. Kern, 52.
92. Ibid., 135.
93. Ibid, 132–133.
94. Jim Traub, personal communication with the author, June 17, 2021.
95. For the author's take on the Manhattan crash, see Rich Stowell, "Safer Maneuvering," *Aviation Safety*, vol. 28, no. 4, April 2008, 4–7 and 29.
96. Langewiesche, 4.
97. NTSB, *NTSB Most Wanted List 2016*, available http://www.ntsb.gov/safety/mwl/Documents/MWL2016_Brochure_web.pdf.
98. Naval Air Training Command, *Air Combat Maneuvering, Flight Training Instruction T-45TS, ADV, and IUT*, 1998, 3.
99. Merkt, 24.
100. Ed Wischmeyer, *Technologies to Reduce Fatal Loss of Control Accidents in Experimental, Amateur-Built Aircraft*, 2015-2016 EAA Founder's Innovation Prize competition entry, 19.
101. Kern, xi.
102. Childs, Spears, and Prophet, 36.
103. Langewiesche, 192–193.
104. Sammy Mason, *Stalls, Spins, and Safety*, (New York: MacMillan, 1982), 81.
105. the Physics Classroom, "Analyzing Circular Movements in Athletics," *Circular Motion and Satellite Motion – Lesson 2*, https://www.physicsclassroom.com/class/circles/Lesson-2/Athletics.
106. Adapted from *Basic Object Motion*, NASA Glenn Research Center, https://www.grc.nasa.gov/WWW/k-12/airplane/bmotion.html, updated May 5, 2015.
107. Theodore A. Talay, *Introduction to the Aerodynamics of Flight*, NASA SP–367 (NASA, 1975), 137.
108. Ibid., 146.
109. Bill Crawford, *Unusual Attitudes and the Aerodynamics of Maneuvering Flight*, Flightlab, 2009, 6.1.
110. FAA, *Airplane Flying Handbook*, 2016, 6-13.
111. the Physics Classroom, https://www.physicsclassroom.com/class/circles/Lesson-2/Athletics.
112. Talay, 169.
113. Bellanca Aircraft Corporation, *Pilot Proficiency Training Manual*, 1978, 23.
114. Naval Aviation Schools Command, *Fundamentals of Aerodynamics*, NAVAVSCOLSCOM-SG-111, April 2008, Information Sheet 1-9-2, 7. The fuselage is a symmetric airfoil. Given an angle of attack, it produces lift and drag just like any airfoil or wing. Engineers refer to the angle of attack of the fuselage as angle of sideslip.
115. Marvin W. McFarland (Editor), "The Papers of Wilbur and Orville Wright," *Volume Two 1906–1948* (McGraw-Hill, 2001), 1143.
116. Langewiesche, 218.
117. FAA, *Airplane Flying Handbook*, 2004, 3-7.
118. A curious thing happens when turning in the oblique and vertical planes: changes in pitch affect the angle of bank. We can illustrate the effect easily in the vertical.

     Imagine an airplane in level, upright flight. The initial angle of bank is zero degrees relative to the horizon. The pilot pulls into a loop. At the top of the loop, the airplane is inverted; the bank angle is now 180 degrees. As the airplane finishes the loop, the bank angle returns to zero degrees again. No aileron input was applied during the loop, yet the bank angle began at zero degrees, increased to 180 degrees, then decreased back to zero degrees.

     The secondary effect during climbing turns is an increase in bank angle; the effect during descending turns, a decrease in bank angle. See also Section 5, *Oblique Turns*.
119. Robert L. Shaw, *Fighter Combat Tactics and Maneuvering* (MD: Naval Institute Press, 1985), 387.
120. Jeppesen Sanderson, Inc., *Aviation Fundamentals*, 6th Edition 1981, 1-31.
121. Crawford, 8.2.
122. Maj Charles Bretana, Jr. and LtCol Edward Tomme, *RT-13 Air-to-Air Reference Text*, 2002, 7.
123. Michael Vaccaro, *RV-Type Training Syllabi, Lesson Plans, Techniques, Procedures and Handling Characteristics*, draft version 3.1, May 15, 2016, 339.
124. Naval Aviation Schools Command, Information Sheet 1-11-2, 10.
125. US Department of Commerce, 124.
126. Jeff Scott, *Bank Angle and G's*, Aerospaceweb.org, October 19, 2003, http://www.aerospaceweb.org/question/performance/q0146.shtml.
127. See Rich Stowell, *Emergency Maneuver Training*, 1996, 61.

128. *Pilot's Handbook of Aeronautical Knowledge*, revised 1980, 31.
129. U.S. Department of Commerce, "Civil Pilot Training Manual," *Civil Aeronautics Bulletin 23*, 1941, 129–130.
130. Langewiesche, Stick and Rudder, 198.
131. Bill Thomas, Fly for Fun (1985), 12.
132. William K. Kershner, *The Flight Instructor's Manual* (Ames, IA: Iowa State University Press, Third Edition, 1993), 32.
133. FAA, *Airplane Flying Handbook*, 2004, 3-7.
134. For example, see the FAA *Pilot's Handbook of Aeronautical Knowledge*, 2008, 4-23 and 4-29.
135. Crawford, 9.3.
136. Langewiesche, 205.
137. Scott, http://www.aerospaceweb.org/question/performance/q0146.shtml.
138. Langewiesche, 202.
139. Amy L. Hoover and R.K. "Dick" Williams, *Mountain, Canyon, and Backcountry Flying* (Aviation Supplies & Academics, Inc., 2019), 102.
140. The 2016 *Airplane Flying Handbook* classifies level turns as shallow (up to 20 degrees of bank), medium (20–45 degrees of bank), and steep (45 degrees of bank or more). See page 3-11.
141. Cherry, https://www.verywellmind.com/what-is-the-just-noticeable-difference-2795306.
142. Correia Grácio, B. J., M. Wentink, E. Groen, and W. Bles, *Subjective Estimates of G-load in Centrifuge-Based Simulation and Applications for G-cueing in Desdemona*, AIAA 2009-5919, AIAA Modeling and Simulation Technologies Conference, August 10–13, 2009, 7.
143. Ibid., 2.
144. FAA, *Airplane Flying Handbook*, 2016, 6-13.
145. International Aerobatic Club, *Official Contest Rules*, revision 19.0, January 2008, 8-10–8-11.
146. Vaccaro, 382.
147. FAA, *Airplane Flying Handbook*, 2004, 9-4.
148. Ibid., 9-5.
149. FAA, *Airplane Flying Handbook*, 2016, 9-4.
150. Ibid., 9-4–9-5.
151. Mark Danielson, "Understanding Lift – What You Don't Know Can Haunt You," *Flight Training*, April 5, 2002, https://www.aopa.org/news-and-media/all-news/2002/april/flight-training-magazine/understanding-lift.
152. Langewiesche, 211.
153. Naval Air Training Command, 5.
154. FAA, *Airplane Flying Handbook*, 2016, 8-6.
155. Ibid.
156. Ibid., 8-30–8-31.
157. Ibid.
158. Crawford, 8.5.
159. See for example ICAS, *Air Show Performers Safety Manual*; Naval Air Training Command, *Air Combat Maneuvering*.
160. Langewiesche, 350.
161. A discussion about stall curves is beyond the scope of this material. For more information, see "Maneuvering Performance: Stall Curves, Picturing the Fluid Nature of Stalled Flight," *The Learn to Aviate Series*, by Rich Stowell and Jim Goodwin, November 2020.
162. FAA, *Amateur-Built Aircraft and Ultralight Flight Testing Handbook*, AC 90-89B, April 27, 2015, 74.
163. FAA, *Transition to Unfamiliar Aircraft*, AC 90-109A, June 29, 2015, Appendix 4, 3.
164. AOPA Air Safety Foundation, 2005 and 2008, 8.
165. eCFR, *Part 23–Airworthiness Standards*, accessed May 23, 2016, 23.203(a); *Airworthiness Standards*, 14 CFR 23.203(a), revised January 1, 1993, 163.
166. Thomas, 14.
167. Danielson, https://www.aopa.org/news-and-media/all-news/2002/april/flight-training-magazine/understanding-lift.
168. Daniel P. Raymer, *Aircraft Design: A Conceptual Approach* (Reston, VA: AIAA, 1999), 520.
169. William K. Kershner, *The Basic Aerobatic Manual* (Ames, Iowa: Iowa State University Press, 1987), 47.
170. See for example Naval Air Training Command, 4-5.
171. International Aerobatic Club, 8-11.
172. Richard Bach, "School for Perfection," *A Gift of Wings* (New York: Delacorte Press, 1974), 159.
173. Langewiesche, 226.
174. Ed Wischmeyer, personal communication with the author, June 26, 2021.
175. "Letter of Introduction," *Aviators Model Code of Conduct*, version 2.0, https://www.secureav.com.

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176. Sgt. Jim Heuston, quoting Lt. Col. Dave Grossman, "'Vaccine' touted for combat stress," *Marine Corps News*, September 20, 2004.
177. Grossman, 135.
178. Trevor Thrasher, "Stress Proofing Skills," *Breach Bang Clear*, July 31, 2017, accessed April 26, 2021 at https://www.breachbangclear.com/stress-proofing-skills/.
179. Ibid.
180. Fred G. DeLacerda, Ph.D., *Peak Performance for Aerobatics* (Ames, IA: Iowa State University Press, 2002), 13.
181. ExRx.net, "Skill Acquisition and Proficiency," *Sports Psychology*, https://exrx.net/Psychology/Skill.
182. Jeff Wise, *Extreme Fear* (Palgrave Macmillan, 2009), 30.
183. Robert M. Nideffer, Ph.D. (n.d.), *Getting Into The Optimal Performance State*.
184. DeLacerda, 30.
185. Daniel Coyle, *The Talent Code* (Bantam Books, 2009), 79–94.
186. Thrasher, https://www.breachbangclear.com/stress-proofing-skills/.
187. Ibid.
188. Dean T. Olsen, "Improving Deadly Force Decision Making," *The FBI Law Enforcement Bulletin*, February 1, 1998, 6.
189. Hui Lynn Toong and MAJ Ta Chui Koh, *Enhancing Performance of Novice Military Parachutists through Mental Skills Training*, Applied Behavioral Sciences Department, Ministry of Defence, Singapore, Internationalmta.org, 2005, 2.
190. DeLacerda, 49.
191. Toong and Koh, 2.
192. DeLacerda, 48.
193. Joel Greenberg, "Psychologists Train Minds of Athletes to Excel." *The New York Times*, September 8, 1981. Cited 4 April 2008, available at http://query.nytimes.com/gst/fullpage.html?res=9907E2DC1639F93BA3575AC0A967948260&sec=health&spon=&pagewanted=print.
194. Ibid.
195. Michael Bungay Stanier, *The Coaching Habit* (Box of Crayons Press, 2016), 7.
196. Bruce K. Siddle, *Sharpening the Warriors Edge* (PPCT Research Publications, 7th printing, 2005), 15.
197. Grossman, 135.
198. Siddle, 14.
199. Dan Coyle, *The Little Book of Talent: 52 Tips for Improving Your Skills* (Bantam Books, 2012), 21.
200. Some object to calling this coordination exercise "Dutch rolls" since the phrase also refers to "a short period oscillation [that] sees the aircraft waddle from side to side, exchanging yaw and roll" (Raymer, 520). The phrase is commonly used in the aerobatic community to describe a specific maneuver practiced by pilots flying light airplanes. In that context, it is clearly differentiated from the waddling Dutch roll.

Bibliography

Aircraft Owners and Pilots Association. *The Flight Training Experience: A Survey of Students, Pilots, and Instructors*, October 2010.

"Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes," *14 C.F.R. § 23.203* (1993).

Anderson, David F., and Scott Eberhardt. *Understanding Flight*. NY: McGraw-Hill, 2001.

AOPA Air Safety Foundation. *Maneuvering Flight – Hazardous to Your Health?* Safety Advisor, Operations & Proficiency No. 8, 2005.

Bach, Richard. "School for Perfection," *A Gift of Wings*. New York: Delacorte Press, 1974.

Bellanca Aircraft Corporation. *Pilot Proficiency Training Manual*. 1978.

Bretana, Maj Charles, Jr., and LtCol Edward Tomme. *RT-13 Air-to-Air Reference Text*. 2002.

Castner, Linda and Rich Stowell. *Effective Outreach: Preserving General Aviation by Putting the "Public" in Public-Use Airports*. Up, Up, and Away in Hunterdon, Inc., March 2017.

Cherry, Kendra. "Just Noticeable Difference (JND) in Psychology." *Verywell Mind*, reviewed by Amy Morin, LCSW on April 30, 2020, https://www.verywellmind.com/what-is-the-just-noticeable-difference-2795306.

Childs, Jerry M., William D. Spears, and Wallace W. Prophet. *Private Pilot Flight Skill Retention 8, 16, and 24 Months Following Certification*. Embry-Riddle Aeronautical University, July 1983.

Christensen, Loren W. *The Bulletproof Mind*. Policeandsecuritynews.com, March–April 2002.

Cohn, Robert L. *They Called It Pilot Error, True Stories Behind General Aviation Accidents*. Tab Books, a Division of McGraw-Hill, 1994.

Correia Grácio, B. J., M. Wentink, E. Groen, and W. Bles. *Subjective Estimates of G-load in Centrifuge-Based Simulation and Applications for G-cueing in Desdemona*. AIAA 2009-5919, AIAA Modeling and Simulation Technologies Conference, August 10–13, 2009.

Coyle, Daniel. *The Talent Code*. Bantam Books, 2009.

______. *The Little Book of Talent: 52 Tips for Improving Your Skills*. Bantam Books, 2012.

Crawford, Bill. *Unusual Attitudes and the Aerodynamics of Maneuvering Flight*. Flightlab, 2009.

Danielson, Mark. "Understanding Lift – What You Don't Know Can Haunt You." *Flight Training*, April 5, 2002, https://www.aopa.org/news-and-media/all-news/2002/april/flight-training-magazine/understanding-lift.

DeLacerda, Fred G., PhD. *Peak Performance for Aerobatics*. Ames, IA: Iowa State University Press, 2002.

Doidge, Norman, M.D. *The Brain That Changes Itself*. New York: the Penguin Group, 2007.

eCFR, *Part 23–Airworthiness Standards*. Accessed May 23, 2016, 23.203(a).

Endsley, Mica R., Ph.D., Daniel J. Garland, Ph.D., et al. *Situation Awareness in General Aviation Pilots*. SATECH-00-01, January 2000.

ExRx.net. "Skill Acquisition and Proficiency." *Sports Psychology*, https://exrx.net/Psychology/Skill.

Federal Aviation Administration. *Acceleration in Aviation: G-Force*. Publication AM-400-09/14.

______. *Amateur-Built Aircraft and Ultralight Flight Testing Handbook*. AC 90-89B, April 27, 2015.

______. *Airplane Flying Handbook*. FAA-H-8083-3A, 2004.

______. *Airplane Flying Handbook*. FAA-H-8083-3B, 2016.

______. *Aviation Instructor's Handbook*. FAA-H-8083-9A, 2008.

______. *Flight Training Handbook*. AC 61-21A, revised 1980.

______. *GAJSC Accident Data Set*. http://www.safepilots.org/documents/GAJSC_Accident_Data_Set.pdf.

______. *Pilot's Handbook of Aeronautical Knowledge*. FAA-H-8083-25A, 2008.

______. *Transition to Unfamiliar Aircraft*. AC 90-109A, June 29, 2015.

FSF Editorial Staff. "Safety Innovations, Solutions Show Contemporary Relevance." *Flight Safety Digest*, Flight Safety Foundation Aug-Sep 2002, 18.

Greenberg, Joel. "Psychologists Train Minds of Athletes to Excel." *The New York Times*, September 8, 1981.

Grossman, Lt. Col. Dave, with Loren W. Christensen. *On Combat*. Warrior Science Publications, Third Edition, 2008.

Heuston, Sgt. Jim, quoting Lt. Col. Dave Grossman. "'Vaccine' touted for combat stress." *Marine Corps News*, September 20, 2004.

Higdon, Dave. "Turn Fundamentals." *Aviation Safety*, June 2016.

Hoover, Amy L., and R.K. "Dick" Williams. *Mountain, Canyon, and Backcountry Flying*. Aviation Supplies & Academics, Inc., 2019.

Hunter, Dr. David. *A Guide for the Conduct of Biennial Flight Reviews*. FAA, Draft May 1999.

International Aerobatic Club. *Official Contest Rules*. Revision 19.0, January 2008.

International Civil Aviation Organization. *Manual on Aeroplane Upset Prevention and Recovery Training*. First Edition, 2014.

International Council of Air Shows (n.d.). *Air Show Performers Safety Manual*.

Jeppesen Sanderson, Inc. *Aviation Fundamentals*. Sixth Edition 1981.

Johnstone, Tony. "Spin Training – Beyond the Basics." *Sport Aerobatics*, January/February 2021.

Kellar, Michael A., Raymond A. Folen, et al., *Autogenic-Feedback Training Improves Pilot Performance During Emergency Flying Conditions*. NASA Technical Memorandum 104005, Ames Research Center, Moffett Field, CA, March 1993.

Kern, Tony. *Blue Threat–Why to Err is Inhuman*. Colorado Springs: Pygmy Books, 2009.

Kershner, William K. *The Basic Aerobatic Manual*. Ames, IA: Iowa State University Press, 1987.

______. *The Flight Instructor's Manual*. Ames, IA: Iowa State University Press, Third Edition, 1993.

Langewiesche, Wolfgang. *Stick and Rudder*. New York: McGraw-Hill, 1944.

Ledegang, W.D., E.L. Groen, and M. Wentink, *Effect of G-cueing on Pilot Performance in Centrifuge-Based Simulation of Unusual Attitude Recovery*. AIAA 2011-6701, AIAA Modeling and Simulation Technologies Conference, August 8–11, 2011.

Lowry, John T. *Performance of Light Aircraft.* Reston, VA: AIAA, 1999.

Mason, Sammy. *Stalls, Spins, and Safety*. New York: MacMillan, 1982.

Mason, Sammy (n.d.). *S.A.F.E. Flight Instruction Manual*.

McFarland, Marvin W. (Editor). "The Papers of Wilbur and Orville Wright," *Volume Two 1906–1948,* McGraw-Hill, 2001.

Merkt, Juan R. "Flight Energy Management Training." *Journal of Aviation Technology and Engineering,* 3:1, 2013.

Miller, Geoff (n.d.). "What's Running through Your Head?" *Peak Running Performance*, 11, 1.

National Transportation Safety Board. http://www.ntsb.gov/safety/mwl/Documents/MWL2016_Brochure_web.pdf.

Naval Air Training Command. *Air Combat Maneuvering, Flight Training Instruction T-45TS, ADV, and IUT*. 1998.

Naval Aviation Schools Command. *Fundamentals of Aerodynamics*. NAVAVSCOLSCOM-SG-111, April 2008.

Nideffer, Robert M., Ph.D. (n.d.). *Getting Into The Optimal Performance State*.

Office of the Federal Register. *Airworthiness Standards*. 14 CFR 23.203(a), revised January 1, 1993.

Pilot's Handbook of Aeronautical Knowledge. EA-AC 61-23B, Basin, WY: Aviation Maintenance Publishers, Inc., revised 1980.

Raymer, Daniel P. *Aircraft Design: A Conceptual Approach*. Reston, VA: AIAA, 1999.

Scott, Jeff. *Bank Angle and G's*, Aerospaceweb.org, October 19, 2003.

Shaw, Robert L. *Fighter Combat Tactics and Maneuvering*. MD: Naval Institute Press, 1985.

Siddle, Bruce K. *Sharpening the Warriors Edge*. PPCT Research Publications, 7th printing, 2005.

Silver, Brent W. *Statistical Analysis of General Aviation Stall Spin Accidents*. SAE, 1976.

Smith, H.C. "Skip." *The Illustrated Guide to Aerodynamics*. Blue Ridge Summit, PA: Tab Books, 1992.

Society of Aviation and Flight Educators, Inc. *Pilot Training Reform Symposium Preliminary Report*. June 6, 2011.

Stanier, Michael Bungay. *The Coaching Habit*. Box of Crayons Press, 2016.

Stinton, Darrol. *Flying Qualities and Flight Testing of the Airplane*. Reston, VA and Oxford, UK: AIAA, 1996.

Stowell, Rich. "Learn to Turn: Antidote to Loss of Control." *AOPA Pilot*, August 2018.

______. *The Light Airplane Pilot's Guide to Stall/Spin Awareness*. Rich Stowell Consulting, 2007.

______. "Banking and Turning in Three Dimensions." *Sport Aerobatics*, September 2006.

______. "Turns: Straight Talk About Curved Flight." *Flight Training*, August 1994.

Stowell, Rich, and Jim Goodwin. "Maneuvering Performance: Stall Curves, Picturing the Fluid Nature of Stalled Flight." *The Learn to Aviate Series*, November 2020.

Talay, Theodore A. *Introduction to the Aerodynamics of Flight*. NASA SP–367, NASA, 1975.

the Physics Classroom. "Analyzing Circular Movements in Athletics." *Circular Motion and Satellite Motion – Lesson 2*, https://www.physicsclassroom.com/class/circles/Lesson-2/Athletics.

Thomas, Bill. *Fly for Fun.* 1985.

Thrasher, Trevor. "Stress Proofing Skills." *Breach Bang Clear*, July 31, 2017, https://www.breachbangclear.com/stress-proofing-skills/.

Toong, Hui Lynn, and MAJ Ta Chui Koh. *Enhancing Performance of Novice Military Parachutists through Mental Skills Training*. Applied Behavioral Sciences Department, Ministry of Defence, Singapore, Internationalmta.org, 2005.

USAF Test Pilot School. *Performance Flight Test Phase.* CA: Edwards AFB, 1998.

US Department of Commerce. *Civil Pilot Training Manual*. Civil Aeronautics Bulletin 23, 1941.

Vaccaro, Michael. *RV-Type Training Syllabi, Lesson Plans, Techniques, Procedures and Handling Characteristics*. Draft version 3.1, May 15, 2016.

Weener, Earl F. http://www.ntsb.gov/news/press-releases/Pages/PR20150908.aspx.

Wischmeyer, Ed. *Technologies to Reduce Fatal Loss of Control Accidents in Experimental, Amateur-Built Aircraft*. EAA Founder's Innovation Prize competition entry, 2015–2016.

Wise, Jeff. *Extreme Fear*. Palgrave MacMillan, 2009.

About the Author

Rich Stowell took his first flying lesson in 1982 and began his career as a full-time flight instructor specializing in spin, emergency maneuver, and aerobatic training in 1987. He authored the books *Emergency Maneuver Training* and *The Light Airplane Pilot's Guide to Stall/Spin Awareness*, and has had more than 80 articles appear in various aviation publications.

Rich is a recognized subject matter expert in loss of control in light airplanes. He is the 2014 National FAA Safety Team Representative of the Year and 2006 National Flight Instructor of the Year, and has delivered nearly 450 safety presentations. Rich served on the organizing committee for the *Pilot Training Reform Symposium* hosted by the Society of Aviation and Flight Educators in 2011, and facilitated the "Flight Training Curricula" breakout session there.

A 20-year Master Flight Instructor (now Emeritus), Rich is a Charter and Life Member of SAFE, and a 37-year member of AOPA, EAA, and IAC. He is one of fewer than 200 pilots who have earned the *All Five* achievement award from the International Aerobatic Club. Rich has logged 10,200 hours of flight time, with 9,100 hours of flight instruction given, 34,700 spins, and 25,700 landings. He also holds a bachelor's degree in Mechanical Engineering from Rensselaer Polytechnic Institute, Troy, NY.

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Avemco Safety Rewards Program: https://www.avemco.com/news-events/safety-rewards

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AOPA Air Safety Institute: https://www.aopa.org/training-and-safety/air-safety-institute

Aviators Code Initiative (Model Codes of Conduct): https://www.secureav.com

Society of Aviation and Flight Educators: https://www.safepilots.org