General Briefing

Anxiety!!!

If you’ve never flown aerobatics (or have had some bad experiences in the past), anxiety is natural. Sometimes people are anxious about safety, sometimes about how well they’ll respond when the instructor places the aircraft in an upset condition. Anxiety disappears as you learn to control the aircraft. We won’t take you by surprise (well, not immediately). We’ll teach you how to follow events so that surprises become manageable.

Even so, there may be times when you feel that too much is happening too fast. That’s not entirely bad: it shows that you’re pushing the boundaries of your previous training. As you gain practice you’ll find that the aircraft’s motions become easier to follow and tracking the horizon becomes less difficult. Your comfort level then quickly rises.

But if you feel confused or unsafe at any time, let us know.

Airsick?

The same goes if you begin to feel airsick. You probably don’t learn well with your head in a bag, so don’t hesitate. Let us know immediately so that we can modify the program and flight schedule for your comfort. If you’re new to aerobatics, you’ll discover that airsickness has nothing to do with the previous number of trouble-free hours in your flying career.

Resistance—or “habituation,” depending on your theory—usually arrives, but it takes time.

Most of our maneuver sets call for repetitions, but we can easily stretch those out over several flights, if you prefer. That’s easier on the instructor, as well. If you’re concerned about airsickness, a good resistance-building technique is to fly somewhat aggressive lazy-eights (which you might remember from the Commercial Flight Test) in a light aircraft a few days before you fly with us. Lazy-eights supply the pitching and rolling motions and variations in g force your body must adjust to. But stop at the first feelings of discomfort. Becoming sick does not help you adapt faster.

Don’t fly aerobatics on an empty stomach. Eat! You look thin! Drink plenty of water, especially when the outside temperature is high. Dehydration reduces g tolerance.

Research done with persons subject to motion sickness suggests what you’ve perhaps already observed: People who report that they’ve recovered from feelings of nausea can remain highly sensitized to vestibular disturbance for hours afterwards. That’s why those airsick passengers who announce with relief that they’re now feeling much better often spontaneously re-erupt as you start to maneuver into the traffic pattern. The temporary disappearance of symptoms doesn’t necessarily mean the battle is over.

What to Read: Ground School Texts

The texts you’ll receive (or download) along with the Maneuvers and Flight Notes cover a wide range of subjects, giving background material you can go into, more or less deeply, according to your interests. Our program is best for pilots who not only want to gain aerobatic and upset recovery skills but who also have a broader curiosity about the principles of aircraft response. Skills can be learned quickly, but satisfying curiosity takes time—because, ideally, curiosity grows. (And the subject of airplanes is vast.) You may find it helpful to read at least the ground school selections “Axes and Derivatives” and “Two-Dimensional Aerodynamics” before the first flight—don’t worry if you don’t have a technical background; they’re not as nerdy as they sound. Treat the ground school texts as a long-term resource, not a short-term burden.

What to Think About

Think about searching out the basic relationships that determine aircraft behavior. At very least, you need to examine two areas. The two ground
school selections mentioned above provide an introduction.

You need to understand how an aircraft responds to its own velocity vector, and to its lift vector. If you know where the velocity vector is pointed (relative to the aircraft’s fixed axes), and where the lift vector is pointed (relative to the horizon), you know how a stable aircraft is likely to behave. This is the core of our presentation of stability and control.

You also need to understand the nature of the pressure patterns over the surface of the wing: how those patterns originate and how they migrate as angle of attack changes. This is especially important as the aircraft approaches the stall, because pressure patterns determine the availability of control.

Where to Look

Unusual-attitude training should take both outside and inside attitude references into account. Aerobatic pilots look outside first. We fly in reference to the real horizon, not the artificial one. Of course, that’s because we fly aerobatics only in VFR conditions; but even if we have an aerobatic-friendly attitude indicator, the real horizon provides much better information.

Unlike aerobatic pilots, many IFR pilots tend to look inside first, even in good weather. If control of aircraft attitude is a reflexive, heads-in activity for you, you may need to reacquaint yourself with the information out the window. Partly because of the essential role peripheral visual cues play in spatial awareness, that’s where the information is best during unusual attitudes. Physiological correlation between what your body feels and what your eyes see also happens much faster when you’re looking outside. Then begin to connect what you’ve learned about aircraft behavior from looking out with the symbolic attitude information available within the cockpit. You’ll find that the symbolic information—which unfortunately lacks the peripheral cues we primarily rely on to perceive our motion within the world—becomes easier to interpret when you can associate it with attitudes and flight behaviors you’ve already seen outside.

One of the drawbacks of simulator training programs for unusual attitudes is that this valuable building block, outside/inside-learning process may not occur with sufficient repetition for the benefits to sink in. Pilots might demonstrate maneuvering proficiency in specific, directed tasks, but still have limited attitude awareness.

Rudder Use

We want you to experience and understand the effects of rudder deflection on aircraft response at high angles of attack. While the same basic aerodynamic principles apply in swept-wing aircraft as in our straight-wing propeller-driven trainers, in practice large aircraft and swept-wing dynamics are different, and more limited rudder use is recommended. On matters concerning rudders, search the Internet for Boeing Commercial Airplane Group Flight Operations Bulletin, May 13, 2002. Also Airbus FCOM Bulletin, Use of Rudders on Transport Category Airplanes, March 2002.

Standard Procedures

• Clear the airspace before each maneuver.

• Acknowledge transfer of control.

• Don’t hesitate to apply your own CRM procedures and call-outs as you think appropriate to the safety of the flight.

• Don’t fret about your mistakes. Mistakes are your best source of information. Bracket your responses until you zero-in on the correct procedure.
Maneuvers and Flight Notes

Maneuver Sets and Lesson Plan

Because certain maneuvers use up motion
tolerance more rapidly than others, and personal
tolerance varies, your maneuver sequence might
be different than the standard schedule. You’ll
also repeat some maneuvers when you fly the
second aircraft.

The core lesson is upset recovery, but we teach
much more than recovery procedures, as you’ll
see when you begin reading. The Flight Notes
below each maneuver description cover
fundamental aerodynamic principles. Together
with the ground school presentations and
supporting texts, they describe aircraft
characteristics you’ll observe and techniques
you’ll learn. They attempt to expand your frame
of reference with examples drawn from different
aircraft types. They’re part narrative, part
explanation, and sometimes a warning.

The information in the Flight Notes is obviously
more than an instructor could give during a
flight, and much more than a student could be
expected to take in. Chances are we won’t have
time to cover every detail, nor will every detail
apply to your type of flying. Don’t let the
material overwhelm you. Familiarize yourself
with the relevant Flight Notes before each sortie,
as you think best. When you review the notes
after the flight, you’ll find them much easier to
absorb, because you can connect them with what
you’ve just done. The ground school texts
reinforce the Flight Notes and add further
information.

We use boldface italics to emphasize important
concepts. (Boldface in the procedure description
reminds instructors of points to emphasize in
setting up and carrying out maneuvers.)

Here’s how the maneuvers break down into
general categories:

Natural Aircraft Stability Modes, Yaw/Roll
Couple:

1. Longitudinal & Directional Stability, Spiral
   Divergence, Phugoid

2. Steady-Heading Sideslip: Dihedral Effect &
   Roll Control

High Angle of Attack (Alpha):

3. Stall: Separation & Planform Flow (Wing tuft
   observation)
4. Accelerated Stalls: G Loads & Buffet
   Boundary, Maneuvering Stability
5. Nose High Full Stalls & Rolling Recoveries
6. Roll Authority: Adverse Yaw & Angle of
   Attack, Lateral Divergence
7. Flap-Induced Non-convergent Phugoid

Roll Dynamics:

8. Nose-Level Aileron Roll: Rolling Flight
   Dynamics, Free Response
9. Slow Roll Flight Dynamics: Controlled
   Response
10. Sustained Inverted Flight
11. Inverted Recoveries
12. Rudder Roll: Yaw to Roll Coupling

Reinforcements and Aerodynamics:

13. Rudder & Aileron Hardovers
14. Lateral/Directional Effects of Flaps
15. Dutch Roll Characteristics
16. CRM Issues: Pilot Flying/Pilot Monitoring
17. Primary Control Failures

High-Alpha/Beta Departures:

18. Spins

Additional Basic Aerobatic Maneuvers:

Loop, Cuban Eight, Immelman, Hammerhead,
Slow Roll, Point Roll
# Maneuvers and Flight Notes

## First Flight

1. Longitudinal & Directional Stability, Spiral Divergence, Phugoid
2. Steady-Heading Sideslip: Dihedral Effect & Roll Control
3. Stall: Separation & Planform Flow (Wing tuft observation)
4. Accelerated Stalls: G Loads & Buffet Boundary, Maneuvering Stability
5. Nose High Full Stalls & Rolling Recoveries
6. Roll Authority: Adverse Yaw & Angle of Attack, Lateral Divergence
7. Flap-Induced Non-convergent Phugoid

Possible:
9. Slow Roll Flight Dynamics: Controlled Response

On Return:
17. Primary Control Failures

## Second Flight

9. Slow Roll Flight Dynamics: Controlled Response
10. Sustained Inverted Flight
11. Inverted Recoveries
12. Rudder Roll: Yaw to Roll Coupling
13. Rudder & Aileron Hardovers
14. Lateral Effects of Flaps
15. Dutch Roll Characteristics

Possible:
19. Spins

Basic Aerobatic Maneuvers

On Return:
17. Primary Control Failures

## Third Flight

Review Maneuver Sets 9-12
16. CRM Issues: Pilot Flying/Pilot-Not-Flying
18. Spins

Basic Aerobatic Maneuvers

On Return:
17. Primary Control Failures (as necessary)

## Fourth Flight

Review and additional aerobatic maneuvers to be determined.

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These maneuvers are for training purposes in appropriate aircraft only. Follow the procedures and obey the restrictions listed in your pilot’s operating handbook or aircraft flight manual.
Trimming for Airspeed in Level Flight

We usually trim an aircraft in climb for $V_Y$, best rate of climb, or perhaps a bit faster to preserve the view over the nose and to keep engine temperatures from rising. In descending from altitude for landing, we might trim for a comfortable descent rate. In the pattern we trim for pattern speed based on habitual power settings, and then for our landing reference speed.

But we usually don’t trim for a particular airspeed in cruise. Instead, we level off at a certain altitude, accelerate a little while nudging the trim forward, and then pull back the power to cruise setting. Last, we final-trim to zero out the control force necessary to maintain level flight. Then we take the airspeed we get.

Sometimes in flight-testing, or in our program, you’ll want to start a maneuver from a specific, trimmed, level-flight airspeed. Here’s what you do:

- Bring the aircraft to the required altitude
- Set the power to the approximate value dictated by experience. Of course, don’t chase airspeed with large power changes. Just get close.
- Use pitch control to bring the aircraft to the desired airspeed.
- While holding airspeed constant, use power to center the VSI at zero climb/descent rate.
- Trim out the control force.

Note that pitch controls airspeed, power controls the aircraft’s flight path angle relative to the horizon.
1. Longitudinal & Directional Stability, Spiral Divergence, Phugoid


   Lesson: Aircraft behavior when disturbed from equilibrium flight.

**Procedures:**

**Longitudinal Stability: Stick force, Phugoid**

*Static stability:* On the climb to the practice area, trim for $V_Y$. Observe longitudinal (pitch axis) stick forces needed to fly at airspeeds greater than or less than trim. Assess force gradient. Look for characteristics due to friction.

Simulate the effect on longitudinal stability of moving center of gravity aft: Trim, pitch up to fly 10 knots slower than trim, hold speed while instructor slowly trims nose up. Note how stick force decreases (simulating a decrease in stability), disappears (simulating neutral stability), and then reverses (simulating static instability).

*Dynamic stability:* Use pitch up and stick release to demonstrate phugoid. Observe period, amplitude, damping.

**Directional Stability:**

Low cruise power, airspeed white arc.

Enter flat turn with rudder, while keeping wings level with aileron. Observe build up of pedal forces to full deflection.

Quickly return pedals and ailerons to neutral; observe overshoots and damping.

Look for characteristics due to friction.

**Lateral Stability: Spiral Mode**

Power and trim for low cruise.

Enter a 10-degree bank angle, return controls to neutral and observe response in roll. Note appearance of phugoid. Repeat bank with additional 10-degree increments until onset of spiral departure.

Look for asymmetries by repeating to the opposite side.

Allow spiral mode to develop as consistent with comfort and safety.

Roll wings level; release controls; observe recovery phugoid.

Reduce entry airspeed and observe the increase in roll amplitude versus time.

**Knife-edge recovery:**

Low cruise power, airspeed white arc.

Roll knife-edge.

Immediately release controls and observe response.
Flight Notes

We’ll start by exploring how an aircraft’s inherent stability determines its free response when disturbed from equilibrium. Free response is what happens when the pilot stays out of the control loop. It’s easier to understand the sources of an aircraft’s complex, self-generated motions when you can break them down into simpler, free response “modes” around each axis. Usually, a moment generated around one axis produces some form of response around another. From the standpoint of unusual-attitude training, if you understand and can anticipate an aircraft’s “basic moves,” managing the control loop properly to maintain or to re-establish control becomes closer to second nature.

In aircraft with basic cable-and-pushrod reversible controls, like our trainers, free response can depend on whether the stick and rudder pedals are held fixed or literally left free so that the control surfaces are allowed to streamline themselves to changes in airflow. Irreversible, hydraulically powered controls are always effectively fixed. See FAR Parts 23 & 25.171-181 for stability requirements.

Longitudinal Static and Dynamic Stability

• We’ll use some maneuvers borrowed from flight test procedures to look at basic aircraft characteristics. We’re going to adapt the procedures to our own purposes, take a general approach, have fun, and not worry about always doing things with the real precision that’s required to gain accurate data points in actual flight test. A rough narrative follows.

• Here’s the deal on longitudinal static stability, as required by Part 23.173: “… with the airplane trimmed … the characteristics of the elevator control forces and the friction within the control system must be as follows: (a) A pull must be required to obtain and maintain speeds below the specified trim speed and a push required to obtain and maintain speeds above the specified trim speed.”

• On the way to the practice area we’ll observe the Part 23.173 requirement. We’ll trim the aircraft and then observe the stick forces necessary to fly at slower and faster airspeeds (a.k.a. angles of attack) without retrimming. When we release the force, the nose initially pitches toward the trim angle of attack. This initial tendency is what we mean by positive static stability (static refers to the initial tendency, dynamic refers to the tendency over time). The more force we have to apply to deviate from trim, the greater the stability. We can increase static stability (and thus the stick forces needed to deviate from trim) by moving the center of gravity forward. We decrease stability (and decrease the forces) by moving it aft. We can fake the effect using trim, as described in the Procedures, above.

• You’ll observe that the push force required to hold the aircraft 10 knots, say, faster than trim is noticeably greater than the pull force needed to hold it 10 knots slower. That’s because the dynamic pressure generated by the airflow you’re holding against is a function of velocity squared, \( V^2 \). The illustration below suggests how stick forces vary with speed. The force is zero at trim speed.

![Stick Force Gradient](image-url)
**Phugoid**: Next, we’ll pitch up about 45 degrees or more, slow down and nibble at the stall, then return the stick to its trim position and let go. (This is a more aggressive entry than actually required to provoke a phugoid, but it’s a good attention-getter during unusual-attitude training.) The nose will start down, again indicating positive static stability, but then go below the horizon. Velocity will increase past trim speed, and the nose will begin to rise. Although the aircraft’s attitude varies, its angle of attack remains essentially constant. The aircraft will pitch up, slow, pitch down again, speed up, and then repeat this up-and-down phugoid cycle a number of times. It will gradually converge back to its original trimmed state. (Had we simply let go of the stick instead of carefully returning it to the original trimmed position, control system friction might have produced a different elevator angle and a different trim. That, in turn, could superimpose a climb or a dive over the phugoid motion.) Your instructor will point out that the amplitude of each pitch excursion from level decreases (indicating positive damping and thus positive dynamic stability) while the period (time to complete one cycle) remains constant at a given trim speed. The period is quite long, so the phugoid is also referred to as the “long period” mode—and the faster you fly the longer the period. Damping in the phugoid comes from the combined effects of thrust change and drag change as the aircraft alternately decelerates and accelerates as it climbs and descends.

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**You’ll need right rudder at the top of the phugoid to counter the slipstream and p-factor and keep the nose from yawing, and maybe some left rudder at the bottom. You might need aileron to keep wings-level, as well—but don’t contaminate the phugoid with inadvertent elevator inputs.**
Directional Stability

• Flat Turn: The next maneuver is the basic flight test for static directional (z-axis) stability. When you depress and hold a rudder pedal, causing the nose to yaw along the horizon, you generate a sideslip angle, \( \beta \). Sideslip creates a side force and an opposing moment. Notice the increased pedal force necessary as rudder deflection increases. For certification purposes, rudder pedal force may begin to grow less rapidly as deflection increases, but must not reverse, and increased rudder deflection must produce increased angles of sideslip. The rudder must not have a tendency to float to and lock in the fully deflected position due to a decrease in aircraft directional stability at high sideslip angles as the fin begins to stall. If it did, the aircraft would stay in the sideslip even with feet off the pedals. (Things could be dicey if the pedal force needed to return a big rudder exceeded the pilot’s strength. Many well-known aircraft had rudder lock problems during their early careers, including the DC-3 and the early Boeing 707, and the B-24 Liberator bomber.)

• A given rudder deflection produces a given sideslip angle, but the force required rises with the square of airspeed. So we won’t have to work as hard if we pull the power back to keep the speed down.

• When you release or quickly center the pedals, the now unopposed side force causes the aircraft to yaw (weather-vane) into the relative wind. In our jargon, the directionally stable aircraft yaws its plane of symmetry back into alignment with the velocity vector. This initial tendency demonstrates positive static directional stability. We’ve entered a dynamic state, as well. Momentum takes the nose past center, which generates an opposing side force that pushes it back the other way. The nose keeps overshooting, but the amplitude of the divergence decreases each time. This time history indicates positive dynamic directional stability. You might notice an increase in damping when you return the rudders positively to neutral and hold them fixed, instead of letting them float free. However, this behavior also depends on the amount of friction in the rudder control circuit.

• Notice that the aircraft tries to roll in the direction of the deflected rudder, and that you have to apply opposite aileron to keep the wings level. This is caused by a combination of dihedral effect (an aircraft’s tendency to roll away from a sideslip angle, \( \beta \), a response we’ll examine presently), and roll due to yaw rate—in which one wing moves faster than the other and produces more lift. An aircraft with reduced directional stability may yaw faster in response to rudder deflection than will a more stable type, and go to a higher \( \beta \), and consequently need more opposite aileron. (You’ll see a difference between the Zlin and the SF 260 in this regard.)

• Finally, note that when you apply aileron against the roll, you’re also applying an additional “pro-rudder” yaw moment, this time caused by the adverse yaw that occurs when the into-the-turn aileron goes down. (There’re other moments in the mix we won’t worry about.)

\[ v = V \sin \beta \]
Spiral Mode

• When you enter a shallow bank and positively return the controls back to neutral (so that unintended deflections or control system friction don’t taint the result) the aircraft should slowly start to roll level after a few moments. The aircraft’s velocity vector (for a definition, see ground school text “Axes and Derivatives”) has a component of motion (sideslip) toward the low wing, which leads to a wings-level rolling moment due to dihedral effect—a response referred to as lateral stability. The aircraft’s lateral stability provides positive spiral stability. Sideslip also produces a yawing tendency, but dihedral effect predominates at smaller bank angles.

• The outside wing in the turn is moving faster than the inside wing—that’s a yaw rate. As you add bank increments you’ll find a point—if the atmosphere’s not too turbulent—where bank angle remains constant (neutral spiral stability). The rolling moments produced by dihedral effect and roll due to yaw rate are now equal and opposite. (Again, there’re other moments in the mix, but their contribution is minor.)

• At some point the aircraft will likely begin a banked phugoid, just like the phugoids we’ve observed, but tipped on its side. The aircraft will bring its nose up and down as it turns. Hands off, the aircraft retains a constant angle of attack, according to trim, regardless of pitch attitude or bank angle.

• When we raise the bank angle further, but don’t increase lift by adding back stick, the aircraft slips increasingly toward the low wing. The yaw rate builds due to the greater side force against the tail. Directional (z-axis) stability causes the nose to weathervane earthward in a descending arc. Now roll due to yaw rate predominates over the opposite rolling moments, and sends the aircraft into the unstable spiral mode.

• Test pilots typically place an aircraft in a given bank angle, center the ailerons (or bank the aircraft with rudder while holding the ailerons fixed), and then time the interval required to reach half the bank angle for the spirally stable condition, or double the bank angle for the unstable. It’s important that control surfaces are positively centered during these tests, because any residual deflection caused by control system friction can create an apparent difference in spiral characteristics. (Friction confuses the picture when you’re trying to figure out how an aircraft behaves. Friction in the elevator system makes you think longitudinal stability is different than it is; friction in the ailerons that prevents them from returning to center automatically when released gives you a roll rate that shouldn’t be there. Normally, you’d accommodate to such things without really being aware of the extra control input—but here we’re paying attention!)

• The coefficient of roll moment due to yaw rate, \( C_{lr} \), goes up with coefficient of lift, \( C_L \), so it’s more pronounced at low speeds, where \( \alpha \) and coefficient of lift are high. And for a given bank angle, yaw rate goes up as airspeed goes down. So you’ll double your spiral bank angle more quickly at lower entry speeds.

• Finally, note that the ball stays essentially centered during a spiral departure. That’s directional stability doing its job, unto the last.
**Phugoid Again**

*Recover from spiral dives by first rolling the wings level with the horizon.* Now we’re back in the more familiar wings-level phugoid. Notice how the aircraft’s positive static longitudinal (y-axis) stability initially brings the nose back to level flight. You’d normally push to suppress the phugoid as the nose comes level with the horizon, but we’ll again allow the aircraft to go past level and progress through the first cycles of the phugoid mode.

• Again, you’ll need right rudder at the top of the phugoid to counteract the slipstream and p-factor and keep the nose from yawing, and some left rudder at the bottom. Jets and counter-rotating twins don’t have this problem.

• An aircraft’s longitudinal stability comes from its tendency to maintain a trimmed angle of attack. As you ride through it, the attitudes, altitudes, and airspeeds change, but in a phugoid the angle of attack, \( \alpha \), remains basically constant. The attitude excursions of our constant-\( \alpha \) phugoid remind us again that an aircraft’s angle of attack and its attitude are two different things. When displaced, aircraft return to their trimmed attitude and airspeed by virtue of maintaining their trim angle of attack throughout a cycle of phugoid motions. In essence, pilots keep altitude pegged by keeping ahead of the phugoid and damping its cycle themselves. A power change provokes a phugoid, unless the pilot intervenes to smooth out the transition.

• We’ll experience an increased g load as airspeed exceeds trim speed at the bottom of the phugoid. At a constant angle of attack, lift goes up as the square of the increase in airspeed. If we trim for 100 knots in level flight (1 g) and manage things so as to reach 200 knots (which we won’t!), airspeed will be doubled and load factor will hit a theoretical 4 g. If we accelerate to 140 knots, that’s a 1.4 increase in speed. \( 1.4^2 = 2 \); thus a load factor of 2 g. (The actual factor can be affected by the mass balance of the elevator, or the presence of springs or bob weights.) We’ll experience less than 1 g over the top.

• The phugoid shows us how a trimmed, longitudinally stable aircraft normally maintains its speed if left to its own devices. After a disturbance, it puts its nose up or down, trading between kinetic and potential energy, until it eventually oscillates its way back to trim speed (or to its trim speed band if control friction is evident). But the trade becomes solely potential to kinetic when a bank degenerates into a spiral and, as we’ve seen, the bank angle becomes too steep for the phugoid to overcome. Think of a spiral departure as a “failed” phugoid, in which the nose can’t get back up to the horizon because the lift vector is tilted too far over.

• What if an aircraft trimmed for cruise rolls inverted for some reason and the befuddled pilot just lets go? Left unattended, the inverted aircraft will pursue its trim by dropping its nose and “reverse-phugoiding” itself around in a rapidly accelerating back half of a loop (a “split-s”). Speed will rise until the structure maybe quits, or the dirt arrives. Inverted, hands-off survival prospects improve in the unlikely situation that the aircraft is at altitude but trimmed for slow flight. Trimmed for 70 knots with power for level flight, and then rolled inverted while the nose is allowed to fall, the Zlin will pull a 4-g split-s, hands-off on its trim state alone, using up some 1,300 feet of altitude. Then it will playfully zoom right back up into a normal but initially high-amplitude phugoid.

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Knife-edge Free Response

• After you’ve observed spiral characteristics, and learned to expect divergence following a high bank angle, knife-edge behavior might surprise you. Starting at knife-edge with the nose on the horizon, when the controls are released an aircraft with positive dihedral effect will generally roll upright and pitch nose-down (and then eventually pitch up into a phugoid if you don’t touch the elevator). The roll response has been associated with the amount of “keel” area above the aircraft’s c.g. Acting at different locations and in opposite directions, aerodynamic side force and gravity produce a roll couple. This wings-leveling couple, added to that generated by dihedral effect, overcomes the opposing spiral tendencies caused by directional stability and roll due to yaw rate.

• If you enter knife-edge flight, or even just a steep bank angle, in a nose-high attitude, however, spiral tendencies will often dominate. It’s fun to examine this by flying aggressive lazy-eights (linked wingovers) and observing which moments win out when you let go of the stick and/or rudder at various points. Note the phugoid embedded in the maneuver as the aircraft climbs and descends.
2. Steady-Heading Sideslip: Dihedral Effect & Roll Control

Flight Condition: Upright, crossed controls, high β.

Lesson: Lateral behavior during sideslips.

Procedures:

- Power for speed in the white arc.
- Apply simultaneous aileron and opposite rudder to rudder stop.
- Aileron as necessary to maintain steady heading with no yaw rate.
- Maintain approximate trim speed. Aircraft will descend.
- Hold rudder/ release stick.
- Repeat in opposite direction.

- Hold stick/ release rudder. Observe sequence of yaw and roll.
- Hold sideslip. Pitch up and down to demonstrate y-wind-axis pitch/roll couple.
- Possible Maneuver: Hold the sideslip and demonstrate “over the top” spin entry, with immediate, controls neutral recovery.

Flight Notes

A directionally and laterally stable aircraft yaws toward but rolls away from its velocity vector when the vector is off the plane of symmetry. Those characteristics are the “basic moves” of directional and lateral behavior. In our steady-heading sideslips, we’ll apply cross-controls—rudder in one direction and aileron in the other—causing the aircraft to fly with its velocity vector displaced from symmetry. The control forces necessary to prevent the aircraft from yawing and rolling in response to that displacement are the reflection of its inherent stability. They tend to change with angle of attack, especially in the buffet boundary, where aileron effectiveness often deteriorates and the rudder takes on increasing importance for lateral control. In that regime, a pilot often displaces the velocity vector on purpose, to assist roll control. (He may not know that’s what he’s doing, but nevertheless...)

Pilots of flapless (usually aerobatic) aircraft are accustomed to using sideslips to control the descent to landing. It’s how they show off in front of the aircraft waiting at the hold line. If you rely on flaps for descent, you may be rusty on aggressive cross-control slips. A little practice with them will improve your ability to respond to control system failures. You counter the rolling moment generated by an uncommanded rudder or aileron deflection by entering an opposing sideslip, modifying the sideslip as necessary for turns.

*Test pilots use steady-heading sideslips to evaluate an aircraft’s lateral stability. That means its tendency to roll away from the direction of a sideslip—in other words, to roll away from the direction the velocity vector is pointed when the velocity vector is not on the plane of symmetry. (The mechanics of lateral stability, or dihedral effect, are explained in more detail in the ground
Steady-heading sideslips are also used to assess directional stability and rudder effectiveness by measuring the rudder deflection and pedal force needed to produce a given sideslip angle, $\beta$. They can also be used to evaluate control harmony and to set up the conditions for observing Dutch roll. Wing-low crosswind landings are steady-heading sideslips, so an aircraft’s behavior in sideslips can limit crosswind capability.

- Pressing the rudder and yawing the aircraft creates a sideslip angle between the aircraft’s velocity vector and its x-axis plane of symmetry, as illustrated to the right, below. This in turn produces a rolling moment due to dihedral effect. We’ll evaluate the strength of this yaw/roll couple at various sideslip angles by observing the aileron deflection needed to counteract the roll and fly the aircraft at a constant, steady heading, although sideways and wing-low.

- You’ll enter a steady-heading sideslip by applying crossed controls: deflecting the rudder while adding opposite aileron to keep the aircraft from turning. Notice how the forces and deflections increase as you move the controls toward the stops. Under FAR 23.177(d), “the aileron and rudder control movements and forces must increase steadily, but not necessarily in constant proportion, as the angle of sideslip is increased up to the maximum appropriate to the type of airplane…. the aileron and rudder control movements and forces must not reverse as the angle of sideslip is increased.”

• Do you notice any differences sideslipping to the left or right, possibly caused by p-factor or slipstream?

• Dihedral effect can depend on aircraft configuration. It can diminish with flap extension. This is important in connection with rudder hard-overs, because flaps lower “crossover” speed, as you’ll see later.

• When you release the stick while holding rudder, the low wing rises due to dihedral effect and to roll due to yaw rate. Dihedral effect, strongest at first, decreases as the sideslip angle goes to zero. Roll due to yaw rate, weak at first, increases as the yaw rate rises; then suddenly disappears when the yaw damps out. The capacity to raise a wing with rudder alone, in case ailerons fail, is a certification requirement for non-aerobatic aircraft, and this stick release is a standard flight-test procedure.

• Aerobatic aircraft without much dihedral effect (such as the Great Lakes, or the Yak-52) often tend not to roll toward level but to pitch down at stick release. An aircraft’s pitching moment due to sideslip may be nose-up or down, minimal or pronounced, different left or right—depending on how propeller slipstream, fuselage wake, and the downwash generated by the wing and flaps affect the horizontal stabilizer. The combination of longitudinal (pitch) and lateral (roll) forces you find yourself holding helps you anticipate how aggressively the aircraft will respond on release. The Zlin is a great trainer in this respect.

**Angle of Attack ($\alpha$) and Sideslip Angle ($\beta$)**

- Angle of velocity vector, $V$, to x body axis gives aircraft angle of attack. Angle of velocity vector to wing cord gives wing angle of attack.

- Velocity vector, $V$, and sideslip angle, $\beta$. Sideslip to the right.

- Left rudder produces right sideslip.
When the stick is released in a sideslip to the left (right rudder down, left aileron), the Zlin can aggressively pitch-up and roll right, the combined motions leading to a sudden increase in the angle of attack of the right wingtip, and a possible tip stall. Much fun!

• Swept-wing aircraft can build up large rolling moments during sideslips, and mishandling can put even a large aircraft on its back. Sideslip angles are generally restricted to around 15 degrees during flight test for transport aircraft. FAR 23.177(d) says that a “Rapid entry into, and recovery from, a maximum sideslip considered appropriate for the airplane must not result in uncontrollable flight characteristics.” “Rapid” is a key word here, since a slow entry to and recovery from a sideslip keeps the aircraft’s angular momentum under control.

• Things get a little complicated now, and we apologize. Notice that when you first release the rudder, while holding aileron deflection constant, the aircraft doesn’t respond to the ailerons and immediately start rolling. Watch how the nose yaws and reduces the sideslip before the roll begins. The vertical stabilizer’s center of lift is above the aircraft’s center of gravity. As a result, the rudder deflection in a steady-heading sideslip actually produces an added roll moment in the same direction as the ailerons. (See Figure 17 in the ground school text “Lateral-Directional Stability.”) Releasing just the rudder eliminates this rolling moment contribution, but replaces it briefly by a rolling moment due to yaw rate as the aircraft straightens out. (Did you get that?) The important point is that only after the aircraft’s directional stability substantially eliminates the sideslip will the ailerons start to dominate and the aircraft roll. This really is less confusing with a hand-held model for demonstration, or in the aircraft where you can see things unfold.

• Our trick of holding the ailerons in place while releasing the rudder allows us to keep the roll moment due to aileron deflection fixed. We can then observe the yaw as the aircraft’s directional stability realigns the nose with the velocity vector. We can observe the ramp-up in roll response and properly attribute it to the vanishing sideslip. This gives us a way to use a steady-heading sideslip to demonstrate the relationship between sideslip and aileron effectiveness. A sideslip can either work for a roll rate, or against it. For a given aileron deflection, in an aircraft with dihedral effect, roll rate goes down when rolling into a sideslip (right stick, right velocity vector, say, as in the sideslip seen from above, illustrated on the previous page). Such an “adverse” sideslip could typically happen in an aircraft with adverse yaw and not enough coordinated rudder deflection when beginning the roll. On the other hand, stomping on the rudder too hard while rolling with aileron will skid the airplane and demonstrate that a proverse sideslip, opposite the direction of applied aileron, increases roll rate—in addition to sliding your butt across the seat. That stomp could be a useful trick for accelerating roll response in an emergency, but in swept-wing aircraft could lead to a severe Dutch roll oscillation. The fundamental relationship between sideslip angle (angle of the velocity vector versus plane of symmetry) and roll rate is something many pilots never really get—maybe because instructors think that the rudder affects only yaw. But in a laterally stable aircraft, yaw just about always provokes a rolling moment.

• Roll couple for a given sideslip angle, $\beta$, and aircraft configuration varies in direct proportion to the coefficient of lift, $C_L$. That’s certainly the case with swept-wing aircraft, and at least apparently the case with straight-wing, although not to the same degree. (See ground school text “Lateral-Directional Stability.”)

• Roll due to yaw rate also varies directly with $C_L$, as noted when we observed the spiral mode. When we fly steady-heading sideslips, we try to isolate dihedral effect by keeping the heading steady and eliminating yaw rate. But there’s always a yaw rate when we enter and leave the maneuver, and of course sideslips and yaw rates occur together in turbulence. Their individual contributions at a given moment can be difficult to sort out.

• You can think of the deflected rudder (or an existing sideslip) as setting the direction and initial rolling tendency, and of the elevator as modulating the rate through its control of $C_L$. 

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This is easy to remember, because when you raise $C_L$ by pulling back on the stick, toward the rudder, roll moment produced through dihedral effect and roll due to yaw rate increases. When you lower $C_L$ by pushing, the contribution decreases. This relationship holds for both straight and especially for swept wings, although the mechanisms and some details are different, as the ground school illustrates. It also works upside-down; as long as you have positive g. You will see this when we do rudder rolls.

• Or, if you prefer a more visceral terminology, put it this way: Hauling back and “loading” an aircraft increases yaw/roll couple; “unloading” decreases it. And that’s not all unloading does, as we’ll note more than once. Imagine that you’re operating at an angle of attack high enough to reduce aileron effectiveness through airflow separation, and high enough to disrupt flow over the tail such that yaw-axis stability is reduced and a sideslip develops. Putting the stick forward and unloading will reattach the flow, bringing the ailerons back while also reducing the sideslip-generated roll couple by reducing coefficient of lift, $C_L$. (Examples might be during an immediate recovery from an initial stall/spin departure—developed spins are handled with rudder first—or during a recovery from a rudder hardover.)

• With a swept wing, the dihedral effect derived specifically from sweep actually disappears at zero $C_L$. A sideslip then no longer produces a rolling moment, unless the wing also has geometrical dihedral (tips higher than roots), which does work at zero $C_L$. (Again, see ground school text “Lateral-Directional Stability.”)

• Wind-Axis: In this maneuver set we pushed and pulled on the on the stick while sideslipping. We watched the motion of the nose relative to the horizon, and discovered that the aircraft was pitching about its y wind axis, not its y body axis. Because of the displacement of the y wind axis from the body axis, a pitching moment also produces a rolling moment, as described in the illustration to the right. This geometrical effect works in the same direction as the $C_L$ effect described above. In other words, pulling will geometrically produce a rolling moment opposite the velocity vector; pushing will produce a rolling moment toward the vector. This is another effect that’s tough to visualize, but if you spend a few minutes fiddling with a small aircraft model you just might have a revelation.
Steady-Heading Sideslip Spin Departure:

More confusing stuff, sorry again: Here’s what happens when we stall the aircraft during a steady-heading sideslip, by holding crossed rudder and aileron while increasing aft stick. In a steady-heading sideslip to the aircraft’s left, as illustrated here, right rudder is deflected; ailerons are left. The horizontal component of lift created by the bank angle pulls the aircraft to its left and thus generates a nose-left aerodynamic force against the tail. We counter the resulting left yaw moment with right rudder to maintain our steady heading. At the stall, as lift goes down so does its horizontal component and the resulting yawing moment to the left. This allows the rightward yaw moment generated by right rudder to dominate. If we hold control positions the aircraft yaws and rolls to the right in an “over the top” entry into a spin.

- Going over the top is the most congenial way for the aircraft to behave, because the wings first roll toward level and there’s more time for recovery. Bringing the stick forward and neutralizing the other controls should keep the aircraft from entering a spin. Opposite rudder might also help. Remember that aircraft always depart toward the deflected rudder (opposite the displaced velocity vector). So you won’t break toward the low wing in a sideslip—it just feels like you might because that’s the direction in which you’re sliding off your seat.

- Note that in a side-slipping spin departure to the aircraft’s right, for illustration, the left aileron we originally hold to maintain a steady heading, and then for demonstration keep in at the stall, doesn’t arrest the rightward roll off. There’s too much airflow separation by that point for the ailerons to generate much opposite roll. But the down aileron still produces lots of adverse yaw, which pulls the right wing back and encourages a spin entry.

**Steady-heading Sideslip Spin Departure**

The horizontal component of lift increases as the stick is pulled back and $C_L$ rises. This component rapidly decreases at stall, as lift drops (dashed arrow).

Roll moment due to sideslip/dihedral effect

Roll moment due to ailerons, here shown in equilibrium with the opposing moment due to sideslip, quickly drops off as the aircraft stalls and airflow separates over the ailerons. But adverse yaw increases and helps drive the aircraft into a spin to its right.

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3. Stall: Separation & Planform Flow (Wing tuft observation)

Flight Condition: Upright, power-off 1 g stall, high $\alpha$.

Lesson: Stall anatomy.

**Procedures:**

Clearing turns.

Power idle.

Trim for 1.5 times anticipated stall speed.

1-knot-per-second deceleration below 70 knots.

Note buffet onset airspeed and stall speed.

Full stall before power-off recovery.

Power as required for recovery and climb.

Repeat with 5-knot-per-second deceleration below 70 knots.

Stalls while watching the wing tufts.

Provoke secondary stall in recovery.

Repeat with flaps. (Is there a difference in “break?”)

**Flight Notes**

We’ll cover boundary layers, adverse pressure gradients, and wing planform effects in the ground school and supporting texts. Then, as an accomplished aerodynamicist, you’ll be able to interpret the sometimes-surprising motions of the wing tufts and the accompanying separation of the airflow from the wing as $\alpha$ rises or the aircraft’s configuration changes. FAR Parts 23 & 25.201-207 cover stall requirements.

*On the way to the practice area, note the turbulence in the boundary layer as shown by the movement of the wing tufts. Note the increased movement as the turbulent layer thickens downstream.*

*Don’t make our stalls a minimum-altitude-loss, flight-check-style exercise. Give yourself time to observe the full aerodynamic progression. Play around. But remember: *This is not procedure training. Follow the recovery techniques in your aircraft’s AFM or POH.*

*For FAR Part 23 and 25 certification, stall speeds are determined for the aircraft configured for the highest stall speed likely to be seen in service. In part, this means at maximum takeoff weight and forward center of gravity limit, trim set for 1.5 anticipated stall speed, and using an airspeed deceleration rate of 1 knot-per-second starting at least 10 knots above stall. We’ll try to maintain this deceleration rate for later comparison to a 5 knot-per-second deceleration entry. Up to a point, increasing the deceleration...*
rate beyond 1 knot-per-second usually drives down the stall speed, but then the load factor starts to rise and stall speed increases. The decrease in stall speed that comes with a somewhat increased deceleration occurs because of the delay in pressure redistribution as \( \alpha \) rises. This delays separation and allows the wing to function briefly at a higher angle of attack and coefficient of lift than normal, a phenomenon called *dynamic lift* to differentiate it from the lift conditions at static angles of attack measured in a wind tunnel. Lift normally creates a downwash over the horizontal stabilizer, and thus a nose-up pitching moment. The nose pitches down when the downwash disappears at the stall. Dynamic lift delays this to a higher angle of attack.

- It’s important that a rapid deceleration produced by a high pitch rate doesn’t compromise control authority. That’s not an issue with our aircraft, but can be with large aircraft in which pitching momentum can carry and momentarily hold the aircraft past stall angle of attack, with insufficient airflow available for positive control. On the other hand, a deceleration rate below 1 knot-per-second may not produce maximum \( \alpha \).

- Watch the tufts. The trainer has the root-first stall progression typical of its wing shape. In contrast, swept wings naturally stall first at the tips. They’re coerced to behave more in a root-first manner by the use of stall fences, vortilons, vortex generators, and changes in airfoil from root to tip.

- Notice the definite relationship between airflow separation at the wing root, as evidenced by the tufts, and the buffet onset in our training aircraft. Do you feel the buffet in the airframe, mostly in the stick (as in the L-39 jet trainer), or in both? In our aircraft the buffet provides plenty of aerodynamic stall warning. Compare this to a T-tail design where the turbulent flow largely passes beneath the stabilizer and stall warning has to be augmented by a mechanical stick shaker, or to planform designs where the wing root separation happens too late to provide much aerodynamic warning. In the MiG-15, for example, there’s no real buffet—the stick gets light and lateral control goes to mush.

- You might want to do a couple of stalls with the instructor assisting in directional control while you concentrate on the wing and play the stick to modulate the full tuft stall progression from root to tip. If you’ve done the relevant ground school, visualize and manipulate the adverse pressure gradient in the chordwise direction, and the change in local coefficient of lift in the spanwise direction. Note the change in airflow over their surfaces (as shown by the tufts) when the flaps or ailerons go down. When the flaps go down, note the vortex that forms on the outboard tip. Acting on the tail, the increased downwash from this vortex causes the pitch-up that follows flap deployment.

- The secondary stall we provoked on purpose, by pulling too hard on recovery, reminds us of
the absence of positive (nose-up) pitch authority at maximum lift coefficient, $C_{L\text{max}}$, regardless of aircraft attitude. **We can run out of elevator (and aileron!) authority in any attitude when there’s no angle of attack in reserve.** The absence of positive pitch authority, in the form of an “uncontrollable downward pitching moment” is one of the ways the FAA defines a stall for certification purposes under FAR Part 23.201(b). We’ll revisit this loss of pitch authority when we fly loops, and during the pull-up recovering from spins.

• Part 23.201(d) states, “During the entry into and the recovery from the [stall] maneuver, it must be possible to prevent more than 15 degrees of roll or yaw by the normal use of the controls.” In coordinated flight, our trainers tend to stall straight ahead, without dropping a wing—at least not initially. If you hold the stick back during the stall oscillation, a wing may drop. Many aircraft, like the sultry Siai Marchetti SF260, will announce a stall more by a wing drop than by a nose-down pitch-break (also called a g-break). Some airfoil and planform arrangements can be demanding, no matter how carefully the pilot keeps the ball centered. A venerable T-6 Texan or SNJ will generally drop to the right. The right wing stalls first, reportedly, because it’s set at a higher incidence. Our ground school video of a T-6 wing shows how the stall pattern leads to early flow separation in the aileron region. Our video of the Giles G-200 aerobatic aircraft shows a rapid trailing-to-leading-edge stall, which gives no buffet warning, and in this particular aircraft produces a sudden drop to the left.

• Stall separation can also begin at the leading edge, and aircraft with leading-edge stalls typically misbehave. The stall break, perhaps caused by the sudden bursting of the laminar separation bubble, is abrupt and usually happens asymmetrically due to physical differences between the leading-edge spans. A wing drop is likely. On various Lear models, if the leading edge has been removed for repair, a test pilot will come out from the factory to do a stall test before the aircraft goes back in service.

• Even if meant to be, aircraft often aren’t aerodynamically symmetrical in behavior. In practice, manufacturing tolerances simply aren’t that tight; and a life of airborne adventure takes its toll. The PA-38 Piper Tomahawk became a particular offender when the production aircraft were built with fewer wing ribs than the prototype used for certification tests. This allowed the wing skins to deform—or “oilcan”—under changing air loads. Unfortunately, the performance of its GA(W)-1 wing is very sensitive to airfoil profile. The deformations led to rapid and unpredictable wing drop at stall. Prompt, proper recovery inputs were necessary. The Tomahawk has about twice the stall/spin accident rate per flight hours as the Cessna 150/152.
4. Accelerated Stall: G Loads & Buffet Boundary, Maneuvering Stability

Flight Condition: Banked, high $\alpha$.

Lesson: Flight behavior under turning loads.

### Procedures:

Power low cruise.
Trim.
Using instrument or outside reference, roll to bank angle specified by instructor.
Keep the ball centered with rudder.
Apply stick-back pressure to buffet, reducing power or increasing bank angle as necessary.
Note buffet speed, stall speed, buffet margin as compared to 1-g stall.

Repeat at higher bank angles. Note **exponential** rise in buffet speeds and stick force.

Explore aileron effectiveness in buffet by rocking wings 15 degrees left and right.

### Flight Notes

Earlier, we increased the airspeed deceleration rate to lower the “book” stall speed. Here we use load factor to raise it.

- Stall speed goes up by the square root of the load factor, $n$ ($n = \text{Lift}/\text{Weight}$).
- Induced drag goes up by the square of the load factor.
- Thus whenever you raise the load factor (pull “g”), stall speed and drag also rise. You can’t feel the latter two directly; you have to learn the association. The increasing stick force is one cue that the numbers are ascending. The force driving you into your seat is another.
- Of course, hangar wisdom holds that a wing’s **stalling angle of attack remains constant** for a given configuration (high-lift devices in or out). That’s a small fiction, but also a profound working “truth” because it emphasizes angle of attack as the essential stall determinant, not just a number on the airspeed dial—a number that itself changes with weight and load factor for a given configuration. If you want to be picky, stalling angle of attack depends on Reynolds Number, which is the ratio between inertia forces and viscous forces in the boundary layer on the surface of the wing. For a given airfoil, stall angle of attack rises with Reynolds Number.
- Notice the increased buffet intensity in the accelerated stalls compared to those at 1 g. There’s more energy in the turbulent airflow shed by the wing at this higher buffet speed (the inboard wing tufts tend to capitulate and blow off after repeated accelerated stalls), and more energy in the surrounding free stream flow.
• At higher g, does the buffet margin change compared to a 1-g stall? The comparison should be made at the same knots-per-second airspeed deceleration rate to be valid. Often stall warning varies inversely with knots-per-second, more rapid entry producing less warning. A rapid entry is probably typical of pilot technique in an accelerated stall.

• The accelerated stall and the 1-g stall both occur at the same angle of attack, but the accelerated stall requires a heftier pull. The aircraft exhibits an increase in pitch stability as the g load rises (meaning a stronger tendency to return to trim speed, which is the tendency you’re pulling so hard against). That’s because the angular velocity of the tail, caused by the pitch rate in the turn, produces a change in tail angle of attack, as illustrated to the right, and thus an opposing damping moment. Increasing the g load means increasing the pitch rate, and ups the damping. The additional elevator deflection needed to overcome more damping requires more force. This effect leads to what’s called maneuvering stability (which we cover in the ground school text “Longitudinal Maneuvering Stability”). Damping is a function of air density, and goes down as you climb.

• The geometry is such that, for a given g, an aircraft has a higher pitch rate (thus higher damping) in a turn than it does in a wings-level pull up. As a result, you’ll pull harder in a 2-g turn than in a 2-g pull up, for example.

• At a given density altitude, in aircraft with reversible control systems, like ours, the necessary stick-force-per-g is independent of airspeed (although Mach effects may increase forces at higher speeds). In other words, the force required to pull a given g doesn’t increase with airspeed, as you might naturally think. (Of course, it’s a bit more complicated. See ground school text “Longitudinal Maneuvering Stability.”)

• The table farther on shows how load factor increases exponentially with bank angle in a constant-altitude turn. It follows that stick forces also increase exponentially, rather than uniformly, with bank angle. A pilot banking into a steep turn has to increase his pull force at a faster and faster rate. Stick force rises slowly at lesser bank angles. Past 40 degrees or so, the increasing force gradient starts becoming more apparent. There’s a surprising difference in the force necessary for a 55-degree versus a 60-degree bank. Steep turns might get a little easier (maybe) once you figure this out.

• Notice the instant transformation in control authority at recovery due to the increased airspeed in the accelerated stall. Watch the wing tufts to see how quickly the airflow reattaches when you release some aft pressure. The damping you generate in the turn pushes the nose right down. At 2 g’s there’s a 40 percent increase in stall speed. Because dynamic pressure goes up as the square of the airspeed increase, that means double the dynamic pressure \(1.4^2 = 2\) available for flight control compared to a recovery from a stall near 1 g. More dynamic pressure means more control response for a given deflection. You can recover from an accelerated stall while the wing is still loaded (pulling more than 1 g). You only have to release enough g to get the stall speed back down.

---

**Pitch Damping**

\[
\Delta \alpha_v = l_T q \quad V_T
\]
Maneuvers and Flight Notes

• But releasing g may not always be equivalent to releasing your aft pressure on the stick. In some aircraft (often former military) you may have to push to expedite things. You may find that the gradient of stick force rises more slowly as g increases, as it does in the L-39 jet trainer because of the bungee cord “boost” within the elevator circuit. Or the aircraft may have an aft c.g., which increases maneuverability at the expense of stability, and thus reduces the tendency to pitch the nose down when aft pressure is released. Early swept-wing fighters had a tendency to stall at the tips first. Because of the sweep, a loss of lift at the tips shifted the center of lift forward and caused the aircraft to pitch nose-up and “dig in” during accelerated stalls.

• The higher dynamic pressure while maneuvering can lead to higher rolling moments if the wings stall asymmetrically. Any wing-dropping obstreperousness an aircraft might hint at during 1-g stalls can intensify at the higher airspeeds of an accelerated stall. Our rectangular-wing trainers stall root-first, and resist roll-off if flown in a coordinated, ball-centered manner. But accelerated stalls in other aircraft can be defined more by a wing drop than by a pitch break or a stolid, straight-ahead mush.

• As the load factor increases, the stall speed starts coming up to meet your airspeed. At the same time, if you didn’t or can’t increase power (“thrust-limited”), your airspeed starts heading down because of the increased induced drag. Eventually, if you pull hard enough, the two speeds converge. If an aircraft is thrust-limited, test pilots will perform descending, wind-up turns to explore its behavior at higher g, by turning altitude into the increasing airspeed necessary to attain increasing g levels.

• Because stall speed rises in a turn, your calibrated airspeed above 1-g stall dictates your bank-angle maneuvering envelope. The closer you are to the 1-g (wings-level) stall speed in a given configuration, the less aggressively you can bank and turn an aircraft while maintaining out of buffet and maintaining altitude. You can certainly enter a steep bank without stalling while flying slowly, since stall speed is not directly related to bank angle. Stall speed depends on load factor—in this case on the load factor required to make a turn happen at a given bank angle without altitude loss. For a constant-altitude turn, load factor goes up exponentially with bank angle, as the table illustrates. You can’t generate the necessary load factor unless you’re going fast enough for your bank angle. If you’re too slow, but nevertheless try to arrest a descent by hauling back on the stick, you’ll stall. Level the wings first. If you have excess airspeed, you can haul back and turn and climb.

<table>
<thead>
<tr>
<th>Deg. bank</th>
<th>Load factor required for constant-altitude turn</th>
<th>Stall speed factor increase over 1-g $V_s$</th>
<th>60 kt stall times increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>1.15</td>
<td>1.07</td>
<td>64.3</td>
</tr>
<tr>
<td>35°</td>
<td>1.22</td>
<td>1.10</td>
<td>66.3</td>
</tr>
<tr>
<td>40°</td>
<td>1.30</td>
<td>1.14</td>
<td>68.4</td>
</tr>
<tr>
<td>45°</td>
<td>1.41</td>
<td>1.19</td>
<td>71.2</td>
</tr>
<tr>
<td>50°</td>
<td>1.55</td>
<td>1.24</td>
<td>74.7</td>
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<td>55°</td>
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<td>1.32</td>
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<td>60°</td>
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</tr>
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<td>65°</td>
<td>2.37</td>
<td>1.54</td>
<td>92.4</td>
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<td>70°</td>
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<td>1.71</td>
<td>102.5</td>
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<tr>
<td>75°</td>
<td>3.86</td>
<td>1.96</td>
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<tr>
<td>80°</td>
<td>5.76</td>
<td>2.40</td>
<td>144</td>
</tr>
</tbody>
</table>

Pilots have it drilled into them that an aircraft can stall at any attitude. Stall speed is also independent of attitude. At a given weight and configuration, an aircraft pulling two g, for
example, has the same stall speed regardless of its attitude relative to the horizon.

• An aircraft constantly rolls toward the outside of a climbing turn. It constantly rolls toward the inside of a descending turn. (You’re right. This is difficult to visualize.) The rolling motion creates a difference in angle of attack between the wings, with the down-going wing operating at a higher angle of attack. As a result, climbing aircraft tend to roll away from the direction of the turn at stall break. This is favorable because it decreases the bank angle. When descending, they tend to roll into the direction of the turn at stall break. But propeller effects, rigging, and poor coordination can gum this up. Watch where the skid/slip ball is and see what happens.

• Prop-induced gyroscopic precession can affect control forces in turns. Precession creates a moment that’s always parallel to the axis of the turn—the axis typically being perpendicular to the horizon. On aircraft with clockwise-rotating propellers, as seen from the cockpit, precession pulls the nose to the dirt in a turn to the right, and to the sky in a turn to the left. If the forces generated are large enough (heavy prop, high rpm, high turn rate, long moment arm from prop to aircraft c.g.) more up-elevator will be needed when turning to the right. And the rudder becomes more involved as the bank angle increases and precession moves closer into alignment with the aircraft’s y axis. Greater rudder deflection may then be needed for coordination. The WW-I pursuits equipped with rotary engines (engine and prop turned together) were famous for their gyroscopic behaviors—quick turning to the left but awkward and vulnerable to the right. If the nose pitched down gyroscopically in a right turn, the pilot could spin out trying to counter with opposite rudder and up elevator.

• Finally, notice the greater rudder force necessary to stop or reverse a steep turn, compared to the coordinating rudder force necessary when beginning the turn. One reason is the higher angle of attack in the turn and thus the greater adverse yaw accompanying aileron deflection. Also, the aircraft has picked up angular momentum, which the rudder has to help oppose. So more rudder deflection is required for coordination coming out.
**Stick-force-per-g test procedure: wind-up turn.**

Fly the test at a constant, trimmed airspeed. Airspeed variations introduce additional forces, as described in the ground school “Longitudinal Maneuvering Stability.” At a constant airspeed and power setting, you will descend during the maneuver as bank angle increases.

Establish trim speed in level flight at test altitude. Record pressure altitude, temperature, and power setting.

Climb with increased power to 1,000 above test altitude. Reset trim power.

Bank as required to obtain desired load while descending as necessary to remain at trim speed.

If equipped, measure stick force when airspeed and g-meter readings stabilize. Establishing a stable state, even briefly, isn’t always easy— it takes practice, especially as bank angle increases! If you’re not equipped for measuring, a subjective assessment of stick force and gradient is still a useful exercise.

If the aircraft does not have a g-meter, use bank angles to establish approximate load factors. As 60° approaches, you might find it easier to control airspeed with your feet: for example, top rudder if speed exceeds trim.

<table>
<thead>
<tr>
<th>Trim speed:</th>
<th>Pressure altitude:</th>
<th>Temp:</th>
<th>Power setting:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank angle</td>
<td>30°</td>
<td>1.15-g</td>
<td>45°</td>
</tr>
<tr>
<td>Actual g-meter reading</td>
<td></td>
<td></td>
<td>60°</td>
</tr>
<tr>
<td>Stick force</td>
<td></td>
<td></td>
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</table>

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5. Nose-High Full Stalls, Lateral Control Loss & Rolling Recoveries

Flight Condition: Wings level, high \( \alpha \), nose-high, limited lateral control.

Lesson: Exposure to nose-high attitudes, limited visual references, lateral control loss.

**Procedures:**

**Full Stall: Nose-High Pitch Break**

25”/2,500 rpm.
Clearing turns.
Pitch up + 60 degrees (use wingtip reference).

**Power idle.**
Hold wings-level attitude as possible, keeping the ball centered with rudder.
Allow full stall with stick held back.

Pitch up + 60 degrees.
Hold necessary power, with stick back, aileron neutral and feet off the rudder pedals.
Allow a yaw rate to develop (aircraft will yaw left due to prop effects).
Observe lateral control divergence.
Recover aileron effectiveness with nose down pitch input.
Recover aileron effectiveness with opposite rudder.

**Rolling Recovery from Nose High**

Recover nose-below-the-horizon.
Recover nose-to-the-horizon.

**Flight Notes**

Nose-high recoveries are practiced in simulators as a standard element in upset training. The *Airplane Upset Recovery Training Aid* gives a procedure based on a push—followed by a roll, as required to get the nose back down. We’ll explore the dynamics of recoveries done badly. We want you to lose lateral control, see why, and see what it takes to get it back.

*The first maneuver gets you familiar with nose-high attitudes and pitch breaks. The pitch break (or g-break) in a 1-g nose-high stall is much more pronounced than in the 1-g stalls done from close to normal pitch attitudes. The aircraft rapidly sinks and the nose will swing well below the horizon before it’s possible to recover a flyable angle of attack. The initial nose-up attitude will block the horizon ahead and force you to use the wingtips for roll, pitch, and yaw reference. (The attitude indicator will be off, unless we forget.) Don’t just stare at one wingtip. We have two! Compare them.*
• We want you to experience lateral control divergence and loss of roll damping. We set this up by holding a nose-high attitude with power on, stick back, feet off the rudders, and ailerons initially neutral. We let the aircraft’s natural tendencies in this configuration take over. P-factor and slipstream will yaw the aircraft to the left. We’ll try to recover from the resulting coupled roll with ailerons alone (stick still held back). Lateral control will be lost.

• Notice that, while you can retain some aileron effectiveness into a stall buffet and break, at high $\alpha$, **ailerons’ effectiveness disappears if the airplane starts to yaw opposite the direction of intended roll**, as we let it do above. Instead of rolling the aircraft as we intend, the ailerons generate more adverse yaw than lift, which simply makes things worse. Once the stick goes forward, however, or the pilot uses rudder to stop the yaw, the ailerons regain authority.

• **The Airplane Upset Recovery Training Aid recommends recovery from a nose-high attitude with a push, followed by a roll if necessary (2.6.3.2-5).** Pushing starts the nose in the right direction and unloads the wing so that the aircraft accelerates and the ailerons retain effectiveness. Rolling tilts the lift vector and allows the aircraft’s z-axis directional stability to assist in bringing the nose down. Confining the roll to less than approximately 60 degrees keeps the wing lift vector above the horizon and makes pitch control easier in the recovery back to level flight. During the time it takes to roll the lift vector back to vertical, the buildup in angular momentum in a heavy aircraft can carry the nose unnecessarily below the horizon if the initial bank angle is too steep.

• In a delayed rolling recovery, if you hold the nose in the buffet and apply ailerons, you won’t have much roll authority. The reduced roll control at low airspeeds and high angles of attack can increase the difficulty of a rolling recovery from a nose-high attitude. This underscores the need to push and unload the airplane if the ailerons aren’t working.

• The “nose below horizon” and “nose to the horizon” rolling recoveries demonstrate the problem of flight path control at high angles of attack. Because nose-up authority disappears at high $\alpha$, stopping the nose on the horizon is difficult without encountering a buffet.

• In a jet, power application in a nose-high recovery will depend on the aircraft’s thrust line and the resulting pitching moment when power is applied. Aircraft with engines mounted on pylons below the wings can pitch up in a manner possibly difficult to control when thrust is increased at low airspeed. In addition, a jet has to accelerate and build up speed before control surfaces regain authority. With a prop, horizontal and vertical stabilizers start to regain authority once the slipstream returns. But ailerons still require airspeed. In an extreme case, if you slam the power forward on a go-around in a P-51 or similar warbird while flying slowly, the torque effect can be more than the ailerons can handle.
6. Roll Authority: Adverse Yaw & Angle of Attack, Lateral Divergence

**Flight Condition:** Upright, power-off 1g stall, high $\alpha$, varying $\beta$, pro-spin.

**Lesson:** Lateral/ directional control at increasing $\alpha$.

**Procedures:**

Spin recovery briefing as required.

Power idle.
1-knot-per-second deceleration below 70 knots.
Instructor demonstrates initial task.

Sample aileron authority: Decelerate toward stall while rolling 15 degrees left and right at a constant roll rate. Alternate between rudder free and coordinated rudder as necessary to hold nose on point.

Note:
1. Change in aileron deflection needed to maintain roll rate.
2. Change in aileron forces.
3. Increase in adverse yaw.
4. Contribution of coordinated rudder to roll rate.
5. Lowest speed for aileron authority.

Continue rolling inputs through stall break. At wing drop, hold opposite aileron. Observe aileron reversal. Hold aileron deflection and recover using forward stick to demonstrate return of aileron authority. Instructor will demonstrate if required.

Sample rudder authority: (Instructor demonstrates initial task.) Establish constant rate left/right yaw tempo sufficient to assess rudder authority during stall entry.

Note:
1. Change in required rudder deflection.
2. Change in rudder forces.
3. Lowest speed for rudder authority.

Observe lowest speed for lateral control using coordinated aileron and rudder.

**Flight Notes**

In the previous maneuver set we observed the loss of aileron effectiveness during delayed nose-high rolling recoveries. In this set we’ll continue to examine changes in lateral control. We won’t intentionally spin the aircraft at this point in the program, but the aircraft will be bopping around pretty aggressively, with the velocity vector wagging left and right, and these are potential spin entries (high angle of attack plus sideslip and yaw rate). Just centering the rudder and ailerons and releasing aft pressure is enough for recovery from an incipient spin departure in our aircraft. (As the spin develops, however, recovery technique becomes more critical, for reasons we’ll cover in spin training.) That said—don’t be timid. Challenge the aircraft to the point where lateral control is lost, and then get it back.
The subject of this maneuver set is mostly the rudder. Rudder-induced sideslips can accelerate a rolling maneuver and contribute to maximum-performance upset recoveries. Proper rudder use is essential for coordination at high $\alpha$; but misuse of the rudder at high $\alpha$ can also cause spin departure, or severe yaw/roll oscillation (Dutch roll), especially in swept-wing aircraft. Following the November 12, 2001 vertical stabilizer failure and crash of American Airlines Flight 587, an Airbus A300-605R, attention has focused on the structural loads generated on a vertical stabilizer when the rudder is deflected to opposite sides in rapid succession. Rapid rudder reversals, even below maneuvering speed, $V_A$, and even with rudder limiters, can result in loads in excess of certification requirements. FAR Part 25.351 rudder and fin load requirements are based on the demonstration of a sudden full rudder deflection (either to the stop or until a specified pedal force is reached) at speeds between $V_{MC}$ and $V_D$ (design dive speed) in non-accelerated flight. This is followed by a stabilized sideslip angle, and then the sudden return of the rudder to neutral, not to a deflection in the opposite direction.

The American Flight 587 accident also raised fears that unusual-attitude training that overemphasizes rudder can in fact provoke an upset if a pilot overreacts with rudder to an otherwise non-critical event, or uses it at the wrong time. Although we’ll demonstrate the effects of rudder and sideslip on rolling moments as $\alpha$ increases, for all the reasons above we won’t define the rudder as the primary high-$\alpha$ roll control, especially not for swept-wing transport aircraft (historical jet fighters are a separate issue). Reduce the angle of attack if necessary to regain lateral authority, and use ailerons or spoilers for unusual-attitude roll recoveries, along with the rudder required for coordination, not roll acceleration. This is consistent with both Boeing and Airbus philosophy, but can be applied to any aircraft. Aggressive rudder use is an important part of aerobatic training, and of course aerobatic training is the basis of unusual-attitude training. But aggressive rudder use doesn’t always carry over—partly because of concern the rudder will be used at the wrong moment and partly because, even with an experienced aerobatic pilot at the controls, the dynamics following a nominally correct aerobatic input may be different in a swept-wing aircraft than in a straight-wing trainer.

• In the golden days, when tail-wheel aircraft with lots of adverse yaw were standard, and pilots could still be seen wearing jodhpurs, flight instructors often had students perform back and forth rolls-on-point, which instructors in jeans today often mistakenly call “Dutch rolls.” (In a real Dutch roll the nose wanders.) The idea was to wake up the feet for directional control during takeoffs and landings, and especially to teach the rudder coordination necessary to counteract adverse yaw. This maneuver set is similar, but the dynamics are more complex and revealing because we roll the aircraft while simultaneously increasing its angle of attack (and thus its coefficient of lift, $C_L$).

• Pay attention to how control authority deteriorates: You’ll need to increase your control deflections to maintain rolling and yawing moments as airspeed (dynamic pressure) diminishes. The down aileron will begin producing proportionally less roll control and more induced drag as the angle of attack rises (induced drag increases directly as the square of lift), and therefore more adverse yaw. You’ll see the result in the movement of the nose. Keeping the nose on point with rudder will demonstrate how the rudder becomes increasingly necessary for directional control when using ailerons for roll control at higher angles of attack, and then increasingly dominant for roll control as the ailerons lose authority and roll damping begins to disappear.

• Rudder-induced roll control doesn’t decline as much as aileron control typically does, because the yaw/roll couple that the rudder provokes goes up in proportion to coefficient of lift. Aileron authority, however, goes down as airspeed diminishes and as flow separation begins to affect the outboard wing sections.

• Ultimately, at aircraft stalling angle of attack the ailerons can (legally, see below) begin to “reverse” (not to be confused with wing twisting, “aeroelastic reversal”). This happens when adverse yaw begins to dominate, and the opposing roll moment the yaw produces (through
sideslip and yaw rate) overcomes the roll moment generated by the ailerons. The airplane then rolls toward the down aileron. This is called lateral control divergence. Its natural prey is an airplane with lots of adverse yaw and lots of dihedral effect, when flown at high angle of attack by pilots who don’t use their feet to keep yaw under control (and thus the velocity vector on the plane of symmetry).

• Adverse yaw goes down and aileron effectiveness returns when you apply forward pressure to reduce $\alpha$: **Push to recover aileron effectiveness.** As in the nose-high stalls done earlier, you’ll see how quickly a “reversed” aileron regains its appropriate authority once the nose comes down.

• After the flight, compare the trainer’s stall behavior to the requirements in FAR Part 23.201-203 (for aircraft under 12,500 pounds) and to the requirements for transport certification under FAR Part 25.201-203. (See the Summary of Certification Requirements.) The wording is different, but 23.201(a) and 25.203(a) say the same thing. According to the latter: “It must be possible to produce and to correct roll and yaw by unreversed use of the aileron and rudder controls, up to the time the airplane is stalled.” [Italics ours] Did we demonstrate capabilities at stall $\alpha$ beyond those explicitly required?

• We’ve demonstrated the continuing authority of rudder, compared to aileron, for roll control in the high-$\alpha$ region of the envelope. Nevertheless, in general, *don’t rely on the rudder for primary roll authority at high $\alpha$, if you can avoid it.* The best course is to push the stick forward and cause normal control authority to return. Certification requirements assume a pilot will do just that. We don’t want our demonstrations to turn into what the airlines call negative learning, so remember: These lateral and directional control exercises are not procedure training. **Recover roll control at high $\alpha$ by pushing to reattach airflow and to restore aileron effectiveness as required.** Use coordinated, ball-centered rudder to enhance roll rate by checking adverse yaw. This is correct for any aircraft, but particularly so for swept-wing—in which yaw/roll couple is more pronounced than for straight-wing aircraft and the gyrations of the real Dutch roll are more severe, and in which the high-$\alpha/\beta$ corners of the envelope may not have been explored during flight test because operational encounter was never intended.
The illustration below puts things in velocity vector terms.

**Velocity Vector, V**

- **X body axis**
- **Z body axis**
- **Lift vector**
- **X-Z plane of symmetry**
- **Velocity vector, V, projected onto x-z plane gives aircraft angle of attack, α.**

- **Y-axis**
- **X-axis**
- **X-Y plane**
- **Velocity vector projected onto the x-y plane gives sideslip angle, β.**

A directionally stable aircraft yaws in the direction the velocity vector is pointed, returning the vector to the x-z plane of symmetry as it does. A laterally stable aircraft rolls away from the velocity vector when the vector becomes displaced from the plane of symmetry. In the illustration, the second aircraft wants to yaw right but roll left.

As an aircraft slows, and angle of attack and thus adverse yaw increase, aileron deflection will increasingly shift the velocity vector off the plane of symmetry, unless the pilot uses “coordinated” rudder deflection to counter the yaw. If present, P-factor and slipstream will also increase, tending to shift the velocity vector to the right unless the pilot compensates with right rudder.

So as speed goes down, the tendency of the velocity vector to wander goes up. The resulting rolling moments away from the velocity vector increase with β, and also increase with angle of attack.

Rolling an aircraft with rudder is a matter of pointing the velocity vector to generate a rolling moment in the desired direction. The dangers of aggressive rudder use at high angle of attack are that the aircraft enters a spin, or enters a Dutch roll oscillation the pilot inadvertently reinforces while trying to correct.
7. Flap-Induced Phugoid

Flight Condition: Longitudinally unstable, varying lateral/directional control.

Lesson: Downwash/horizontal stabilizer interaction, control practice.

Procedures:

Speed for white arc in level flight.
Student’s hands in “prayer” position (palms facing inward but not touching stick, rudder/aileron control only).
Instructor lowers flaps approximately 15 degrees.
Student maintains directional and lateral control. No pitch input.
Instructor manipulates flaps as required, monitors flaps-extended speed.

Observe the effect of lowering the landing gear.

Flight Notes

A dynamically stable phugoid motion is convergent. We can produce a non-convergent phugoid by lowering the flaps, but we don’t retrim. The flaps increase the downwash angle over the horizontal stabilizer and, with the stick free, the nose pitches up in response. As the wing roots stall and the downwash disappears, the nose pitches down. When lift then returns, the downwash reappears, driving the nose back up for the next stall. Your job, during this stall-and-recovery roller coaster, is to keep the aircraft under directional and lateral control, using aileron and rudder only.

• The center of lift moves rearward along the wing chord when you lower the flaps. This produces a nose-down pitch moment. (The drag you create below the aircraft’s center of gravity also contributes.) But watch the tufts when the flaps go down and note the vortices that form around the flaps’ outboard tips. These vortices increase the angle of the downwash affecting the horizontal stabilizer. This down flow produces a nose-up pitch moment. The pitch-up from the downwash on the stabilizer is greater than the pitch-down from the reward shift in lift. As a result, the aircraft pitches up at flap deployment.

• Anytime you (or a gust) raise the angle of attack of a wing you also increase the downwash angle. Typically, the downwash angle changes more rapidly with AOA when the flaps are deployed. Because the change in downwash angle reinforces rather than opposes a change in wing angle of attack, flaps generally reduce longitudinal (pitch axis) stability. One reason for T-tails is to raise the stabilizer out of the area of downwash (and propwash) influence.

• As the aircraft stalls and recovers, you’ll experience changes in lateral and directional control, already familiar from earlier nose-high maneuvers. Propeller and slipstream effects will be more pronounced, however, because of the need to maintain power to keep the maneuver going.

**Flight Condition:** Knife-edge & inverted, free yaw/pitch response.

**Lesson:** Free response behavior in rolling flight, attitude familiarization.

**Procedures:**

Check: Seat belt, cockpit, instruments, altitude, outside.

About 23”/2,300 rpm.

From **level** flight with **elevator and rudder neutral** throughout.

360-degree roll with **full aileron**.

Recover from dive (instructor notes g’s pulled in recovery).

If **motion sickness is not a concern**, repeat the same as above but use **partial aileron deflection** to decrease roll rate and allow the nose to fall farther below the horizon.

**Flight Notes**

We teach you to roll an aircraft through 360 degrees before we tackle emergency upset roll scenarios. This is less demanding on your motion tolerance at the start of training because the flying is smoother and you remain in control. You’ll begin by observing how the aircraft responds in pitch and yaw to changes in bank angle during a 360-degree rolling maneuver. Then you’ll learn to control that response.

• You’ll end up losing altitude, with the nose well below the horizon at the completion of these introductory rolls. They’re not the way an experienced aerobatic pilot rolls an aircraft—but we start with this ailerons-only, nose-in-level-flight technique to demonstrate the airmanship problems that an actual unusual-attitude rolling departure would involve. You’ll gain more sophisticated, aerobic control inputs as we fly.

• The aircraft’s free-response directional and longitudinal stability characteristics are designed for upright flight. They produce nose-down moments (with respect to the horizon) during a roll. Directional stability drives the nose down at each knife-edge, and longitudinal stability does the same at inverted. The more stable the aircraft, the more adverse the result.

• Notice the important relationship between roll rate and pitch attitude at roll completion. **The slower the roll rate the steeper the final pitch-down attitude.** The aircraft’s free response has more time to bring the nose down. Larger passenger aircraft roll far more slowly than aerobatic trainers. As a result, a badly executed maneuver for a trainer might actually simulate a best-case controlled-response outcome for a less
responsive aircraft. So, keep the roll going at the highest possible rate.

• While we want you to understand the importance of holding full aileron deflection to achieve maximum-rate recoveries, the idea of keeping the roll going needs qualification when we think about vortex encounters, and for the sake of primacy we should state it right off. By the time a pilot reacts to a vortex with opposite aileron the aircraft probably has already been tossed to a different part of the paired vortex flow field (and/or the individual vortex has snaked around to a different part of the aircraft) and the imposed rolling moment has changed. The compilation of NASA vortex encounter videos you’ll see in ground school will demonstrate how an aircraft is dispelled from a vortex core. You’ll see why you shouldn’t assume that even a violent initial roll acceleration caused by a vortex encounter is handled best by keeping the vortex-induced roll going through 360 degrees. That being said, note that The National Test Pilot School, in Mojave, California, does recommend using the aircraft’s existing rolling momentum, if advantageous, and continuing a roll once past 160 degrees.

• For a given control deflection, roll rate varies directly with airspeed. In aircraft with reversible controls, like our trainers, for a given deflection, aileron stick force goes up as the square of airspeed. Assuming no aeroelastic reversal, you’ll roll faster when flying faster, although you’ll have to push the ailerons harder and harder, and eventually will come to a point where the stick force is too much to handle and roll rate starts back down. The problem for us is at the low-speed end, where low roll rates going into the maneuver permit the nose more leisure to fall below the horizon if the pilot allows, and rolling recoveries back to upright take more time.

• A recovery at higher g after a partial-deflection roll allows you to experience sensations typically past the minimum 2.5-g positive limit load allowable for an aircraft certified under FAR Part 25.337(b). (Unfortunately a 360-degree roll followed by high g can trigger motion sickness in some, so let’s be cautious.) For aerobatic certification, which we operate under, FAR Part 23.337(a)(3) requires a positive limit load of 6 g.

• Remember that for a given g load the radius of a turn (or of a pull-up at the completion of a roll, as is the case here) at any instant varies directly with the square of the true airspeed. Double the speed means four times the altitude consumed. A recovery in a piston aerobatic trainer’s low-airspeed/high-g envelope consumes much less altitude than recovery in a jet operating at higher speeds and lower limit loads.

Roll Rates Depend on Airspeed and Control System Design

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Max force pilot can sustain with reversible controls.

Pilot maintains max force but deflection starts going down as airspeed increases.

Roll rate decreases for reversible controls because pilot can’t hold deflection.

Airspeed for max roll rate with reversible controls.
9. Slow Roll Flight Dynamics: Controlled Response

**Flight Condition:** Knife-edge & inverted, controlled yaw/pitch response.

**Lesson:** Control in rolling flight.

**Procedures:**

**Task:** Complete the roll with the nose on or near the horizon, not in a dive.

**Check:** Seat belt, cockpit, instruments, altitude, outside.

**Roll 1:** 25”/2,500 rpm.
- Airspeed at instructor’s discretion.
- Raise the nose 20-30 degrees.
- Release aft pressure/rudder neutral.
- **Full** aileron.

**Roll 2:** Raise the nose as instructor directs.
- **Top rudder at second knife-edge.**

**Roll 3:** Raise the nose as instructor directs.
- **Forward pressure at inverted.**
- Top rudder at second knife-edge.

**Roll 4:** Raise the nose as instructor directs.
- **Top rudder at first knife-edge.**
- Forward pressure inverted.
- Top rudder at second knife-edge.

**Roll 5:** Roll in the **opposite** direction.

**Flight Notes**

There’re three standard aerobatic rolls (and one weird one). The first exercise in this sequence is an **aileron roll**, so named because the ailerons do all the work. The next exercises introduce the **slow roll**—an aerobatic competition maneuver that uses help from rudder and elevator to keep the center of gravity of the aircraft moving in a straight line (as opposed to the climb and descent of the aileron roll). Slow rolls give you the tools to handle roll emergences with minimum altitude loss. The third standard roll is the **barrel roll**, which is actually a combination loop/roll that takes a path through the sky as if the aircraft were following the outline of a barrel laid on its side. The idea behind the barrel roll is to keep the aircraft at positive g for the sake of fuel flow and lubrication if it lacks inverted systems. It also keeps the occupants more confidently in their seats and permits the trick of pouring coffee from thermos to mug while upside down. We won’t do barrel rolls as part of your standard training sequence (although we can toss some in) but the **rudder roll** (the weird one), which we will do, is fairly similar.
Maneuvers and Flight Notes

Learning to slow roll is actually easier—and the exercise is more informative—when you take it as a problem to be solved by experimentation, and not as a textbook set of sequenced control inputs. Then, to make it easier still, you learn the rudder and elevator skills in reverse.

• In Roll 1, raising the nose high enough at the beginning of the maneuver and then rolling fast enough solves the procedure task by default. Start high and the nose simply falls through to meet the horizon at the end. (Of course, this doesn’t represent a typical nose-down unusual-attitude scenario.)

• In Roll 2, the rudder helps hold the nose up at the second knife-edge. The resulting sideslip can accelerate the roll rate through dihedral effect and roll due to yaw rate. Your instructor will make sure you experience this acceleration, because—with certain reservations—it’s an important emergency skill. As you gain experience, you’ll learn to amplify the effect by aft pressure on the stick. (The ultimate amplification becomes a snap roll, an aerobatic rather than emergency maneuver. Aerobatic pilots, especially competition pilots, actually avoid accelerating aileron rolls with rudder and elevator, since it leads to a sloppy-looking and physically unpleasant maneuver. But fighter pilots have used snapping roll entries since the First World War to quickly reverse direction and shake an attacker from their tail, especially at low speeds where aircraft usually snap roll faster than aileron roll.)

• Roll 3 uses forward pressure at inverted to keep the nose up. Remember that the necessary stick pressure and movement is much less in an aerobatic trainer, and the response much greater, than in an aircraft with more longitudinal stability.

• Roll 4 begins to approximate the technique used in competition slow rolls: initial top rudder at the first knife-edge, transitioning to forward elevator and back to the opposite top rudder at the second knife-edge. This produces a constant nose up (with respect to the horizon) yawing/pitching/yawing moment throughout the roll, working in opposition to the aircraft’s natural stability tendencies.

Sideslip Enhances Roll Rate

Top rudder causes a sideslip-induced roll moment, in addition to the aileron roll moment. This increases roll rate.

• The roll sequence is done first in one direction to ease the development of perceptual and motor skills. Roll 5, done in the opposite direction, is often confusing for the beginner because the now expected motor sequence is reversed. That’s why we do it! Here, your confusion makes us happy. Consider it a memorable training opportunity. Don’t freeze! Keep the roll going with full aileron deflection—rudder and elevator are secondary to aileron when you are learning to roll.

• Don’t expect to fly rolling maneuvers step-by-step using a memorized formula. The maneuver can break down dramatically if the aircraft’s attitude falls out of phase with your programmed
inputs and expectations. Instead of trying to establish a sequential muscle-motor program at the start, concentrate on reacting to the aircraft’s attitude with the correct muscle-motor response—your muscles will then program themselves. These rolls are building your perceptual familiarity with unusual attitudes along with the motor habits needed to respond as required. Learn to fly in response to what you see.

• On the subject of “flying what you see,” you can tell that we’re suspicious of applying memorized, step-by-step control sequences, or “mantras” at the initial stages of unusual-attitude recovery training. We’d rather try to help you to discover the correct inputs—under guidance—you. They’ll stick that way, and you’ll develop the necessary coordination and harmony. Memorized sequences are most appropriate when a pilot can’t figure out what’s happening and sequenced inputs are the only way to catch up and get things under control. In aerobatics, that kind of situation is most likely to occur when spins accelerate or change modes and the pilot loses visual tracking. Mantras are only safe when the initial input can be inserted at any time in the departure: otherwise out-of-phase inputs can actually make things worse. You may feel differently about this. It’s worth talking over.

• Once you’ve done a few rolls and experimented with control inputs and their results, the notion of tail-force vector will help you understand what you’ve in fact already begun to practice. You’re familiar with an aircraft’s lift vector from the standard illustrations of lift, weight, thrust, and drag. The tail-force vector is our term for the sum and direction of the “lift” produced by the rudder and elevator together. In coordinated, upright flight the tail-force vector comes entirely from the elevator/horizontal stabilizer (we’re neglecting any directional trim forces the rudder/fin might be producing). It usually points earthward, normal to the relative wind over the tail, and balances the nose-down pitching moment that results when an aircraft’s center of gravity is forward of the neutral point (see ground school text “Longitudinal Static Stability”). When flying inverted, forward stick is necessary to produce the same balancing, earthward tail-force vector. Otherwise, the nose heads downhill. In knife-edge flight, top rudder replaces elevator in keeping the tail-force vector pointed down, and the nose (as much as possible) up.

• To prevent the nose from falling, to delay the onset, or to reduce the rate at which the nose falls in a roll, we keep the tail-force vector pointed toward the Earth—using whatever
changing combination of elevator and rudder the current bank angle requires. Note that, in using the elevator and rudder in this way, we’re keeping the aircraft’s total lift vector pointed roughly heavenward. See “Axes and Derivatives” in the ground school texts.

• But here come the caveats: In non-aerobatic aircraft the effectiveness of these control inputs depends on the effectiveness of the control surfaces in flight attitudes neither they nor the rest of the aircraft were specifically designed to experience! Jet transports typically have a trimmable horizontal stabilizer with an attached elevator. The design facilitates wide c.g. and airspeed range, but pitch authority is limited by the position of the stabilizer. Even if the elevators are effective enough to slow the rate the nose drops while inverted, the resulting decrease in positive g may lead to fuel flow, lubrication, or hydraulic system failure. In the unlikely event the elevators are effective enough to actually push the nose up inverted, the resulting negative g may be insupportable structurally.

• There’s more to worry about: In an aerobatic aircraft, rudder forces are usually well harmonized with elevator and aileron. Dutch roll is usually well damped. But that may not be the case in a jet, especially swept-wing. In transports, rudder breakout forces can be high—and in some designs at certain speeds can be close to the force required for full deflection, a situation that can lead to over control. Because the sideslip angle has to build up before the resulting rolling moment appears, and because of roll inertia, there may also be a time lag between the rudder input and the roll response. Such factors make it difficult to achieve the rudder-input harmony and timing possible in an aerobatic trainer. The result of overzealous rudder use can be the build up of such a large sideslip angle and consequent roll moment that the recovering aircraft continues rolling past wings level. If the pilot reacts to the ensuing Dutch roll by deflecting the rudder against the sideslip (left sideslip, left rudder, say), the moments generated by the sideslip angle and the rudder together can “over yaw” the aircraft to the opposite side, causing it temporarily to reach an extreme, overswing sideslip angle. Suddenly reversing the rudder against the swing can set up the forces necessary to damage, or destroy, the vertical tail. Always use the rudder cautiously in a swept-wing aircraft.


• As we’ve shown, in an intentional roll you can finesse with top rudder at knife-edge and with forward stick through inverted in order to keep the nose up. You can use top rudder and slight aft pressure to accelerate the roll rate after passing from knife-edge back toward upright (as long as the wing isn’t too near stall and rudder likely to cause a departure). You can apply the same finesse to emergency recoveries as appropriate to your aircraft type, but don’t forget the most important control. In a recovery from a roll upset, use full aileron. It’s easy to relax aileron pressure inadvertently. Every student does it. Learn not to!
10. Sustained Inverted Flight

Flight Condition: Inverted, -1g.

Lesson: Situational awareness, trim forces, AI interpretation.

Procedures:

Instructor:
- Check: Seat belt, cockpit, instruments, altitude, outside.
- Cruise power.
- Fly a cardinal heading.
- Instructor asks student to point quickly to cockpit instruments and outside cardinal headings.
- Instructor rolls aircraft inverted and maintains control.
- Instructor asks student to point quickly to cockpit instruments and outside cardinal headings while inverted.
- Student takes control and rolls upright.

Student:
- Raise nose about 20 degrees.
- Roll inverted.
- Forward pressure as required to maintain level flight.
- Rock wings approximately 15-20 degrees left and right (note any sensation of adverse yaw).
- Roll upright.

Flight Notes

We teach full, 360 degree rolls before we teach half rolls to inverted because the distracting physiological effects of negative-g inverted flight are easier on the student when encountered later in training. Negative 1-g level inverted flight is an interesting training experience, but it’s actually more an aerobatic than an emergency skill. In reality, unless you assert yourself with forward pressure, and the aircraft has sufficient elevator power, you’re not going to experience sustained negative-g during an upset emergency short of an inverted spin (nor would you want to in an aircraft without proper fuel and lubrication systems). The aircraft will assert its longitudinal stability and start pitching toward positive g, as this maneuver illustrates.

- Reference points are hard to retain when you’re hanging upside-down. Students who can respond quickly to the instructor’s request to point out an instrument inside or a cardinal direction outside the cockpit when right-side-up often have trouble doing the same thing when inverted under actual negative g. There’s a tendency to tense the body and stare at a point, and just turning the head and looking around can require real effort. Flight skills don’t come naturally under these conditions, especially when you just discovered that your seat belt wasn’t as tight as you thought.

- When the instructor rolls inverted and transfers control and asks you to roll upright, you’ll be surprised at the amount of forward pressure he or she was holding. Don’t let up and let the nose fall too far. When you roll the aircraft from upright to inverted, remember how that push force felt and blend it in as you complete the half
roll. Notice inverted that the junk that was on the floor or loose in your pockets is now on the canopy. A little dust is inevitable, but anything that could jam the control system requires immediate recapture and a better preflight next time around.

• On rolling upright from inverted: If you’ve flown or read about aerobatics, you might know that strict procedure often requires rudder input opposite to aileron, followed by rudder input with aileron, when rolling upright from negative-g inverted flight. That’s because inverted adverse aileron yaw calls for some rudder deflection opposite to stick deflection. Such cross-control technique is usually confusing to the student at first, and tends to delay recovery actions. It’s important in precision roll training with aerobatic aircraft equipped with inverted oil and fuel systems. But it creates unnecessary confusion in unusual-attitude training for pilots who will fly non-aerobatic aircraft with conventional systems and much heavier control forces in pitch. Even if the pilot pushes as the aircraft rolls through inverted, the load will probably remain positive and inverted adverse yaw won’t occur.
11. Inverted Recoveries

Flight Condition: Inverted, high & low kinetic energy states.

Lesson: Attitude recognition and recovery practice.

Procedures:

Instructor:
Check: Seat belt, cockpit, instruments, altitude, outside.
23”/2,300 rpm.
Pitch up to about 45 degrees.
Student closes eyes.
Roll inverted; decelerate on ascent.
Idle power.
Gently pull nose below horizon.

Student:
Opens eyes on instructor’s command.
Rolls upright to recover.

Repeat from different inverted bank angles.

Student pitches up, closes eyes, rolls inverted, opens eyes and recovers on instructor’s command.

Instructor transfers control to the student inverted at a nose-high, low-kinetic-energy state.

To prevent excess airspeed during inverted recoveries, the instructor will normally close the throttle before the student takes control. In that case the student should simulate proper throttle use.

Flight Notes

Identify the Nearest Horizon (fewest degrees away): Push & Roll, Top Rudder, Pull

When using the AI, roll toward the sky pointer, or roll the lift vector toward the sky.

In this maneuver set we’ll apply the lessons learned in slow-roll flight dynamics to a more challenging attitude environment. Your instructor will fly the maneuvers to the descent line at the start, allowing you to recover. The initial goal is to get you going downhill, upside-down, horizon obscured, at as slow a speed as possible, with as gentle an entry as possible. This makes the fewest demands on your motion tolerance, and keeping the speed down allows you time to discover what the world looks like when you’re descending inverted. We may use rudder to accelerate the roll recovery, but we’ll take note of the caution required.
• In the first maneuvers, you’ll already know that you’re pointing down and accelerating. In that case, it’s correct to **Push** to keep the nose from falling farther. In subsequent nose-high transfers of control you’ll be very slow. You’ll be able to see the horizon, but will need to allow the nose to come down below it to let gravity help accelerate the aircraft so that control authority returns. Don’t reflexively push. If the aircraft somehow picks up a yaw rate, pushing while inverted at low speed could lead to an inverted spin.

• **Roll to the nearest horizon with full aileron.** The nearest horizon is the fewest degrees away. On instruments, that means rolling toward the sky pointer, or rolling the lift vector toward the sky.

• As the aircraft rolls upright from inverted to knife-edge, start applying **Top Rudder** and release the forward pressure. If you hold forward pressure past knife-edge you’ll sacrifice some of the dihedral effect necessary to assist the roll, and you’ll push the nose down and yourself out of the seat. Top rudder holds the nose up through knife-edge and starts a sideslip that accelerates the roll.

• Begin your **Pull** as the aircraft rolls through roughly 45 degrees. Come off the rudder as you near upright. Ailerons are primary, but past knife-edge combining top rudder and elevator can bring the nose up to the horizon following the shortest line.

• **The top-rudder deflection accelerates the roll and also keeps the airplane from turning when you begin your pull.** As you roll upright, rudder and elevator work together to keep the tail-force vector pointing roughly earthward, so that the nose comes up to the horizon in a direct vertical path and sideslip assists roll rate.

• You’re using rudder and elevator in an expert way in these recoveries. Just remember that the rudder and the elevator can cause trouble. We’ve already worried about misapplication of or inappropriate reliance on rudder at high $\alpha$, because of possible stall/spin departure. We’ve worried about differences between aerobatic trainers and swept-wing aircraft in their Dutch roll response to rudder deflection. Now worry about this: If you pull an aircraft to limit load while rolling with aileron and/or rudder (a rolling pull-up) the asymmetrical load generated across the span can take the up-going wing past structural limits. This could occur from the rolling moment generated by modest rudder application alone, since even a small moment applied at limit load would cause the wing to exceed that limit. This wrecks airplanes. See “Maneuvering Loads, High-G Maneuvers” in the ground school text.

• Any general statement about handling an aircraft in an upset emergency has to balance the risks of misunderstanding against the rewards of airmanship. A given control input or combination could either get you into trouble or else help you out of it…depending. So what’s best to say? A general statement also has to avoid optimistic assumptions concerning both a pilot’s ability and the unknown areas of an aircraft’s response. It has to assume that the expertise shown in training will deteriorate and that a pilot will become confused if too many half-remembered nuances exist in his mind. Aerobatic instructors know this from the experience of watching students fumble through roll recoveries as they try to remember what to do with the rudder and elevator. In light of the above, here’s a general, baseline, “I’m out of practice so what do I do now?” statement that applies to aircraft with standard flight controls and flying qualities. Embed this in your mind as the primary response: **In a roll-upset emergency, go to the ailerons first.** Unless you initially need them to lower the nose to regain airspeed for aileron authority, **rudder and elevator are secondary**. So much the better if you’re more expert than that!
Roll toward the Sky Pointer

Roll the Lift Vector toward the sky
12. Rudder Roll: Yaw to Roll Coupling

Flight Condition: High $\alpha$, high $\beta$, upright & inverted.

Lesson: Roll control by means of sideslip, yaw rate, and angle of attack.

Procedures:

Check: Seat belt, cockpit, instruments, altitude, outside.
$25^\circ$/2,500 rpm.
Pitch up to 45 degrees.
**Full** rudder deflection.
Ailerons remain neutral.
**Hold aft pressure.**
**Full** rudder throughout.

Repeat as above with **temporary forward pressure at inverted** to observe decrease in roll rate; restore aft pressure to completion.

Flight Notes

The rudder roll is similar to the old-fashioned barrel roll in terms of the flight path the aircraft follows through the sky, except the ailerons remain neutral and the heading changes are not as great. It’s also a kind of slow-motion snap roll, although the aircraft doesn’t go all the way into autorotation. It’s not often taught in civilian aerobatics, but has a history in the military as a way of rapidly reversing bank angle in a high-g turn. We fly rudder rolls to underscore yaw/roll couple, and to add their more complex motions to your unusual-attitude experience. The rudder roll also demonstrates that yaw/roll couple responds the same to longitudinal stick position whether the aircraft is inverted or upright (or in any other attitude), as long as the wing is at a positive angle of attack. Caution: Rudder rolls can rapidly erode motion tolerance.

- The aircraft will roll 360 degrees on dihedral effect, roll due to yaw rate, and y-wind-axis pitch/roll couple. Constant pitching, yawing, and sideslip drive the maneuver. Unlike the slow rolls we’ve been working on, where we try to keep the tail-force vector pointing earthward, in the rudder roll (and barrel roll) the tail-force vector rolls with the airplane.

- Notice how reducing the angle of attack with forward stick (unloading) while inverted reduces the roll rate. If you relax the stick (or rudder) too much the roll rate will really decrease and the nose will just head downhill. If necessary, recover with full aileron in the normal way.

- If you pull too hard the aircraft can snap roll suddenly (high angle of attack + sideslip and yaw rate = departure!). Release aft pressure and rudder if you feel the roll begin to accelerate too quickly. (A snap roll at the top of a loop is called an “avalanche”—which is nicely expressive of the tumbling feeling it produces. A snap departure out of a rudder roll feels the same, and causes the same spatial confusion on first encounters.)
13. Rudder & Aileron Hardovers

Flight Condition: Uncommanded rolls.

Lesson: Effects of pitch inputs during uncommanded rolls.

Procedures:

Demonstrate effect of pitch input during normal spiral, rudder neutral.

- Power for low cruise.
- Enter spiral mode.
- At 45-degree bank, observe response to stick-back pitch input.
- Release and recover.

Demonstrate effect of pitch input during rudder hardover spiral, rudder deflected.

- Aileron neutral.
- Roll 30 degrees with rudder only.
  - Hold rudder input.
  - Hold aileron neutral.
- Aft pressure to accelerate roll.
- Release and recover.

- Alternate aft pressure and forward pressure while holding rudder input and observe roll response.

Demonstrate recovery from rudder hardover below crossover speed.

- Begin rolling the aircraft with rudder, then apply a partial aileron deflection using too little aileron to stop the roll. (The aircraft is below crossover speed for the partial aileron deflection.)
- As the aircraft rolls, hold rudder and aileron fixed, pitch down for speed to regain aileron effectiveness.
- Add power in the recovery as necessary to remain above crossover speed.

Demonstrate recovery from uncommanded aileron deflection, showing the effect of rudder and aft stick.

- Partial aileron deflection.
- Apply rudder sufficient to slow but not stop the roll.
- Stick back (or nose-up trim) to increase $\alpha/C_L$.

Flight Notes

Concerns about rudder hardovers, and the development of the concept of crossover speed, stem directly from accidents involving Boeing 737s, which were caused or complicated by uncommanded rudder deflection. (See http://www.ntsb.gov/publictn/2001/aar0101.htm) Here we start by observing that in a rudder-neutral spiral attitude, back stick gives you a pure pitch response. But during a rudder-deflected spiral attitude, as produced by an uncommanded rudder hardover, back stick accelerates the roll. Although aircraft attitude relative to the horizon might appear identical to the pilot, in the rudder-deflected...
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case the aircraft is in a sideslip toward the high wing. Pitch will couple to roll in the presence of a sideslip. While the hardover issue may not affect all planes and pilots, it’s difficult to confirm one’s immunity, and the exercise does provide more evidence for flying’s least instinctive but most encompassing maxim: Sometimes you have to aim for the ground to keep from hitting the ground! In the uncommanded rudder deflection case, you aim for the ground to regain aileron effectiveness.

• Here’s an official definition, evidently approved by the attorneys, from The Airplane Upset Recovery Training Aid. At a given rudder deflection, crossover speed is “the minimum airspeed (weight and configuration dependent) in a 1-g flight, where maximum aileron/spoiler input (against the stops) is reached and the wings are still level or at an angle to maintain directional control.” (2.5.5.4.3)

• In other (if only slightly more digestible) words, rudder deflection produces a rolling moment, in the direction of deflection, due to sideslip and yaw rate. You can counter an uncommanded rudder deflection with opposite aileron, just as you do in a steady-heading sideslip, but only if you’re going fast enough to generate a sufficient opposing moment—that is, if you’re going above the speed where excess roll power crosses over from rudder to aileron. The more rudder deflection, the greater the corresponding rolling moment and therefore the higher the crossover speed. If you fly below crossover speed the aileron/spoilers can’t supply a sufficient opposing roll moment against the rudder, and an uncommanded roll in the rudder direction results. Wing-mounted multi-engine aircraft need powerful rudders to overcome asymmetric thrust conditions during engine failures. Uncommanded rudder deflections can produce powerful roll moments, especially in swept-wing aircraft.

• You’re familiar with cross-controlled maneuvers from our earlier steady-heading sideslips, and noticed (maybe) that we reached the rudder stops before reaching the aileron stops. To simulate a crossover problem at a reasonable angle of attack, we simply limit our aileron deflection and pretended we’re “against the aileron stops.”

• When an uncommanded rudder deflection creates a rolling moment, the aircraft’s nose will begin to fall through the horizon. Since roll couple for a given sideslip angle and aircraft configuration varies directly with coefficient of lift (with \( \alpha \)), as does roll due to yaw rate, the rudder-induced roll rate will increase if you try to raise the nose with aft pressure. This just tilts the lift vector more toward the horizon and makes the nose fall even faster (as we demonstrate in this maneuver set).

• In an emergency, if the hardover roll continues despite full opposite aileron, lower the nose to regain aileron effectiveness. Diving even more to regain bank control is not intuitive if the nose is already coming down in an unwelcome manner! But reducing the angle of attack will reduce yaw/roll couple, which in turn reduces crossover speed. Meanwhile, the airflow picks up the dynamic pressure necessary for aileron authority. As you raise the nose, set the power as required for flight above crossover speed. Then take a breath and pull out the Emergency Checklist for the recommended rudder hardover flap setting, if there is such a thing. (Maneuver set 14 demonstrated how flap deployment reduces a sideslip-induced yaw/roll couple, and thus would reduce crossover speed.)

• In an aileron hardover, you’d obviously try opposite rudder. Then if necessary you’d raise the nose to increase the \( C_L \) and increase the yaw/roll couple the rudder provides. Flaps would probably stay up, or go up if that were an option, again to increase yaw/roll couple as necessary to combat the ailerons.

• Remember that the basic relationship between what you do in pitch and what happens in roll remains constant. Pushing forward reduces rudder/sideslip-coupling effects and increases aileron authority, pulling back (literally toward the rudder) decreases aileron authority and increases rudder/sideslip-coupling effects.
14. Lateral Effects of Flap Deployment

Flight Condition: Changing $\beta$ & spanwise lift distribution.

Lesson: Lateral lift distribution and lateral stability.

Procedures:

Power as required for speed in white arc.
Enter steady-heading sideslip.

Hold rudder and aileron fixed.
Lower and raise flaps and observe lateral response.
Observe pitch response due to the changes in downwash angle.

With the flaps down in a sideslip and the aircraft trimmed, hold the rudder and release the stick:
Compare the roll rate with the flaps-up condition explored in maneuver set No 2.

If desired, repeat at idle power, maintaining airspeed in descent, to assess the contribution of propeller slipstream effects.

In the Zlin, full flaps, wings level, apply full rudder.
Observe pitch change with downwash/propwash shift.

Flight Notes

Here we’ll alter the rolling moments in a sideslipping aircraft by changing flap position. This ties into the concept of crossover speed during rudder hardovers. Crossover speed may go down in a flaps-down configuration because of the phenomena we’ll observe here.

• Putting the flaps down increases the lift generated at the wing roots and thus shifts the lift distribution inboard. This is partly because of the increased camber inboard, and partly because, after we’ve re-trimmed, the wingtips operate at a lower angle of attack. In effect, we’ve increased their washout. The inboard shift in center of lift reduces the effective moment arm and therefore the rolling moment that results from the sideslip. Accordingly, when you lower the flaps in a steady-heading sideslip, the ailerons will have less to fight against and the aircraft will roll in the pro-aileron direction.

• Because of this inboard shift in lift, an aircraft’s lateral stability (its tendency to roll away from the sideslip caused when a wing goes down) is typically reduced with flaps deployed. Its roll due to yaw rate may also decrease because of the washout effect. We’ve already noted the
reduction in longitudinal stability with flap deployment caused by downwash effects.

• The flap effect you’re seeing is magnified in propeller airplanes by the shifting of the slipstream over the wings toward the side opposite the sideslip, as the illustration shows. This means that the flaps on the high side during our steady heading sideslip work in an area of higher dynamic pressure. This increases the lift on the high wing, reduces it on the low wing, and produces a rolling moment in the same direction as the ailerons. With the power at idle, you’ll need more flap deflection to get the same roll response you got when lowering the flaps with power on.

• The last maneuver in the set demonstrates how a sideslip combined with flaps can cause a sudden change in the downwash/propwash over the horizontal stabilizer. The nose may suddenly pitch in response. Unless you really know how it will behave, don’t aggressively slip an aircraft with full flaps on final.

• In some aircraft, flaps can decrease aileron authority. This is one reason why using only partial flaps during a gusty, crosswind landing is a good idea. (The other, of course, is that a higher landing speed increases overall control effectiveness and leaves the aircraft vulnerable for less time.)
15. Dutch Roll Characteristics

Flight Condition: Coupled yaw/roll.

Lesson: How directional and lateral stability interact dynamically.

**Procedures:**

- About 23”/2,300 rpm.
- Trim.
- Instructor performs sinusoidal rudder inputs.
- Observe roll/yaw ratio at wingtip.
- Release rudder and observe rudder-free damping and overshoots.
- Compare with rudder fixed damping and overshoots.

**Flight Notes**

Your instructor will probably want to do this demonstration on the return from the practice area. Dutch rolls can erode motion tolerance rapidly, and that’s best saved for other things. FAR Parts 23.181 & 25.181 cover the requirements for Dutch roll characteristics. (Note: Our sinusoidal rudder inputs are consistent with FAR Part 25.351 yaw maneuver load requirements.) The Dutch roll is the natural outcome of aerodynamic stability: an aircraft’s tendency to yaw toward but roll away from its velocity vector.

- As already mentioned, the term Dutch roll is often misused. The real Dutch roll is not an exercise in rolling on point, but a coupled combination of yaw rate, sideslip, and roll. You can think of it as a rough marriage between an aircraft’s roll axis (lateral) stability and its yaw axis (directional) stability. In the Dutch roll, a disturbance in either axis, whether pilot-induced, as here, or caused by turbulence, creates a sideslip. A sideslip that sends the velocity vector to the left, for example, leads to an opposite rolling moment to the right (through dihedral effect and roll due to yaw rate). At the same time the aircraft’s directional stability works to eliminate the sideslip by causing the nose to yaw to the left. However, momentum causes the nose to yaw past center (past zero β), and this sets up a sideslip in the opposite direction, which in turn sets up an opposite roll. The resulting out-of-phase yawing and rolling motions would damp out more quickly if they occurred independently. Instead, each motion drives the other. Part 23 aircraft are required to damp to 1/10 amplitude in 7 cycles. Part 25 requires only positive damping.

- Aircraft with lots of lateral stability (the tendency to roll away from a deflected velocity vector), compared to their directional stability, tend to Dutch roll. Reducing dihedral effect will ease the Dutch roll problem, but at the expense of reduced lateral stability. Without a yaw damper to do it for them, it’s difficult for pilots to use the rudder to control a persistent Dutch rolling tendency because the period is short. It’s hard to “jump in” with the correct rudder input at the right time. (Failure of a yaw damper can also cause fin overstress if Dutch roll develops.) Swept-wing aircraft are inherently vulnerable to Dutch roll. Pilots of swept-wing transports are frequently trained to damp the rolling motion with quick, *temporary* applications of aileron against the prevailing roll. Temporary applications prevent the pilot from inadvertently driving the rolling motion. An aircraft with lots of lateral stability may also require lots of aileron.
deflection to hold the upwind wing down during crosswind landings.

• Aircraft with greater directional than lateral stability tend to be spirally unstable. Traditionally, the design compromise between Dutch roll and spiral instability suppresses the former and allows the latter, because spiral dives begin slowly and are normally easier to control than Dutch rolls. And Dutch rolls make people airsick. (Which sounds like the dealmaker until you realize that spiral instability can kill you if you lose or misinterpret your instruments in clouds, or in poor visibility at night.)

• Watch the wingtip while driving the Dutch roll with continuous, uniform, opposite sinusoidal rudder inputs. Observe if its motion pattern is circular or elliptical. An ellipse lying on its side (1.) means more yaw than roll—in other words a low roll-to-yaw ratio. This is typical of aerobatic and tactical aircraft required to have fast roll rates. A circular wingtip motion (2.) indicates equal amounts of roll and yaw, as might be typical of a general aviation aircraft, in which a pilot can use the rudder for bank control.

• An upright ellipse (3.) would indicate more roll than yaw—a high roll-to-yaw ratio. That’s typical of a sailplane and indicates that roll performance will require good rudder coordination during roll maneuvering. Any uncorrected adverse yaw will generate an opposing sideslip and large roll moments opposite the intended roll direction. (The long wings of high-performance sailplanes produce substantial adverse yaw due to roll rate, so footwork is essential.)

• The tendency to Dutch roll increases at higher \( C_L \), because increasing the coefficient of lift increases both dihedral effect (especially with swept-wings) and roll due to yaw rate. Dutch roll tendency also increases at higher altitudes, where damping effects diminish. Since aircraft fly at high \( C_L \) at high altitudes, the problem compounds.
16. CRM Issues: Pilot Flying/Pilot Monitoring

Flight Condition: Various.

Lesson: Upset recovery and the two-person cockpit.

Procedures:

Ground Briefing: Students formulate a plan of response, listing potential unusual attitudes and potential control errors, plus appropriate pilot monitoring actions.

Instructor:
- Check: Seat belt, cockpit, instruments, altitude, outside.
- Places aircraft in an unusual attitude.
- Announces: “Now recovering.”
- Begins recovery.

Student:
- Monitors instructor’s recovery technique.
- Guards controls with hands against improper deflections.
- Verbally coaches best recovery.
- Takes control as required.

Flight Notes

“Pilot monitoring” has replaced the earlier term “pilot not flying.” The change keeps both pilots in the loop, at least rhetorically. As pilot monitoring, your ability to coach your instructor and respond as necessary will confirm your understanding of recovery techniques. And you’ll be exposed to potential conflicts in CRM—in this case, recovery management.

- Your instructor may initiate recovery with the proper control inputs, but with inadequate control deflection. In that case you might coach, “More aileron,” then push the aileron if he doesn’t respond. Or your instructor may call out “Vertigo!” or initiate an incorrect recovery, in either case requiring rapid intervention on your part. One example might be a pull when inverted.

- If relevant, it’s important that all pilots in your flight department discuss the results of this drill at the completion of the course, and the possible changes or additions you might make to your CRM procedures.
17. Primary Control Failures

Flight Condition: Stick failure/loss of elevator, elevator trim, aileron.

Lesson: Re-establishing and evaluating control.

Procedures:

Fly parallel to a ground reference line (simulated runway).

Instructor places aircraft in nose-high or nose-low bank angle.
Student recovers and maintains control with rudder, elevator trim, and throttle only.
Turn 180 degrees and descend over reference line.
Establish landing attitude and a zero rate of descent at an altitude the instructor specifies.
Repeat without elevator trim.

Flight Notes

This maneuver set assumes the loss of both primary longitudinal (elevator) and lateral (aileron) control systems. Below are the FAR Part 23 requirements concerning loss of primary controls. In this maneuver set you’ll conduct, in essence, a FAR Part 23.145(e) and Part 23.147(c) flight test. The initial recovery from a nose-high or nose-low bank angle would not be part of such a test. That’s ours. Attempting the procedure without elevator or trim is also ours.

FAR Part 23.145(e) By using normal flight and power controls, except as otherwise noted in paragraphs (e)(1) and (e)(2) of this section, it must be possible to establish a zero rate of descent at an attitude suitable for a controlled landing without exceeding the operational and structural limitations of the airplane, as follows:
(1) For single-engine and multiengine airplanes, without the use of the primary longitudinal control system.
(2) For multiengine airplanes --
(i) Without the use of the primary directional control; and
(ii) If a single failure of any one connecting or transmitting link would affect both the longitudinal and directional primary control system, without the primary longitudinal and directional control system.

FAR Part 23.147(c) For all airplanes, it must be shown that the airplane is safely controllable without the use of the primary lateral control system in any all-engine configuration(s) and at any speed or altitude within the approved operating envelope. It must also be shown that the airplane's flight characteristics are not impaired below a level needed to permit continued safe flight and the ability to maintain attitudes suitable for a controlled landing without exceeding the operational and structural limitations of the airplane. If a single failure of any one connecting or transmitting link in the lateral control system would also cause the loss of additional control system(s), compliance with the above requirement must be shown with those additional systems also assumed to be inoperative.
Observations:

1. Using rudder, how aggressively should you bank the aircraft?
   - Does a phugoid appear during the turn?
   - How much altitude is lost after turning if you can’t trim?

2. Do the flaps produce a pitching moment that can be easily trimmed?

3. Do flaps affect the ability to turn using rudder (diminished dihedral effect)?

4. With the aircraft at a given trim state, gear down, what power settings are necessary for:
   - Level flight?
   - Positive rate of climb at moderate pitch attitude?
   - Controlled descent along a standard glide path?

5. Without trim available, can you achieve a landing attitude using power and/or flap deployment?

• FAR Part 23.145(e) assumes that the power and trim systems are available. It doesn’t require the test pilot to complete an actual landing. Flying without elevator but with trim in a more-or-less normal fashion presupposes that the elevator floats free, as it might with a broken cable. A jammed elevator is rotten news, even if it jams at a favorable angle. With the elevator frozen and trim tabs operating, trim input will reverse (nose-up trim will produce a nose-down pitch moment, for example). But don’t expect a trim tab to be an effective longitudinal control under these conditions. They’re designed to generate enough moment to deflect the elevator, not pitch the aircraft.

• Without primary controls, a long, stabilized final approach is absolutely essential. Without primary longitudinal and trim control, you’re stuck with an approach speed according to the aircraft’s trim state. Manipulate the glide path with power. Find a long runway, into the wind!

• Without the stick for primary longitudinal and lateral control, and without elevator trim, the phugoid suddenly becomes your constant pal. You’ll provoke a phugoid every time you bank using rudder. It’s difficult to damp a phugoid with power, but you should try during this exercise, just to see. Without trim control, your best policy is to ride the phugoid out. An aircraft at an aft c.g. may have a neutral or a divergent phugoid, however.
18. Spins

Flight Condition: High angle of attack plus roll due to sideslip and yaw rate. 

\[(\alpha + C_{l\phi} + C_{\mu})\]

Lesson: Departures and recoveries.

Entry Procedures:

1. Basic spin entry:
   - 4,000 feet agl.
   - Rudder and elevator trim to neutral.
   - Mixture rich.
   - Power idle.
   - Back stick for standard 1-knot-per-second deceleration.
   - Ailerons neutral.
   - Full rudder in desired spin direction at buffet onset.
   - Stick full back.

2. Nose-high, yaw-rate entry:
   - 4,000 agl.
   - Cruise power.
   - Hold steep climb attitude, rudder free.
   - Allow propeller effects to yaw aircraft to the left.
   - Back stick until stall/spin break.

3. Skidding-turn-to-final entry:
   - 4,000 feet agl.
   - Rudder and elevator trim to neutral.
   - Mixture rich.
   - 12 inches manifold pressure or as required.
   - Begin skidding turn with rudder.
   - Hold wings level with aileron.
   - Apply back stick until stall/spin break.

   Experiment with power to determine propeller effects.

   Apply sudden aileron toward the direction of the turn while holding rudder and elevator.

4. “Lazy-eight” departure/recovery drill:
   - Linked opposite-side half-turn spin departures and recoveries.

PARE Recovery Procedure:

   Power as spin state requires.
   Ailerons neutral.
   Rudder full opposite rotation.
   Elevator forward to neutral or past neutral according to AFM or POH.
   Recover from dive with rudder neutral.
**Flight Notes**

Spins have become a culminating skill in wide-envelope stick-and-rudder airmanship. In earlier days, under a different training philosophy, they were a pre-solo foundation skill. Pilots—and also aircraft—are different today as a result of this fundamental shift. The ground school text contains extensive material on spin procedures and theory. We review the PARE recovery technique here.

**Power to idle.** (Reduces propeller gyroscopic effects and slipstream-induced yaw.)

**Ailerons neutral.** (Removes any inadvertent deflection that may delay recovery. In a fuselage-loaded aircraft the ailerons go toward the spin direction to produce an anti-spin inertia moment in yaw.)

**Rudder opposite yaw direction.** (Provides anti-spin aerodynamic yaw moment.)

**Elevator forward to neutral or past neutral.** (Unstalls the wings; for wing-loaded aircraft generates anti-spin inertia moment in yaw.)

**When the spin stops, pull out with the rudder neutral.** (If recovery rudder is still deflected and you pull too hard, the aircraft can snap roll into a spin going the opposite way. Holding recovery rudder is a common mistake.)

Recovery inputs immediately following the break may be less critical (but not always).

• Note that in the PARE sequence, opposite rudder precedes forward stick. Forward stick applied before opposite rudder can accelerate the spin through aircraft gyroscopic effects, and can also cause the elevator to block the airflow to the rudder in some aircraft, each of which delays recovery. The acceleration isn't necessarily the case in an immediate recovery right after departure, however, as we’ll demonstrate and discuss. In our trainers the roll acceleration on departure is initially high; then the yaw rate picks up. As a result, angular momentum is greater in roll initially than in yaw. Pushing the stick forward causes gyroscopic precession around the roll axis that leads to an anti-spin moment in yaw. Plus, pushing gets the angle of attack back down. But once the aircraft’s yaw rate and angular momentum about the yaw axis have begun to build, forward stick will cause momentary gyroscopic acceleration in roll, even when it follows the rudder in proper sequence. Our introductory spins will go at least to the point where you can begin to feel the “push back”—the increase in pressure needed to bring the stick forward for recovery as angular momentum picks up in yaw and the aircraft becomes increasingly resistant to displacement, and also experience the momentary roll acceleration. It’s important to observe these characteristics and to recognize them as normal. One to one-and-a-half turns before initiating recovery will accomplish this in our aircraft. Multiple-turn spins beyond that have dubious value in introductory training. In the beginning it’s better to go for lots of entries and recoveries, do a careful analysis each time, and not waste training time recovering large chunks of altitude.

• As part of the analysis, after each spin try to describe the aircraft’s motions to your instructor.
You may find post-stall spin behavior difficult to follow at first, especially if your attention is occupied with remembering the recovery steps and wondering if they’ll actually work. But report each time. The task helps build tracking skills and confidence, and keeps the instructor updated on your progress.

• The infamous skidding-turn-to-final spin (spin entry 3) will produce a departure in some aircraft, while others are resistant (too much directional stability for the available rudder power; too little elevator power). Some will do it engine power off; some need a boost in yaw and pitch from the slipstream hitting the stabilizer and tail. The slipstream increases the upwash on the left wing, which then operates at a higher angle of attack and in a left turn stalls first. Spiraling slipstream also encourages a departure to the left. Frankly, a high-α skidding turn is hard to imagine from a properly trained pilot—the necessary control forces ought to warn the pilot off. But what about after an engine failure in an aircraft with a departure-prone wing, or when some other distraction arises? At low altitude and low speed, no matter how good the pilot, if obstacles are approaching it will be hard to resist the impulse to rudder rather than bank the airplane. If the pilot then pulls up the nose—there’s your spin.

• In the Zlin, and quite probably in many other aircraft, a rapid reversal of the ailerons toward the turn direction, while in-turn rudder and back stick are still being held, can cause a departure. When the opposite aileron is removed, the aircraft rolls and yaws suddenly in the direction of the skidding turn, and enters a spin. This may in fact be the true cause of many skidding-turn-to-final accidents. The pilot suddenly realized his error, but corrected with aileron alone.

• The fourth spin exercise is based on the lazy-eight. It’s done back and forth across a reference line on the ground. Each reversal of direction is accomplished as a spin departure, followed by a recovery to the half-turn point. Then you add power and pull up across the line, then cut power and spin a half turn to the opposite side. Next, go the other way. Your feet and hands are busy departing and recovering; you have to maintain orientation with the ground and stay well ahead of the aircraft to do the maneuver smoothly. If you can do all this, you’re definitely a hot stick!

• The pull up when the spin stops is full of important lessons. Depending on when in the spin the recovery was introduced, and whether the pilot as forgotten to neutralize the rudder (holding recovery rudder too long is a universal beginner’s mistake), the aircraft may end up in a sideslip, and may roll rather than raise its nose when the pilot applies back stick. Or, even if the pilot uses the rudder correctly, but pulls too hard before the aircraft has gained sufficient speed, the aircraft may enter the buffet and lose nose-up pitch authority. Remember this: When you see a substantial increase in pitch rate at low speed, the buffet won’t be far behind. If you penetrate the buffet too far, nose-up pitch authority may largely disappear! Ease off.