Lesson:
Turning Flight

Prerequisites:
Airspeed Control

Objectives:
- Knowledge
  - An understanding of the aerodynamics related to directional (yaw) stability
  - A basic understanding of induced and parasitic drag
- Skill
  - The ability to make constant airspeed, constant bank, streamlined turns

Materials / Equipment

Publications
- Flight Training Manual for Gliders (Holtz)
  Lesson 4.5 – Shallow / Medium-bank Turns

Documents
- Turning_Flight_Control_Position_Diagrams.pdf

Simulation Files

Flight Plan
- Turning_Flight.fpl

Replays
- Directional_Stability.rpy
- Turning_Flight.rpy
- Turns_To_Headings.rpy
- UnCommanded_Behaviors.rpy

Aerodynamics – Directional Stability

Directional stability is the tendency of an object to remain aligned with its direction of flight.

To minimize drag, aircraft are designed to keep the fuselage (longitudinal axis) aligned with the direction of flight. Directional stability is sometimes referred to as "weathervaning", as it is based on the same fundamental principles that cause a weathervane to align with the direction of the wind.

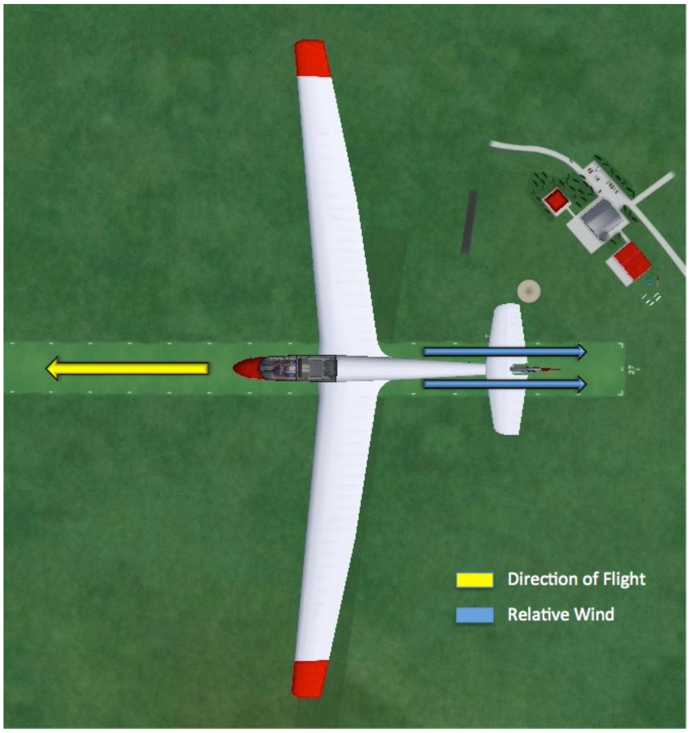
The glider's vertical stabilizer is the structure that provides its directional stability. Located well behind the glider's center of gravity, the vertical stabilizer has the leverage needed to easily keep the glider pointed in the direction it is moving.

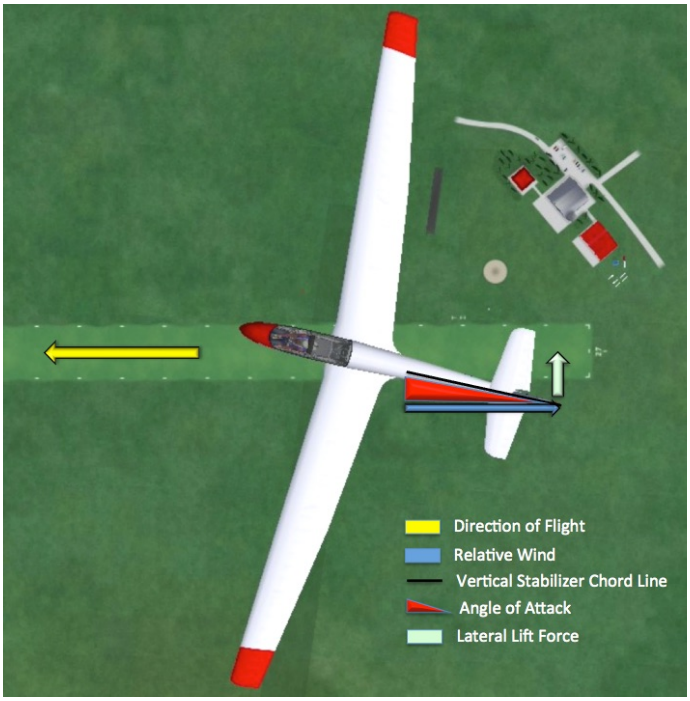
As we will see later in the lesson, directional stability is one of two key factors enabling a glider to turn, thus its introduction and discussion here.

In the image to the right, the glider's flight path is straight down the runway. The fuselage is aligned with the direction of flight. The vertical stabilizer is streamlined with the relative wind.

Note: This same weathervane effect is used to stabilize the flight of an arrow. The feathers on an arrow are basically directional stabilizers.

The tail section of an aircraft is often referred to as an "empennage"; French for "placing feathers upon."

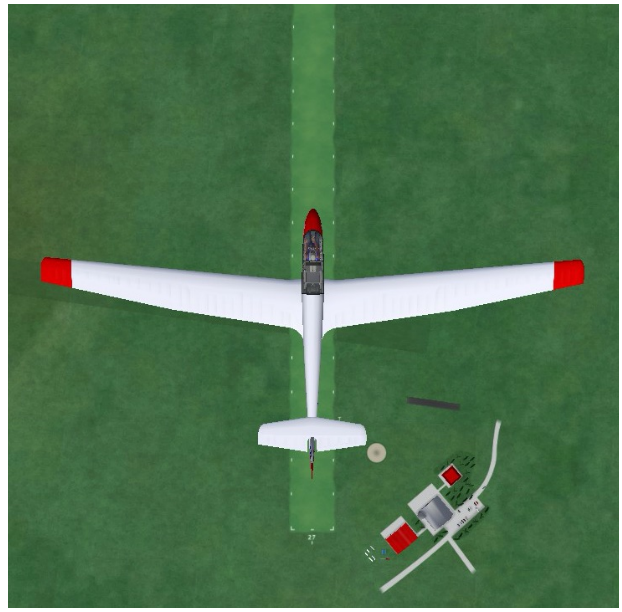




Should the fuselage of the glider (longitudinal axis) become misaligned with the direction of flight, the airflow past the vertical tail (relative wind) would form an angle of attack with the chord line of the vertical stabilizer. The resulting lateral lift force would move the tail back into alignment with the direction of flight.

Demonstration – Directional Stability

The purpose of this demonstration is to help you visualize how the glider's direction stability works to maintain alignment of the fuselage with the direction of flight.



Set-up

- View Replay == Directional_Stability.rpy
- Reset Replay to the Beginning (<<)
- Set Replay Camera to OFF (F9)
- Select External Glider View (F2)
- Adjust The view to match the image at the right

Description

The glider's direction of flight is straight down the runway. Using the rudder, the pilot yaws the aircraft out of alignment with the direction of flight, and then releases rudder pressure.

Notice how the glider's directional stability very quickly realigns the fuselage with the direction of flight.

- Press PAUSE (P) key to start the demonstration

Aerodynamics – Turning Flight

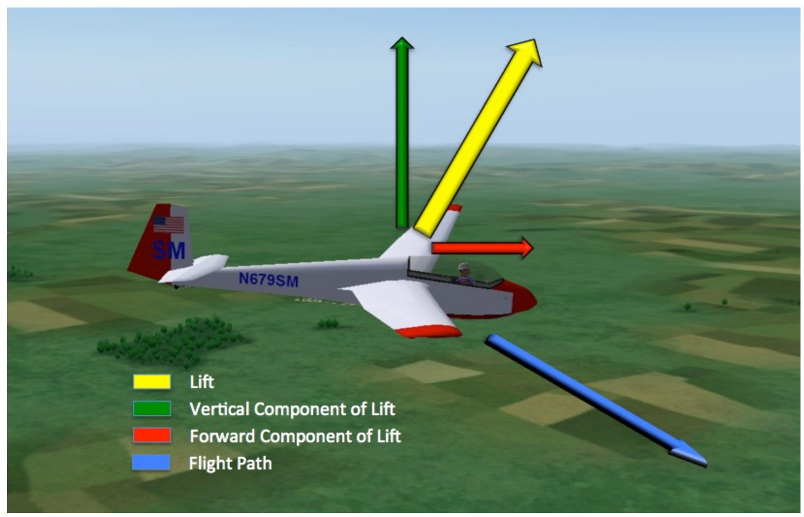
Everything I have ever read about what makes an aircraft turn has claimed it is "the horizontal component of lift" generated by banking the wing. Recently, a fellow glider instructor and mechanical engineer made me question whether that assertion fully explained things. So, before writing this lesson, I checked in with another CFIG, who is currently working on his P.H.D. in aerodynamics, and asked:

"What makes a glider turn?" His response was, "That depends on what you call a turn."

Later in this sequence of lessons, you will discover it is possible to alter the glider's direction of flight without changing its heading (where it is pointed), and to change its heading without changing its direction of flight.

To my way of thinking, a "turn" would require a change in both "direction" and "heading". In fact, that is exactly what the glider does. But to help you better understand what makes a glider turn, we need to take another look at what's happening with the lift vector in a turn, and then break the maneuver down into its component parts.

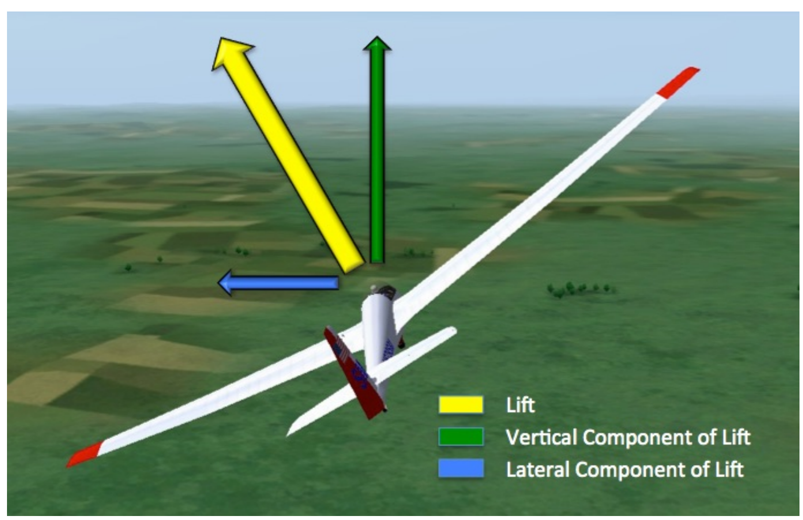
However, before discussing what makes a glider turn, let's review what makes it move forward.



By definition, lift acts perpendicular to the flight path. As such, a glider's lift vector has a forward slant (exaggerated here), which both resists the pull of gravity and moves the glider forward.

According to Newton's First Law of Motion, our glider will continue to fly straight ahead (forward) unless some additional force is applied to make it do otherwise, i.e. turn.

As shown at the lower right, when the glider is banked, the lift vector is redirected. In addition to its vertical and forward components, the lift vector now has a lateral component, which pulls (forces) the glider sideways.



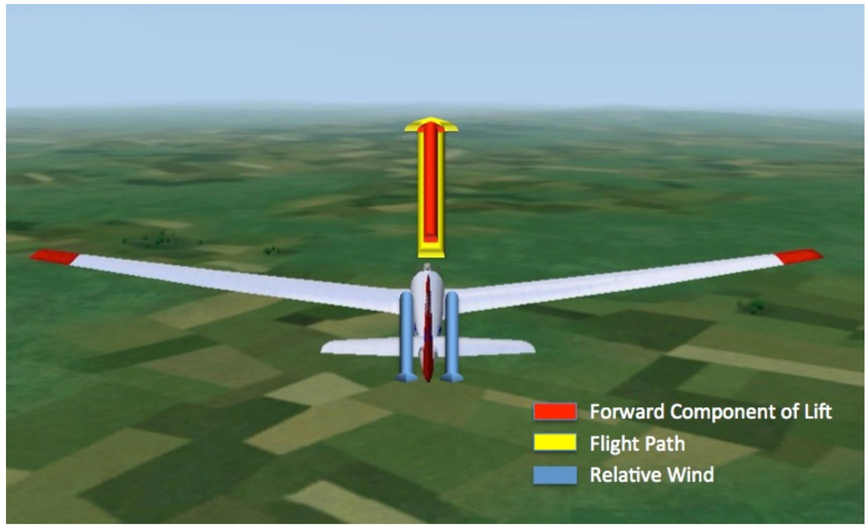
This is lateral force is the infamous "horizontal component of lift".

Note: Because the forward component of lift also acts horizontally, I prefer to use the term "Lateral Component of Lift".

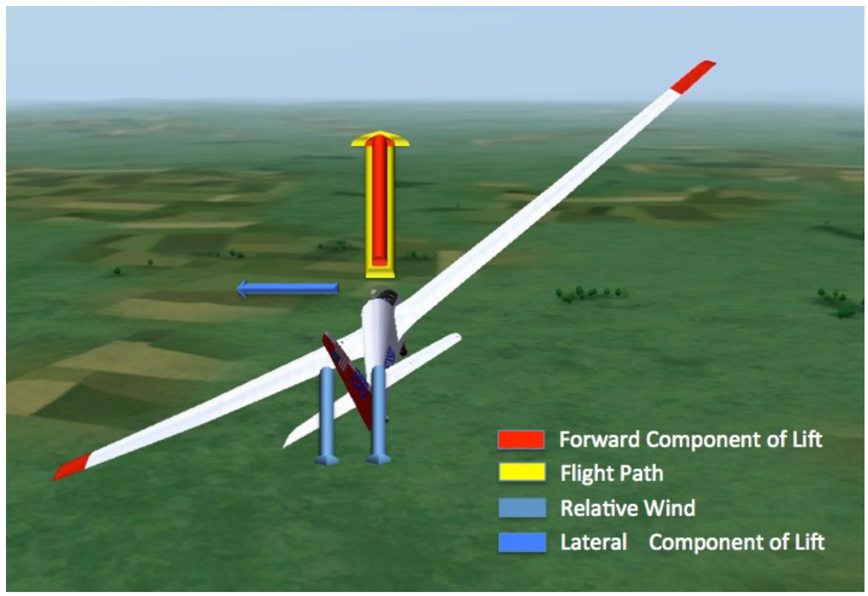
As mentioned earlier, **Directional Stability** is one of two key factors enabling a glider to turn. The **Lateral Component of Lift** is the other.

The image at the right shows our glider in wings-level flight.

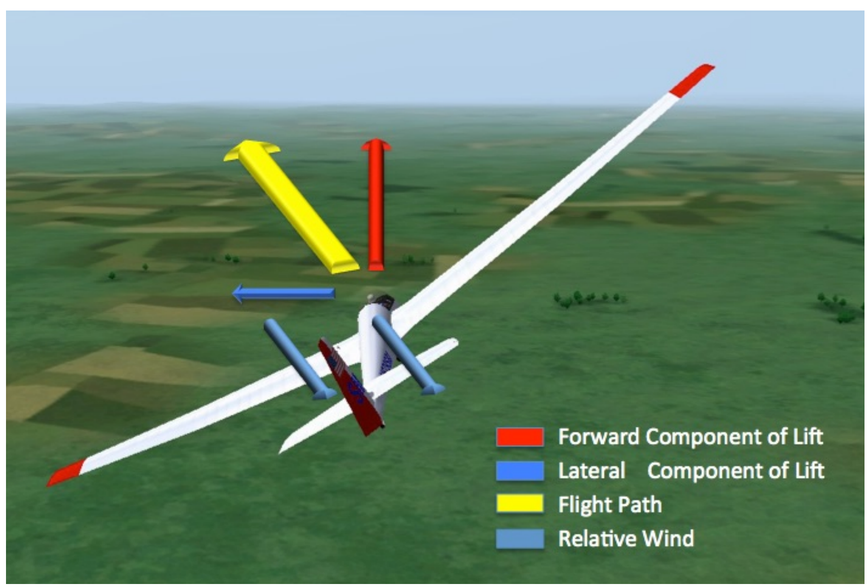
- The forward component of lift is moving it along the flight path.
- The vertical stabilizer is keeping the fuselage aligned with the flight path, i.e. the direction of flight.



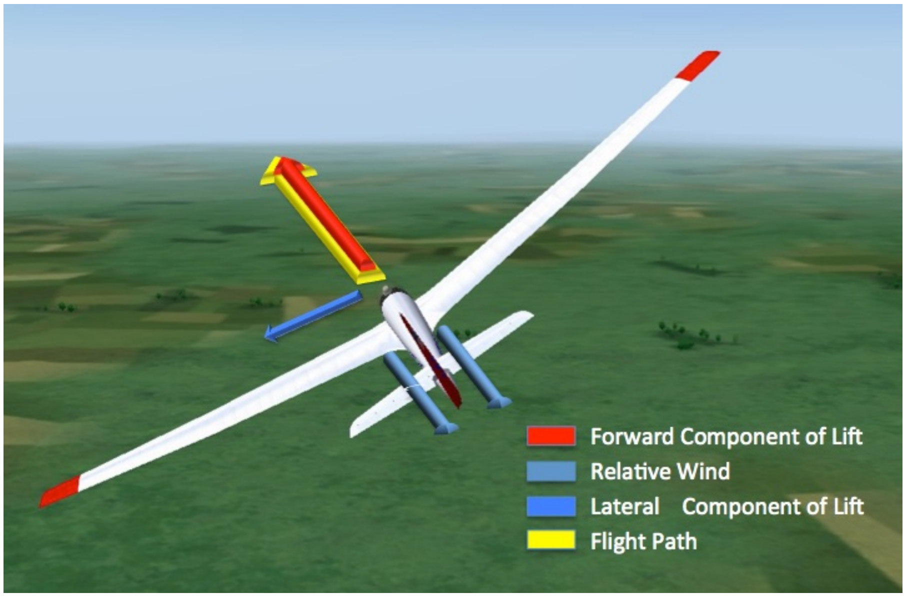
When the glider is banked, an additional lateral force is generated.



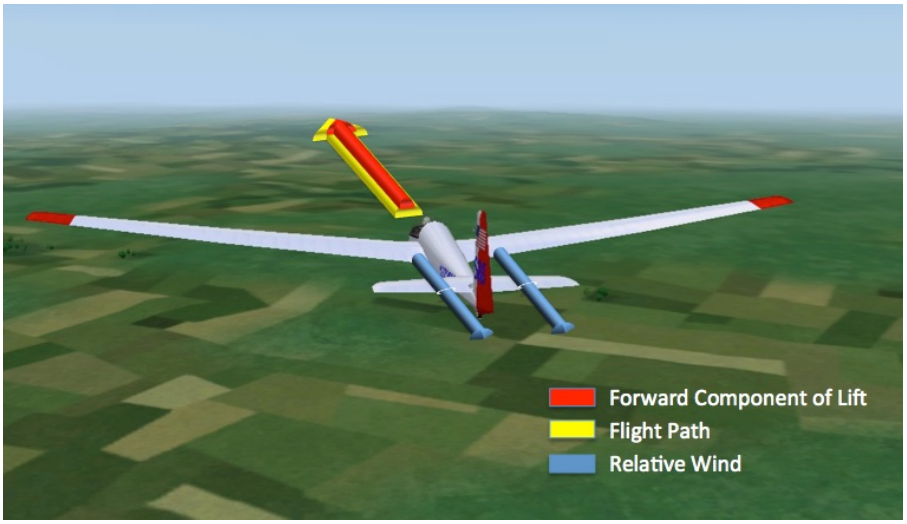
The combination of forward and lateral forces (components of lift) now acts to move the glider in a different direction.



The glider's directional stability then realigns the glider's fuselage with the direction of flight.



When the glider is returned to level flight, the lateral component of lift disappears, and the turn is complete.



Aerodynamics – Drag
To better understand the control inputs required to turn our glider, a basic understanding of "drag" is useful.

Start by reading the **Drag** section on pages 28 through 30 of the Glider Pilot's Handbook of Aeronautical Knowledge (Holtz).

For the purposes of this lesson, the important things to know about Drag are:

1. Induced drag is a function of angle of attack
   Any change in angle of attack produces an exponential change in induced drag

2. Parasite drag is a function of airspeed
   Any change in airspeed produces an exponential change in parasite drag

Demonstrations – Turning Flight
If our only objective is to turn the glider, we need only roll the glider into a bank, maintain the bank until reaching our desired heading, and then roll the wings back to level.

However, if we aspire to meet the objectives of this lesson, i.e. "a constant speed, constant bank angle, streamlined turn", the combination of control inputs is considerably more complicated, and requires that we understand and manage what I call "*the four un-commanded behaviors of a glider in a turn*".

1) Roll-induced Adverse Yaw

Set-up
- View Replay == UnCommanded_Behaviors.rpy
- Reset Replay to the Beginning (|<<)
- Place the cursor at the base of the yaw string as shown at the right. The cursor helps you visualize the glider's direction of flight.
- Press PAUSE to start/stop each Replay time segment

12:00:00 – 12:00:19
The glider's airspeed is stabilized at 42 knots.

12:00:19 – 12:00:22
The pilot initiates a roll to the left by moving the stick to the left. This causes the aileron on the right wing to deflect downward, increasing the angle of attack on the right wing, thereby causing the right wing to develop more lift. The aileron on the left wing is deflected up, reducing the angle of attack on the left wing, causing the left wing to develop less lift. With the right wing producing more lift than the left, the glider rolls to the left as commanded.

Notice too that the glider yaws to the right, opposite the roll command, and it does so with no control input from the pilot. The yaw is un-commanded.

Q. Why did the glider yaw opposite the roll?

A. The increased angle of attack on the right wing generated a corresponding increase in induced drag. The decrease in angle of attack on the left wing produced less induced drag there. With more drag on the right wing, and less on left, the glider yawed to the right.

This opposing-yaw effect is commonly referred to as "adverse yaw", and it occurs anytime the ailerons are deflected. I like to further qualify this effect as **"roll-induced" adverse yaw**, because, as we will see later in this lesson, adverse yaw can result from at least one other effect.

12:00:22 – 12:00:25
The pilot centers the stick, thereby moving the ailerons back into trail. This equalizes the angles of attack, lift, and induced drag, on each wing. The glider stops rolling, and is established in a bank.

Notice too, as the stick is centered, the glider yaws back in the direction of the turn; again un-commanded.

Without the differential induced drag on the wings, the glider's directional stability is now free to realign the longitudinal axis with the direction of flight. In fact, were it not for the glider's directional stability, the roll-induced adverse yaw would be even more pronounced.

12:00:25 – 12:00:34
The glider is longitudinally stabilized in the turn.

12:00:34 – 12:00:38
To stop the turn, the pilot initiates a roll to the right by moving the stick in that direction. This causes the aileron on the left wing to deflect downward, increasing the angle of attack, and generating additional lift. The aileron on the right wing is simultaneously deflected up, reducing the angle of attack on that wing, resulting in a corresponding reduction in lift.

With the left wing now producing more lift than the right, the aircraft rolls to the right, as commanded.

Once again, the deflection of the ailerons generates a differential induced drag between the two wings. The glider yaws opposite the roll command, this time yawing to the left, even as the glider is rolled to the right.

12:00:38 – 12:00:44
As the wings return to level, the pilot centers the stick. The ailerons return to a neutral position, the angles of attack on the wings equalize, and the glider stops rolling.

With the ailerons neutralized, the differential induced drag on the wings disappears, and without any input from the pilot, the glider realigns its fuselage with the direction of flight.

12:00:44 – 12:01:12
Watch this segment of the Replay without pausing. The pilot makes a right turn.

Pay particular attention to the control inputs:

1. Stick Right to initiate a roll to the right
2. Stick Centered to stop the roll and establish a bank
3. Stick Left to initiate a roll to the left
4. Stick Centered to stop the roll and return to level flight

12:00:44 – 12:01:12 (Repeat)
Watch this segment of the Replay again without pause. This time, notice the adverse yaw that develops each time the ailerons are deflected, and how the glider's directional stability realigns the glider to its flight path whenever the ailerons are neutralized (stick is centered).

Set-up

- Reposition the Replay to **12:00:44**
- Replace the cursor at the base of the yaw string
- Press PAUSE to start/stop the time segment

Roll-induced Adverse Yaw - Outside View
For another visual perspective on roll-induce adverse yaw, watch this Replay segment from outside the glider.

Set-up

- Reset Replay to the Beginning (|<<)
- Set the Replay Camera to OFF (F9)
- Set the View to In-Trail (F3)
- Zoom OUT to the limit
- Place the cursor under the glider as shown

12:00:00 – 12:01:12
As the demonstration begins, the glider 's main wheel will appear to be balanced on the cursor. The glider then makes two complete turns; first left, then right.

As the pilot initiates each turn by deflecting the ailerons, the glider appears to rotate on the cursor as it yaws opposite the roll command. Each time the pilot neutralized the ailerons to stop a roll, the glider's directional stability yaws it back in the direction of the turn.

To complete each turn, the pilot moves the stick so as to roll back to level flight. Again, the glider yaws opposite the roll, as the deflection of the ailerons generates different amounts of induced drag on each wing.

As the wings roll level and the pilot neutralizes the ailerons, the induced drag on the wings equalizes, and the vertical stabilizer aligns the fuselage to the direction of flight.

- Press PAUSE to start the demonstration.
- Press PAUSE to stop the Replay after the 2^{nd} turn.

Managing Roll-induced Adverse Yaw
From the previous demonstrations, it seems clear the glider can be turned using only aileron control inputs, but all this yawing back and forth is very inefficient. When the glider is longitudinally misaligned with its flight path, the side of the glider is exposed to the airflow, thereby creating a lot of unnecessary drag.

As the demonstration continues, rather than allowing the glider to yaw in opposition to each roll, the pilot deflects the rudder in the direction of the roll whenever the ailerons are deflected, and centers the rudder as the ailerons are neutralized. By commanding the glider to yaw in the direction of the roll, the pilot is essentially counterbalancing the glider's tendency to yaw in the opposite direction. The result is a streamlined entry into the turn.

Set Up

- Set the View to Cockpit (F1)
- Set the Replay Camera to ON (F9)
- Place the cursor at the base of the yaw string
- Press PAUSE to start/stop each time segment

12:01:12 – 12:01:20
The pilot initiates a roll to the left by applying left stick, while simultaneously applying left rudder to counteract the adverse yaw. She then terminates the roll (establishes a left bank) by neutralizing the rudder as she centers the stick.

Notice that the cursor remains aligned with the yaw string, and the yaw string remains straight.

12:01:20 – 12:01:38
With the rudder centered, the glider's directional stability maintains a relatively streamlined left turn.

12:01:38 – 12:01:50
To stop the turn, the pilot initiates a roll to the right, and counteracts the adverse yaw by simultaneously providing just the right amount of right rudder input.

12:01:50 – 12:02:14
The pilot enters and stabilizes a streamlined right turn.

12:02:14 – 12:02:26
While rolling out of the turn, however, the pilot does not provide quite enough left rudder input.

The base of the yaw string moves to the right of the cursor indicating a slight roll-induced adverse yaw to the right. The pilot recognizes the deficiency and corrects it by the time the wings roll level.

Managing Roll-induced Adverse Yaw – Outside View
Contrast often serves to make a point. This demonstration segment comprises four turns; the first two turns are made with aileron inputs only; the last two turns incorporate the coordinated use of aileron and rudder.

Set-up

- Reset Replay to the Beginning (|<<)
- Set the Replay Camera to OFF (F9)
- Set the View to In-Trail (F3.1)
- Zoom OUT to the limit
- Place the cursor under the glider as shown

12:00:00 – 12:02:26
The first two turns look like a clown act. The second two, by contrast, are graceful and elegant.

- Press PAUSE to start the demonstration
- Press PAUSE to stop after the 4th turn

2) Pitch / Airspeed Excursions

Set-up

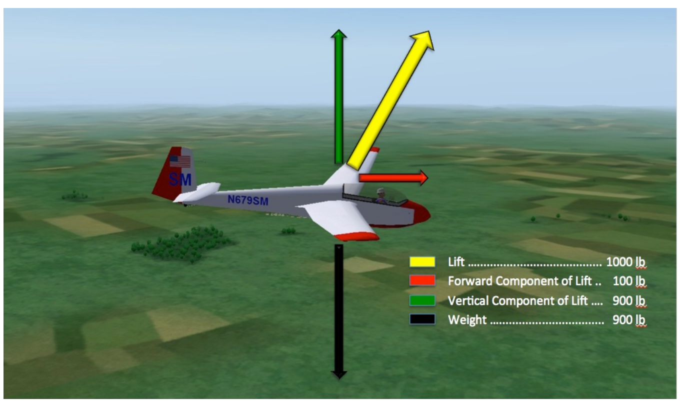
- Set the View to Cockpit (F1)
- Turn the Replay Camera ON (F9)
- Press PAUSE to start/stop each Replay time segment

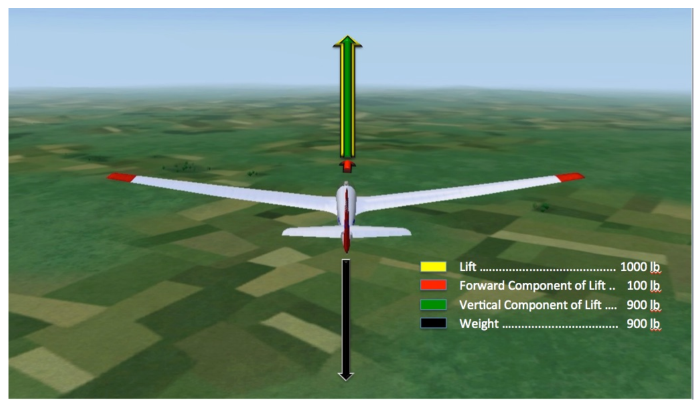
12:02:26 – 12:02:53

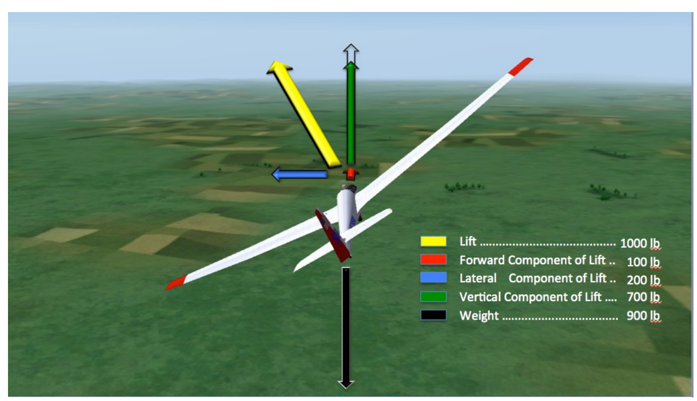
As we begin this next segment, the pilot rolls the glider into a left turn using coordinated aileron and rudder control inputs. Almost immediately, another un-commanded behavior becomes apparent; the glider pitches down and begins to pick up speed.

Q. Why did the glider pitch down?

A. In level flight, the vertical component of lift is in equilibrium with the pull of gravity on the glider (weight). The images below show this relationship, first in profile, and then from behind the aircraft.







As the glider is rolled into a bank, the lift vector is redirected so as to generate the lateral force needed to turn the glider. However, redirecting the lift vector also results in a reduction in the vertical component of lift, the component that opposes the pull of gravity (weight).

With gravity now having the upper hand, the glider accelerates downward. The pilot sees this downward acceleration as an increased rate of descent on the variometer. The glider senses it as an increase in angle of attack, resulting from a steeper flight path.

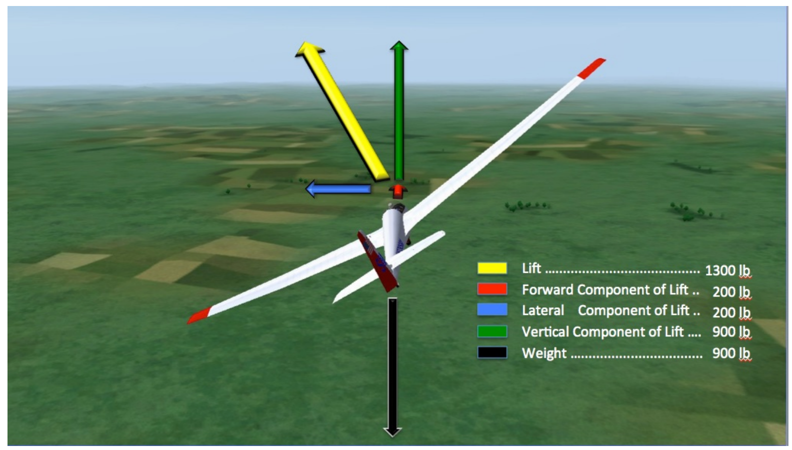
The glider's longitudinal stability then seeks to restore (reduce) the angle of attack to its trimmed value, and glider pitches down (toward the new steeper flight path).

Q. Why did the glider speed up?

A. As the glider pitches down, the lift vector is directed farther forward.
Reference: Airspeed Control self-study guide – Page 4
"In very simple terms, you control the speed of the glider by tilting the Lift vector; tilt the lift vector farther forward to go faster; tilt the lift vector back to slow down."

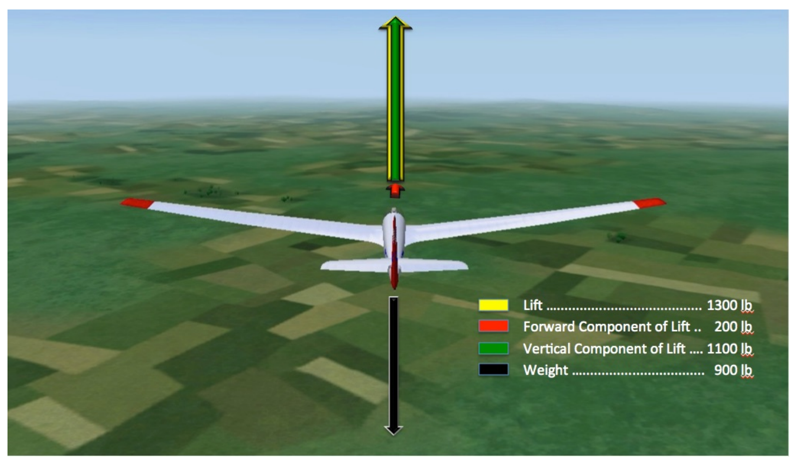
The more-horizontally tilted lift vector not only increases the forward component of lift, but also further reduces the vertical component of lift, thereby further increasing the glider's rate of descent.

Even as the glider accelerates, the longitudinal stability is holding the angle of attack fixed. With angle of attack fixed, any increase in airspeed generates additional lift, with a corresponding increase in each of the lift components.

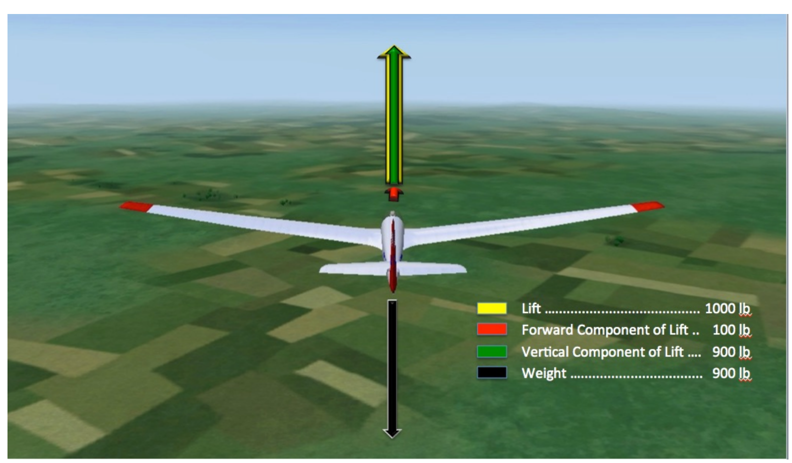


The glider's decent rate stabilizes when the vertical component of lift returns to equilibrium with the pull of gravity, and the glider's airspeed stabilizes when total drag (induced + parasitic) increases to equal the forward component of lift.

12:02:53 – 12:03:11
As you might expect, the process reverses as the glider is rolled back to wings level. The magnitude of the lift vector in the turn is greater than is required in level flight. As the glider is rolled out of the turn, this larger lift vector generates a correspondingly large vertical component, larger than is needed to balance the pull of gravity (weight) in level flight. This imbalance in forces results in a reduced descent rate, which the glider senses as a decrease in angle of attack as the flight path shallows.



Again, the glider's longitudinal stability works to restore (increase) the glider's angle of angle of attack by pitching up. The pitch change tilts the lift vector farther aft, reducing the forward component of lift and slowing the glider down. The glider's descent rate stabilizes, at the wings-level value, as the vertical component of lift returns to equilibrium with the glider's weight.



12:03:11 – 12:04:00
This segment further demonstrates the 2nd un-commanded behavior in a turn, i.e. pitch / airspeed excursions, this time in a turn to the right. An external view is used to give you a different perspective on the effect, and provide you with digital readouts of the airspeed and descent rate (“vario” indication).

Set-up
- Turn the Replay Camera OFF (F9)
- Set the View to External – In Trail (F3.1)

Notice how the descent rate increases almost immediately as the glider is rolled into a bank. Notice too how the airspeed and descent rates eventually stabilize. The values at which they stabilize are a function of bank angle, the steeper the bank angle, and the higher the airspeed and descent rate. What drives this effect is the imbalance that occurs between the vertical component of lift and the pull of gravity, as the glider’s lift vector is redirected, both when entering and exiting the turn.

- Press PAUSE to start
- Press PAUSE to stop the Replay as the glider rolls level

Managing Pitch / Airspeed Excursions in a Turn

The amount of lift (L) generated by a wing is a function of both airspeed (V) and angle of attack (α). The following expression is often used to express this relationship.

$$L \sim V^2 \alpha$$

The previous discussion and demonstration showed that more lift is required in a turn than in level flight. Left to its own devices, the glider's longitudinal stability holds the angle of attack fixed at the trimmed value. So, if lift is to increase, airspeed must increase; and indeed it does as the glider enters the turn. Coming out of the turn, the additional lift is no longer needed and the glider eventually sheds it by slowing down. The result, however, is a pair of rather annoying pitch / airspeed excursions.

In this next demonstration segment, you will see how the glider pilot is able to control the amount of lift needed at various stages of the turn by modulating the wing's angle of attack, and in so doing, is able to maintain a relatively constant airspeed throughout the turn (an objective of this lesson).

Set-up

- Set the View to Cockpit (F1)
- Turn the Replay Camera ON (F9)
- Position the cursor at the top of the control stick, as shown at the right

  Note: *The Replay Control panel somewhat obscures the control stick. To see the stick better, press the "~"key to hide the Replay Control panel. Unfortunately, this action also hides the cursor, so once you know where to put the cursor, press the "~" key again and place the cursor at the top of the stick.*

  The stationary cursor helps you visualize changes in the stick's position during the turn.

- Press PAUSE to start/stop each time segment

12:04:00 – 12:04:05

The glider is stabilized, wings level, at an airspeed of 42 knots. The pilot then moves the stick and rudder to the left to initiate a roll in that direction, and then centers both controls to stop the roll and establish the bank.

Turning Flight

12:04:05 – 12:04:17

To generate the increase in lift needed in the turn, the pilot applies backpressure on the stick. The increase in angle of attack (α) produces an increase in lift (L) while holding the airspeed (V) constant.

$$\uparrow L \sim V^2 \alpha \uparrow$$

Notice the stick being held back relative to the cursor.

As in level flight, the airspeed in a turn is controlled primarily by reference to the horizon, with an occasional glance at the airspeed indicator as a cross-reference.

12:04:17 – 12:04:22

The pilot continues to modulate the stick position to maintain a pitch attitude that results in a 42-knot airspeed.

12:04:22 – 12:04:34

The pilot moves the stick and rudder to the right to initiate a roll to level flight. At the same time, the stick is moved forward to reduce the wing's angle of attack, thereby reducing lift to that required in level flight.

$$\downarrow L \sim V^2 \alpha \downarrow$$

Notice the pitch attitude and airspeed remain constant throughout the rollout, and the turn ends with the stick positioned where it was at the beginning of the turn; aligned with the cursor.

12:04:34 – 12:05:10

This segment demonstrates a turn to the right in which both roll-induced adverse yaw, and airspeed, are properly managed.

3) Over-banking Tendency

You may have noticed, during each of the turns in the previous demonstration, that the stick was not only being held back, it was also being held somewhat opposite the direction of the turn. While counter-intuitive, this control input is necessary to the management our next un-commanded behavior.

Set-up

- Position the cursor at the top of the control stick
- Press PAUSE to start/stop each time segment

12:05:10 – 12:05:40

The glider is again rolled into a left turn. The adverse yaw is managed using coordinated application of the rudder. The airspeed is managed by moving the stick back, thus increasing the wing's angle of attack as the method used to generate the addition lift required to execute the turn at a constant airspeed.

As the turn progresses, the glider exhibits the 3rd in our series of un-commanded behaviors; it continues to roll in the direction of the turn, even with the ailerons neutralized (stick centered laterally). For obvious reasons, this undesirable behavior is called "**over-banking tendency**".

In the image to the right, the glider has over-banked to nearly 60 degrees.

Q. Why does the glider continue to roll into the turn?

A. In a turn, the outside wing of the glider is flying faster than the inside wing.

To help visualize this, imagine the wing tips being on the inside and outside of a merry-go-round.

Because the outside wing is traveling faster, it generates more lift than the inside wing. Any difference in lift between the two wings, regardless of its cause, will generate a rolling tendency.

12:05:40 – 12:05:55

The glider is rolled out of the turn. Adverse yaw and airspeed are properly managed.

12:05:55 – 12:06:40

Over-banking tendency is demonstrated again, this time in a turn to the right. For another perspective on the effect, watch the turn from outside the glider.

Set-up

- Turn the Replay Camera OFF (F9)
- Set the View to External – In-Trail (F3.1)
- Press PAUSE to start
- Press PAUSE to stop as the glider rolls level

Managing Over-banking Tendency
Over-banking tendency is managed much like adverse yaw, i.e. by applying an appropriate counter-balancing control input.

Set-up

- Set the View to Cockpit (F1)
- Turn the Replay Camera ON (F9)
- Position the cursor at the top of the stick to indicate a neutral control position
- Press PAUSE to start/stop each time segment

12:06:40 – 12:07:10
The glider is again rolled into a left turn using the stick and coordinated rudder to control the roll-induced adverse yaw. The stick is then held back to increase the wing's angle of attack, and generate the additional lift needed to turn the glider, without an increase in airspeed.

Notice too the stick is now being held to the right, as well as back.

By holding the stick to the right, the pilot is inducing a right rolling tendency to counterbalance the over-banking (left rolling) tendency in a left turn.

The result is a constant bank angle, another one of the objectives of this lesson.

12:07:10 – 12:07:20
The glider is rolled back to level flight with no adverse yaw and at a constant airspeed.

All controls are back to their neutral positions.

12:07:20 – 12:07:46
The glider is again rolled into a streamlined, constant-speed turn, this time to the right.

Once established in the turn, the pilot uses a left roll command (stick left) to exactly counterbalance the glider's tendency to over-bank to the right.

12:07:46 – 12:07:56
The glider is rolled back to level flight.

4) Speed-induced Adverse Yaw

Set-up

- Adjust the Replay position so the yaw string appears vertical
- Position the cursor at the very top of the yaw string as shown in the image to the right.
- Press PAUSE to start/stop each time segment

12:07:56 – 12:08:23
The glider is once again rolled into a turn to the left.

Notice, however, with the glider established in the turn, the yaw string appears to be indicating a slight yaw to the right. With the ailerons already deflected to the right to counter-balance the over-banking tendency, one would expect the glider to exhibit a roll-induced yaw to the left (into the turn). Yet the position of the yaw string to the right of cursor would indicate an adverse yaw (opposite the turn).

To be clear, the deflection of the ailerons is generating a roll-induced yaw to the left (into the turn), but the roll-induced yaw is being over-powered by our 4th, and final, un-commanded behavior; **speed-induced adverse yaw**.

Q. Why is the glider yawing to the right, even with a right stick deflection?

A. Page 6 of this study guide identifies two types of drag:

- Induced drag: a function of angle of attack
- Parasite drag: a function of speed

As it turns out, the same difference in wing speed that causes the glider to over-bank, also generates a difference in parasitic drag between the wings. The high speed of the outside wing produces more parasite drag than the slower moving inside wing. The difference in drag between the two wings results in a yaw toward the outer wing, the one with the greater drag.

12:08:23 – 12:09:16
The glider is rolled out of the left turn and then into a stabilized right turn.

Notice again the **speed-induced adverse yaw** resulting from the greater parasite drag on the outer (left) wing.

Managing Speed-Induced Adverse Yaw
You have probably already figured out that speed-induced adverse yaw is managed using the same control input used to manage roll-induced adverse yaw, i.e. enough rudder in the direction of the turn to keep the yaw string straight.

12:09:16 – 12:10:38
In these next two turns, the pilot holds just enough rudder, into the turn, to counteract the speed-induced adverse yaw.

However, as often happens when concentrating on one aspect of flight management, another suffers. You may notice the pilot does not properly manage the roll-induced adverse yaw, while rolling out of the left turn at **12:09:47**, and then again on entry to the right turn at **12:09:54**.

But let's not be too critical of our intrepid Condor demonstration pilot. In the exercises that follow, you will begin to appreciate the skill and concentration needed to keep all your Turning Flight ducks in row.

Demonstration – Turning Flight
Watch this short demonstration of two properly executed turns. As you develop your turning skills, occasionally create a Replay of your performance; and compare it to the one in this demonstration.

When you can't tell the difference, you will have mastered turning flight in a glider.

Set-up
- View   Replay == Turning_Flight.rpy
- Reset   Replay to the Beginning (|<<)
- Press   PAUSE to start/stop as needed

Exercise: Making Streamlined Turns at a Constant Airspeed and Constant Bank

Set-up
- Select Free Flight
- Load Flight Plan / User == Turning_Flight.fpl
- Select Start Flight
- Press "ESC"
- Select "Ready for Flight"
- Press PAUSE as needed to give yourself time to think.

Play-by-Play

1. **Stabilize the Glider in wings-level flight**
   Establish a trimmed airspeed of 42 knots.

2. **Initiate the Turn**
   Control Inputs
   1) Stick left to roll the glider into a banked attitude

   2) Rudder left to counteract the roll-induced adverse yawing tendency

3. **Stabilize the Turn**
   To establish the glider in a stabilized turn, you first need to stop the entry roll, and then begin managing the remaining three un-commanded behaviors of a glider in a turn.

   Control Inputs
   1) Stick centered to neutralize the ailerons, which stops the roll

   2) Rudder centered with the ailerons neutral, the roll-induced adverse yaw disappears; no yaw to counteract; no rudder input needed

   3) Stick back to increase the wing's angle of attack, thus generating the addition lift required in the turn, without an increase in airspeed

      Hold the pitch attitude as needed to maintain a constant airspeed; 42 knots for this exercise

   4) Stick right to command a rolling tendency opposite the turn, thus counteracting the glider's tendency to continue rolling into the turn (over-banking), even after the ailerons have been neutralized

   5) Rudder left to counter act the speed-induced adverse yawing tendency

4. Roll Out of the Turn

Control Inputs

1)	Stick	right	to roll the glider back toward a level flight attitude
2)	Rudder	right	to counteract the roll-induced adverse yawing tendency
3)	Stick	forward	to decrease the wing's angle of attack, thus dissipating the addition lift required in the turn, without a decrease in airspeed Hold the pitch attitude as needed to maintain the 42-knot airspeed

5. Stabilize the glider in level flight

Control Inputs

1)	Stick	centered	to stop the exit roll
2)	Rudder	centered	with the ailerons neutral, there is no roll-induced adverse yaw to manage

Practice

Continue to execute turns, both right and left, using the control sequence described above. Use the "Q" button to buy yourself extra altitude (more time) to practice.

Take your time rolling into, and out of, your turns; there are no points awarded for doing either quickly. In fact, the more quickly you try to roll the glider, the more difficult it is to coordinate the control inputs.

Limit your angle of bank to no more than 30 degrees. Steeply banked turns are much more difficult to control.

That Darned Yaw String

Managing adverse yaw, i.e. keeping the yaw string straight, is commonly the most challenging aspect of turning flight. In a properly executed turn, the yaw string should behave like it has a piece of tape on both ends. If the yaw string leans in the direction of the turn, you are using too much rudder in that direction; if it leans away from the turn, you are not using enough.

Another way to interpret the yaw string is to think of it as a downward pointer. When it's not straight, the yaw string will always point down toward the rudder pedal that needs more attention (forward deflection). I often refer to it as a tattle-tail, always pointing at your lazy foot.

The question is often asked: "How much rudder needs to be applied in a turn?"
The simple answer is: "Whatever is required to keep the yaw string straight."

That answer used to drive me crazy, but I have come to appreciate it. How much rudder input to apply, and when to apply it, depends on a number of factors, including the roll rate employed by the pilot, the design of the glider, the glider's airspeed, etc.

Rudder control in a glider is a bit like dancing; for best results, you need to keep your feet moving.

Muscle Memory Training
Learning to make proper turns in a glider is hard work and takes a lot of practice. PC-based simulation is an excellent learning environment, but even it can be too complex at times.

Properly turning an aircraft is a complicated process. At first, the combination of physical and mental tasks can be overwhelming. Your body has a hard time keeping up with your brain, and vice versa.

You can simplify the learning process by separating out your physical training.

Play by Play
Position yourself at your flight controls as you normally would, but do not run Condor. Simply close your eyes, so you have no actual visual distractions.

For each phase of a turn, position the controls as they would be at the beginning of the phase, visualize the required control inputs, make the control inputs, and imagine seeing the glider responding properly. Be conscious of, i.e. feel, the control movements.

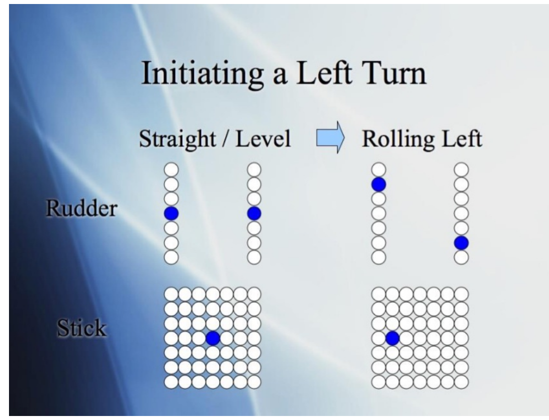
Repeat the process for that phase of flight until it becomes comfortable; then move on to the next phase.

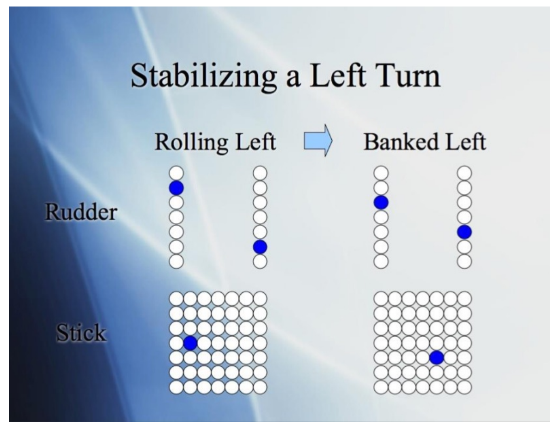
After mastering the control inputs for each phase, begin practicing the transition from one phase to the next, e.g. level flight into the entry roll; the entry roll into a stabilized turn, etc. Finally, work your way up to making complete turns.

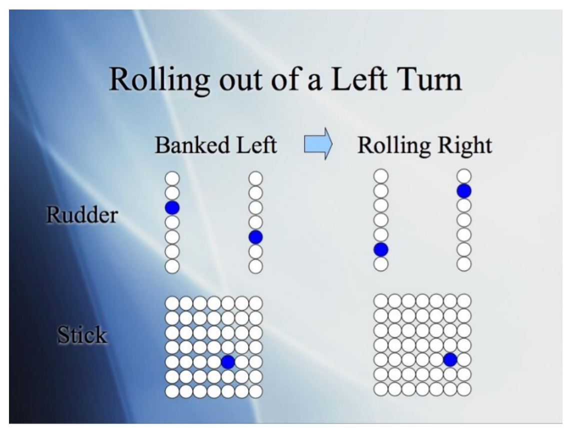
Regardless of how you how you develop your turning skills, the set of diagrams at the right should prove helpful. They represent a bird's eye view of the control positions before and after entering each phase of the turn.

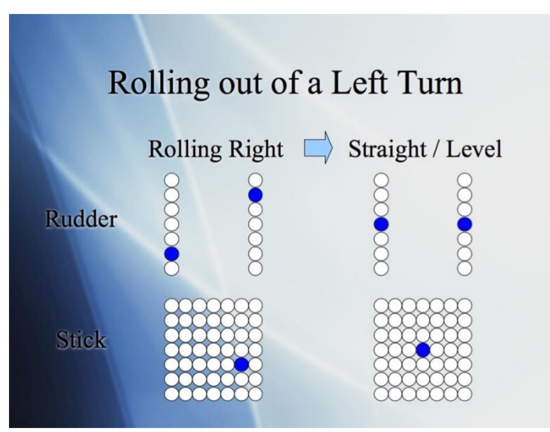
In actual flight, the control inputs in a turn are not made sequentially, as described in the preceding exercise, but are instead made in smooth, simultaneous combinations. These position control diagrams represent those combined inputs.

For example:
When stabilizing a left turn, the stick is not first moved to neutral, then backward, and finally to the right; it is moved from left to back/right all at once. The rudder is not first neutralized and then reapplied; it is simply moved from the "Rolling Left" position to the "Banked Left" position. The reason for initially presenting the control inputs as a sequence of events is to simplify the learning process; to help you understand "why" you do "what" you do.



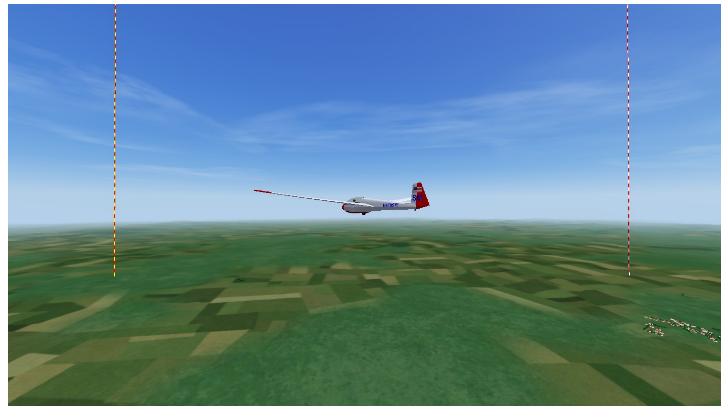






Turns to Headings
Being able to turn the glider to a specific heading is a requirement for a glider rating. “Turns to Headings” is task “B” under Area of Operation VII – Performance Maneuvers, in the Private Pilot Glider Practical Test Standard (PTS). The PTS requires that during the turn, the pilot “maintain the desired airspeed, +-10 knots, and roll out on a specified heading, +-10 degrees.”

Demonstration – Turns to Headings
Because Condor’s scenery lacks the visual detail that allows a real-life pilot to easily identify specific headings, the Flight Plan used in the following demonstration and exercises has been enhanced with visible heading indicators (striped poles), located at 90-degree intervals around the horizon.



Set-up
- View Replay == Turns_To_Headings.rpy
- Reset Replay to the Beginning (|<<)
- Press PAUSE to start/stop each time segment

09:00:18 – 09:01:18
The pilot executes a 360-degree left turn, at an airspeed of 42 knots, +-10 knots, and rolling out on the original heading, +- 10 degrees.

09:01:18 – 09:02:10
The pilot repeats the initial maneuver, but this time to the right.

09:02:10 – 09:03:20
The pilot makes a 180-degree left turn within the required standards, followed by a 180-degree right turn back to the original heading.

09:03:20 – 09:04:15
The pilot executes a pair of 90-degree turns; first to the left, then the right.

Exercise: Turns to Headings

Set-up

- Select Free Flight
- Load Flight Plan / User == Turning_Flight.fpl
- Select Start Flight
- Press ”J” to make the heading indicator poles visible
- Press “ESC”
- Select “Ready for Flight”

Reference:

Making “Turns to Headings” requires rolling out of the turn on a specified heading, +-10 degrees. The image to the right is meant to give you a good idea of what 10 degrees looks like. The vertical dashed yellow lines are located 10 degrees either side of the heading indicator pole.

You won’t have vertical yellow lines to work with in real life, or as you roll out of your turns in this exercise. So, you will need another frame of reference for determining whether you are meeting the standard. For example, you may want to use your kneecaps, or the outside edges of the bottom row of instruments as your 10-degree references.

Better yet, practice making turns to headings until you can stop the turn with the yaw string right on the turn point. That way you don’t need to care what 10 degrees looks like.

Play by Play

1) Execute a 360-degree left turn

2) Execute a 360-degree right turn

3) Execute a pair of 180-degree turns, one left, one right.

4) Execute a series of 90-degree turns, direction at your discretion.

5) Continue to make left and right turns, randomly selecting the heading indicator on which to complete your turn.