Aerodynamics

A study guide on aerodynamics for the Piper Archer
Aerodynamics

The purpose of this pilot briefing is to discuss the simple and complex aerodynamics of the Piper Archer.

Please use the following references:
- Pilot’s Handbook of Aeronautical Knowledge
- Flight Theory for Pilots
These fundamental basics first must be acknowledged:

- Air is a fluid. It can be compressed & expanded

The atmosphere is composed of

- 78% nitrogen
- 21% oxygen
- 1% other gases

Most of the oxygen is below 35,000 feet. (WHY?)
Aerodynamics-Basics

- Newton’s Laws of motion:
  - Law 1 – A body at rest will remain at rest. A body in motion will remain in motion
  - Law 2 – F=MA Force is equal to mass times acceleration
  - Law 3 – For ever action there is an equal and opposite reaction

Bernoulli’s principle of Pressure:
An increase in the speed of movement or flow will cause a decrease in the fluid’s pressure.
- Example: the Venturi
Bernoulli’s principle:

Air going over a wing. Notice the shape of a wing creates a Venturi. Thus, the low pressure develops on top.
Aerodynamics-Basics

Because air is a fluid, it utilizes the properties of the Coanda effect: the tendency for a fluid to follow the object along its flow path.

http://www.youtube.com/watch?v=AvLwqRCbGKY
http://www.youtube.com/watch?v=S-SAQtODAQw
Aerodynamics - Stalls

- When does an airplane stall?
  - When it exceeds the critical angle of attack.

What is angle of attack?
Angle of attack is the angle between the chord line and the relative wind.

Chord line = the line from the leading edge of the wing to the trailing edge.

Relative wind = perpendicular to lift, relative to the airfoil.
Aerodynamic-Stalls

- Stall speed vs. Ground speed

- An airplane will stall at the respected Indicated airspeed. It does NOT matter what the groundspeed is!

- If you have a stiff enough headwind at altitude, on a given day, you can stall an airplane with a negative groundspeed.

- Indicated airspeed is the speed read directly from the airspeed indicator; it is the speed the plane thinks it is at.

- Groundspeed is the speed of travel over the ground. There is minimal correlation with indicated airspeed; because groundspeed is dependent upon outside wind velocities.
Aerodynamics-Stalls

A stall occurs first at the wing root, then works out toward the tip. This design characteristic is so that you still maintain aileron control as long as possible.

http://www.youtube.com/watch?v=9eoboZNL9R8

Stall speed refers to straight and level, 1G, unaccelerated flight. Regardless of airspeed, the plane will **ALWAYS** stall when the critical angle of attack is exceeded.
Aerodynamics-Stability

“The balance of an airplane in flight depends, therefore on the relative position of the center of gravity (CG) and the center of pressure (CP) of the airfoil” (PHAK 2-7).

What is center of pressure (CP)
Answer: CP is the point where the resultant force crosses the chord line. Because AOA changes, pressure forces (positive and negative) are constantly changing. The resultant force is the total positive and negative forces for each angle of attack.

Figure 2-9. Force vectors on an airfoil.
Aerodynamics-Stability

Therefore, if AOA increases, CP moves forward. If AOA decreases, CP moves aft.

As the CG and CP get closer, the aircraft becomes less stable. The farther apart they are, the more stable the aircraft is.

Because CP is located aft of the CG, the aircraft wants to tumble forward, as it rotates around the CG. Hence, the horizontal stabilizer, counteracting the flipping rotation by creating downward lift.

The CG is usually forward of the CP. Rotations around the different axis (lateral, longitudinal, and vertical), occur around the CG.
Aerodynamics-Stability

- **Stability** = the tendency to correct back to the original state
- **Maneuverability** = the ability to change attitude and withstand stresses
- **Controllability** = the aircraft’s response to pilot inputs

- Types of Stability: Static & Dynamic
  - Static - the aircraft’s initial response
  - Dynamic - the response over a period of time
Aerodynamics-Stability

Static Stability (initial tendency)
- Positive Static = immediately return to the original state
- Neutral Static = remain in the new position
- Negative Static = continue away from the original state

Dynamic Stability (over time)
- Positive Dynamic = returns to original state
- Neutral Dynamic = Once displaced, the plane neither increases or decreases in amplitude, stays the same
- Negative Dynamic = continues going away, becomes more divergent if displaced
Aerodynamics-Stability

(a) Equilibrium flight.
Lift = weight
Thrust = drag
No net moments

(b) Statically unstable airplane.
Equilibrium
Disturbed moments increase disturbed condition

(c) Neutral static stability.
Equilibrium
No moments - airplane holds disturbed condition
Aerodynamics-Stability

Dynamic Stability:

- (a) Statically and dynamically stable. Moments tend to return airplane to equilibrium - oscillations decay.
- (b) Statically stable; neutral dynamic stability. Moments tend towards equilibrium but oscillations are divergent.
- (c) Statically stable; dynamically unstable.
Aerodynamics-Stability

Phugoid Oscillations- Result from the worse type of stability (Positive static, neutral dynamic). They are long oscillations, and very slow. Phugoid oscillations occur with a close CG and CP (inherently unstable).

http://www.youtube.com/watch?v=khi25FmOrI

Above is a video of a case study done on Japan Airlines flight 123.

-Caution- Long video
Aerodynamics-Stability

- Dihedral- This is the angle that exists between the wings and the fuselage. Dihedral affects longitudinal stability
- Yaw stability-developed from the vertical stabilizer

Longitudinal stability-roll
Vertical stability-yaw
Lateral stability-pitch
*Through the CG*
Aerodynamics

Definition of Camber - curvature of the wing

**Adverse Yaw** – You change the camber of the wing with the ailerons when executing a turn. The upward wing has more lift than the lower wing. In adverse yaw, the aircraft tends to slip towards the upward wing due to the difference in lift. An *increase in lift* results in an *increase in drag*. Therefore more drag on the upward wing causes the shift/twist around the vertical axis resulting in an uncontrolled turn.

This demonstrates the need for a rudder.
Aerodynamics-CG

- Center of Gravity (CG) is the center point where all the weight acts through.

- “The center of gravity is a point at which an airplane would balance if it were suspended at that point…The center of gravity is not necessarily a fixed point; its location depends on the distribution of weight in the airplane.” (PHAK 8-2).

- Longitudinal unbalance = too forward CG (nose heavy) or too aft CG (tail heavy)
Aerodynamics-CG

- What is the CG range in a Piper Archer?
  - Answer: 82”-93” aft of datum.
  - Datum is right at the tip of the nose of the plane. The datum is established by airplane designers. Really, the Archer only has about 11 inches for CG adjustment.

Where is that located with reference to you sitting in the pilot seat?
  - Answer: right below your feet
Aerodynamics-CG

Characteristics of an aft CG:
- Decreased stability – Because when the CG moves rearward, it causes an increase in AOA.
- More difficult to recover from stalls and spins.
- Easy to overstress the airplane – due to “very light control forces” (PHAK 8-2).
Characteristics of a forward CG:

- Increased stall speed – Because the critical angle of attack is reached at a higher speed due to an increased wing loading.
- Increased cruise speed – Due to decreased drag because of a decreased AOA from the nose down pitch tendency.
- Difficulty in takeoff – Struggles to raise the nose with in a nose-heavy situation.
- Difficulty in the flare – Hard to raise the nose in the flare.
Aerodynamics-Load Factor

- Definition: “Any force applied to an airplane to deflect its flight from a straight line produces a stress on its structure; the amount of this force is termed load factor” (PHAK 3-26).

- It’s a ratio of total airload : gross weight

- Load factor is defined in G’s.

- Example: the ratio = 3:1 therefore the load factor is 3, and you are producing 3’Gs.
Aerodynamics-Load Factor

Why is load factor important:

“Dangerous overload that is possible for a pilot to impose on structures” (PHAK 3-26)

“Increased load factor increases the stalling speed and makes stalls possible at seemingly safe flight speeds” (PHAK 3-26)
Aerodynamics-Load Factor

What is the load factor in a 60 degree steep turn?
- Answer: 2Gs

What will I weigh in this type of steep turn if I weigh 150lbs in 1G flight?
- Answer: 300lbs
Aerodynamics-Load Factor

Load Factor and stall speed are proportional. The load factor squares as the stalling speed doubles.

Therefore, in a Piper archer with a stall speed of 50 in 1G, unaccelerated flight, what would the stall speed be in a 2G steep turn?

Answer: Approximately 73 kts
Aerodynamics-Va

- What is maneuvering speed?
  - Practically, it is the speed that you slow to in the event of turbulent situations.

- Why is VA (maneuvering speed) a range? What affects it?
  - Answer: weight affects maneuvering speed. The heavier the plane is, the higher your maneuvering speed should be (113). If you are lighter, Va should be lower (89).
How to calculate Va for any given flight:

Va = 113 * \( \sqrt{\text{Current Weight}/2550} \)

Example: You weigh 2200lbs

- \( \text{Va} = 113 \times \sqrt{(2200/2550)} \)
- \( \text{Va} = 113 \times \sqrt{0.88} \)
- \( \text{Va} = 113 \times 0.938 \)
- \( \text{Va} = 106 \)

Definition of Va:
“At any speed below this speed the aircraft cannot be overstressed. It will stall before the limit load factor is reached. Above this speed, however, the aircraft can exceed the limit load factor before it stalls.”
Aerodynamics-Drag

- There are two main types of drag:
  - Induced
  - Parasitic:
    - Form drag
    - Skin friction
    - Interference drag

- Definition of induced drag: This type of drag is based upon efficiency. Because no machine is 100% efficient, induced drag exists. With an increase in efficiency, there will be a decrease in induced drag.
  - It is the drag due to lift.

- * Drag is defined in pounds *
Aerodynamics-Drag

- Parasitic Drag types:
  - Form Drag: Due to the shape of an aircraft, form drag is a result of airflow going around it. – Consider a flat plate vs. a sphere when being thrown –
  - Interference Drag: This occurs at the intersection of air currents. For example, the wing root connected to the fuselage.
  - Skin friction: This drag is the aerodynamic resistance from the contact of air with the surface of the airplane.
What are wingtip vortices?

This is the wake that is generated from the wingtips. They are counter-rotating vortices that are caused from air spilling over the end of the wing.

“This pressure differential triggers the rollup of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wingtips” (PHAK 12-13).

- The pressure difference the PHAK is referencing is the Low pressure above the wing, countered with a High pressure below the wing.

http://www.youtube.com/watch?v=E1ESmvAmOs
Always land beyond an aircraft generating significant wingtip vortices.

Rotate prior to their rotation point. ALWAYS give yourself plenty of time to avoid them. Remember to sidestep upwind.

Problem: Have you ever seen a Piper Archer out climb a 727? Probably Not. So, what good will it do to rotate prior to their rotation point if you can’t remain high above their climb out path? You will eventually fly through them. Time will solve this problem so that they can dissipate.
Aerodynamics-Drag

Imagine an infinite wing…would it have wingtip vortices?

Answer: No. This is because an infinite wing would not have wingtips, therefore it would not develop wingtip vortices.

Wingtips generate induced drag. Therefore if an infinite wing does not have wingtips, it would not generate induced drag.
Aerodynamics-Drag

- Ground effect- “Fly an airplane just clear of the ground (or water) at a slightly slower airspeed than that required to sustain level flight at higher altitudes” (PHAK 3-7)

- Ground effect alters:
  - Upwash
  - Downwash
  - Wingtip vorticies

Ground effect is a reduction of induced drag
Aerodynamics-Drag

“On entering ground effect:
1. Induced drag is decreased
2. Nose-down pitching moments occur
3. The airspeed indicator reads low

Upon leaving ground effect:
1. Induced drag is increased
2. Nose-up pitching moments occur
3. The airspeed will read higher (correctly)”
Aerodynamics-Drag

According to the diagram, in ground effect, less thrust is required to maintain any given velocity, compared with the thrust required out of ground effect.

"Therefore, the wing will require a lower angle of attack in ground effect to produce the same lift coefficient or, if a constant angle of attack is maintained, an increase in lift coefficient will result" (PHAK 3-7).
Aerodynamics-Airspeed

There are different types of airspeed:
- Indicated
- Calibrated
- Equivalent
- True
Aerodynamics-Airspeed

- Indicated airspeed - simply the airspeed that is read off the airspeed indicator. The raw speed.

- Calibrated airspeed – The airspeed corrected for instrument and position error. Errors occur from limitations where the pitot tube is located, or even where the static port is placed.

- Equivalent airspeed – The airspeed after it is calibrated for compressibility. For the Piper Archer, compressibility is not a factor due to the slow speeds it cruises at. It becomes an issue above 250kts.

- True airspeed – The final airspeed that we calculate for flight planning at.
Aerodynamics-Airspeed

Callibrated can be either higher or lower than indicated. Equillivant is always lower than Callibrated. True is always higher than equilivant.

It is easy to remember with the acronym: ICE T (like Ice Tea)
And with the square root symbol
Aerodynamics-Boundary Layer

- The boundary layer is located a few millimeters above the surface of the airfoil, at the microscopic level.

- Within the boundary layer airflow decreases in velocity; it slows going over the wing due to surface friction.

- Interference occurs with the wing and the air flowing around it.
At the surface, the velocity of the air equals 0.

As the distance increases above the airfoil, the velocity increases, until it is equivalent to free stream velocity.
There are two types of airflow going over a wing:

- Laminar – Smooth, constant, uninterrupted airflow
- Turbulent – Rough, bumpy airflow

As you move farther back on the wing, the boundary layer becomes thicker. This causes unstable airflow (turbulent air).

Therefore, the airflow separates with the surface, due to the increased boundary layer and decreased velocity of airflow.
Aerodynamics-Boundary Layer

Airflow over a smooth ball flying through the air

Separation exists, and at the rear, airflow is not going over the surface.
Aerodynamics-Boundary Layer

- It is bad for airflow to separate when going over an airfoil. Recall Bernoulli's principle: When air travels over the surface of a wing, it creates lift.

- If there is no airflow going over a wing, no lift will be produced.
This is why turbulent airflow is important.

If the surface of the airfoil is disrupted (example rivets), it will create turbulent airflow.

Turbulent airflow will continue to stick to the surface, thus allowing lift to be produced.

Turbulent airflow is better than no airflow at all!
Consider a golf ball. It was developed with indents (dimples). Thus, it creates turbulent air, allowing the airflow to stick to the airfoil longer than if it were developed with a smooth surface.