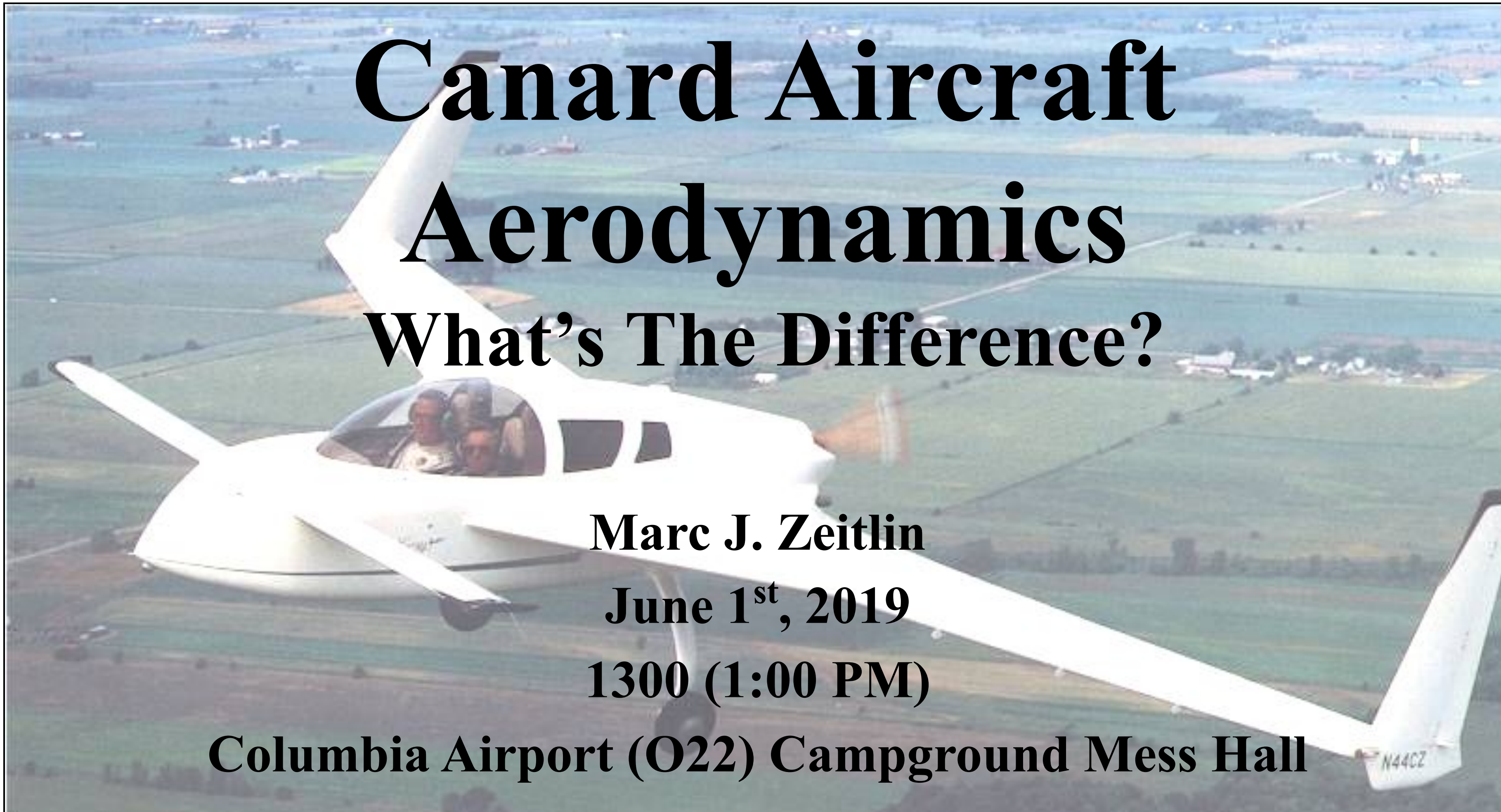

Canard Aircraft Aerodynamics

What's The Difference?

Marc J. Zeitlin

June 1st, 2019

1300 (1:00 PM)

Columbia Airport (O22) Campground Mess Hall

What Will I Talk About?

- *My Background*

- *General Aircraft Aerodynamics - Conventional AND Canard*
  - *Lift Generation*
  - *Angle of Attack (AOA)*
  - *Stalls*
  - *Aspect Ratio*
  - *Wing Sweep*
  - *Stability - Pitch / Roll / Yaw*

- *Winglets*
  - *Operation - Lift vs. Drag*
  - *Actual usage on our canards / Why Wing Sweep on Canards?*

- *Relative Efficiency / Performance / Capability*
  - *All else being equal…*
  - *Wings larger than Optimal (Deep Stall Resistance)*
  - *Canard Downwash Effect on Main Wing*
  - *But, But, But, Both Wings are Lifting!*
  - *Short / Soft Field Performance*
  - *Relative Field Length - Rotation on Takeoff*
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- *Incomplete List of Aerodynamic Modifications*
  - *With Pictures*
    - *Long Nose*
    - *Remove / Reduce Size Lower Winglets*
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    - *Blended Winglets*
    - *Dihedral Canard*
  - *Other Modifications - No Pictures*
    - *Canard Tip Plates*
    - *Canard Span Changes*
      - *GU / Roncz Differences*
      - *COZY MKIV Mandatory Modifications*
    - *Semi-Symmetric Winglet Airfoils*
    - *COZY MKIV Wider Fuselage*

- *Questions and Answer – until done (ANY topic)*

My Background

- Biography / Resume'
  - http://www.mdzeitlin.com/Marc/bio.html
  - https://www.burnsideaerospace.com/resume/

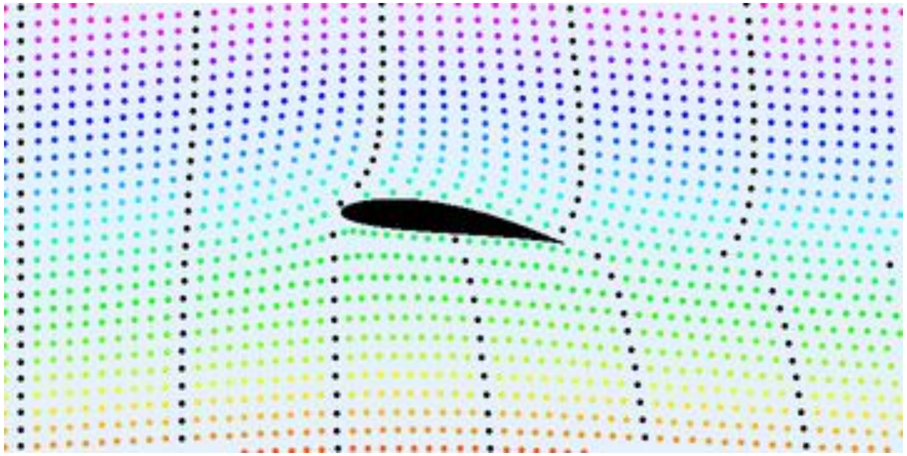
- Built Quickie Q2 (1980 – 1985)
- Built COZY MKIV #386, N83MZ – ~1530 flying hours
- Started / Administer Unofficial COZY Builders Web Page and COZY Builders Mailing List (~725 members)

- As **Burnside Aerospace**, provide:
  - E-AB / canard A&P services (Pre-Buy, Pre-Sale, Condition Inspection, Builder Assist, Modifications, Upgrades, Sale Assistance, etc.)
  - Consulting to multiple commercial clients re: canard composite aircraft

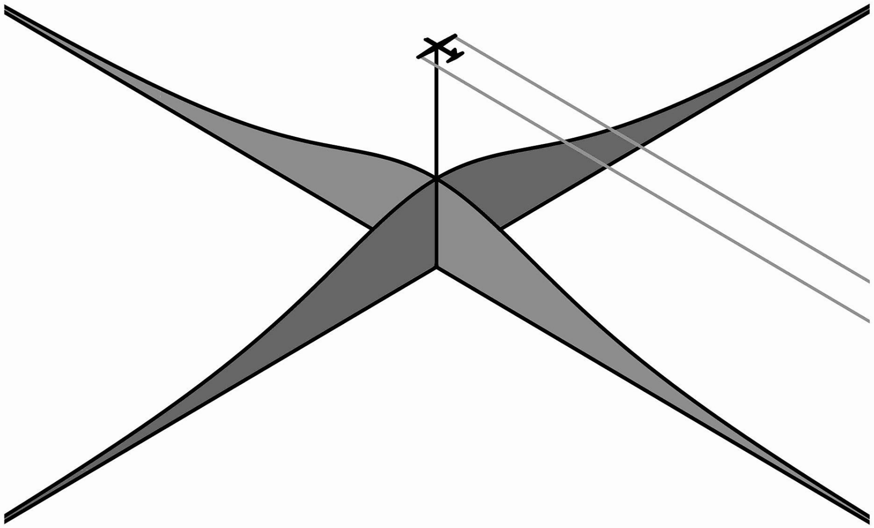
- I provide **UNOFFICIAL** technical support for **COZY** aircraft (and other canards) to all builders, flyers and prospective builders

Lift Generation (Subsonic)

- Airflow Over Surface
  - Relatively higher pressure below - relatively lower pressure above - creates upward force
  - Streamlines and air particles
  - **NOT** equal transit times
  - **UPWASH** ahead of airfoil and **DOWNWASH** behind airfoil
  - Stagnation point below leading edge (hence position of vortilons)

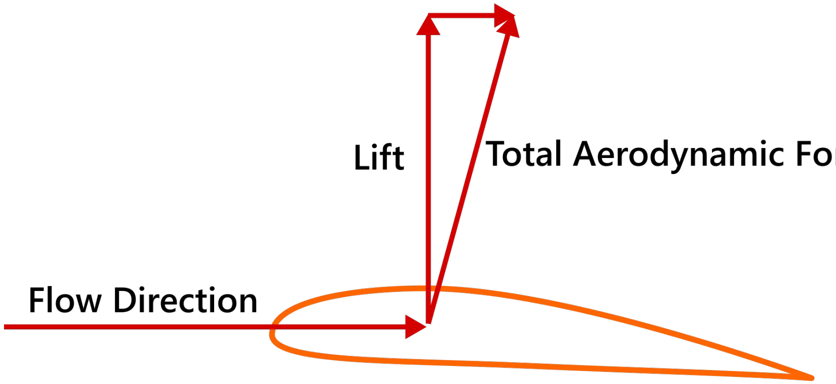


- Far Field Pressures
  - **LARGE** area of increased pressure
  - **SMALL** pressure difference
  - Adds up to weight of aircraft



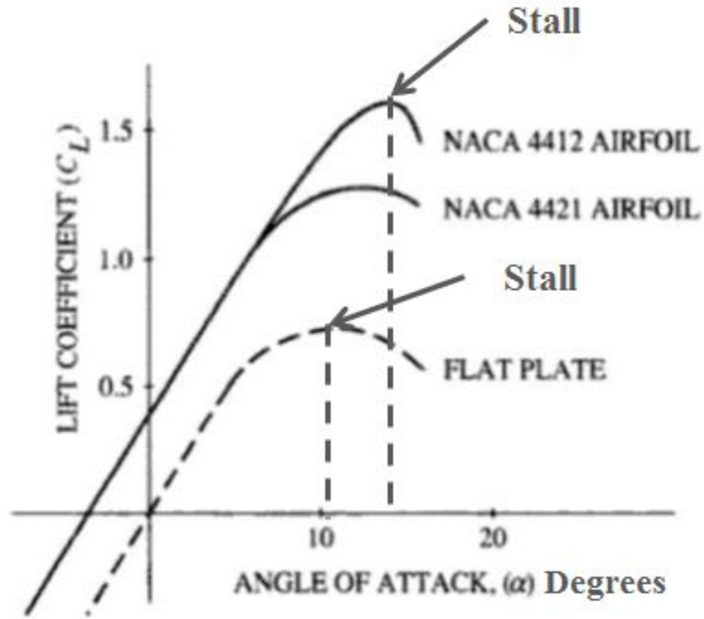
Lift Generation (Subsonic)

- Forces on Airfoil
  - Lift
  - Drag
  - Forces intrinsic in finite (3D) airfoils - only infinite span (2D) airfoils do not have drag



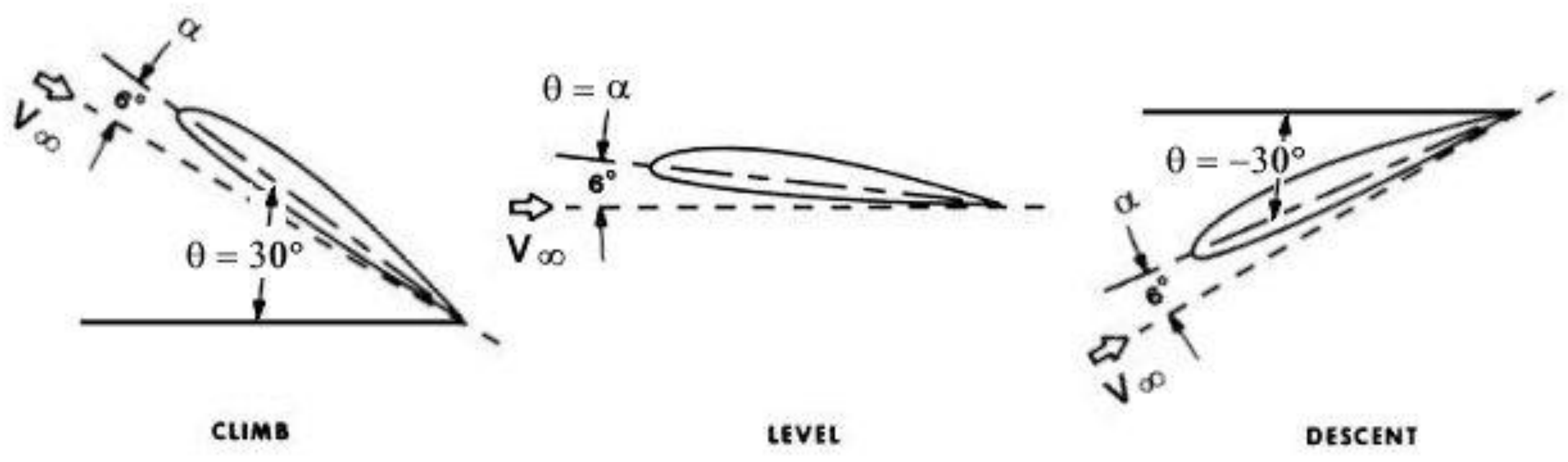
- Airfoil shape effects
  - flat plate
  - symmetric airfoil
  - cambered airfoil

Aerofoil Performance (After Cayley 1810)



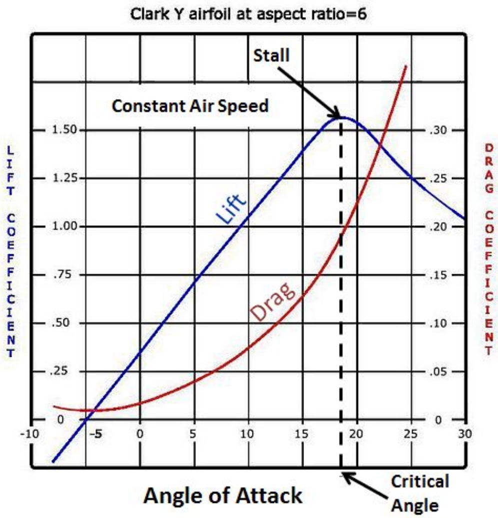
Angle of Attack

- Direction of Flight (V_∞)
- Angle of Attack (AOA - difference between Direction of Flight and chord line of airfoil)
- Can have **EXACTLY** the same AOA whether level, in climb, in descent or turning

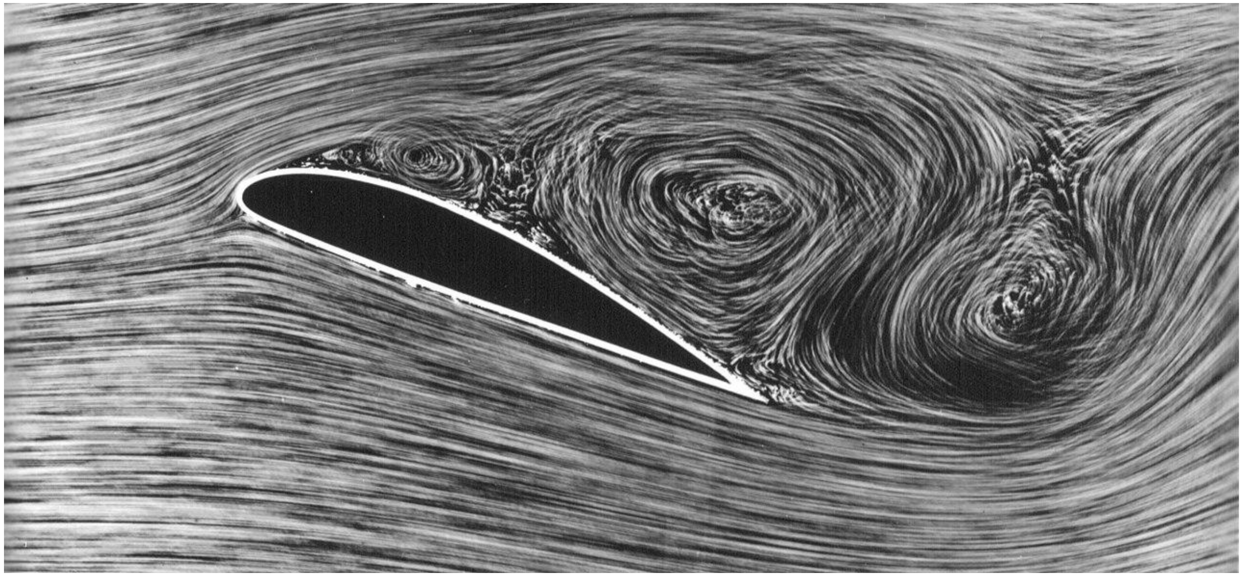


Stalls

- Critical Angle of Attack
  - Lift stops increasing with increasing AOA
  - Lift does **NOT** go to zero or disappear!
  - Note: still very high lift coefficient beyond critical AOA
  - Similar to "back side of power curve"
- Drag increases greatly at high AOA

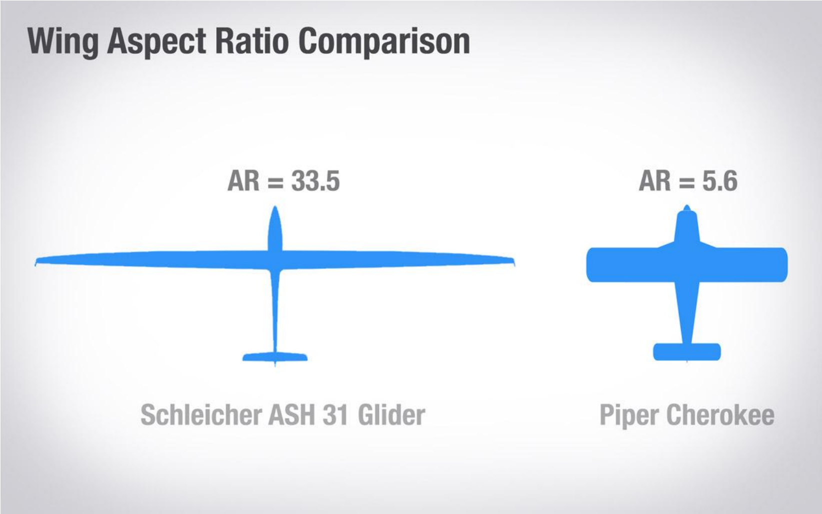


- Stall occurs when upper surface flow separates

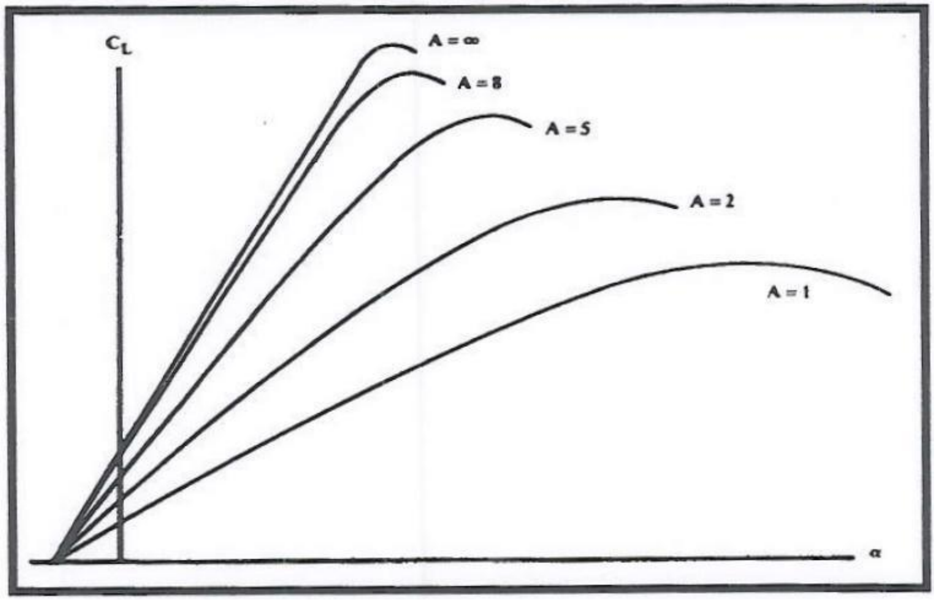


Wing Aspect Ratio (A/R)

- Ratio of Span^2 to Wing Area (or span / chord on simple wings)
  - Gliders - high
  - GA aircraft - low to medium
  - Delta wings/supersonic aircraft - low
    Our canard main wing - about 8

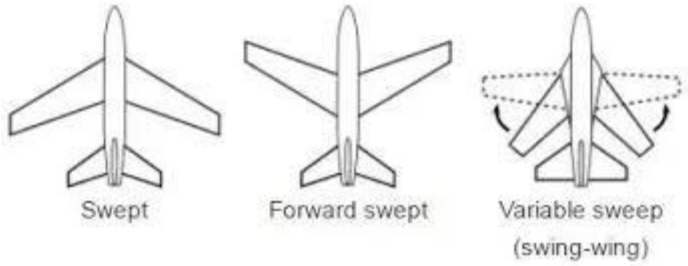


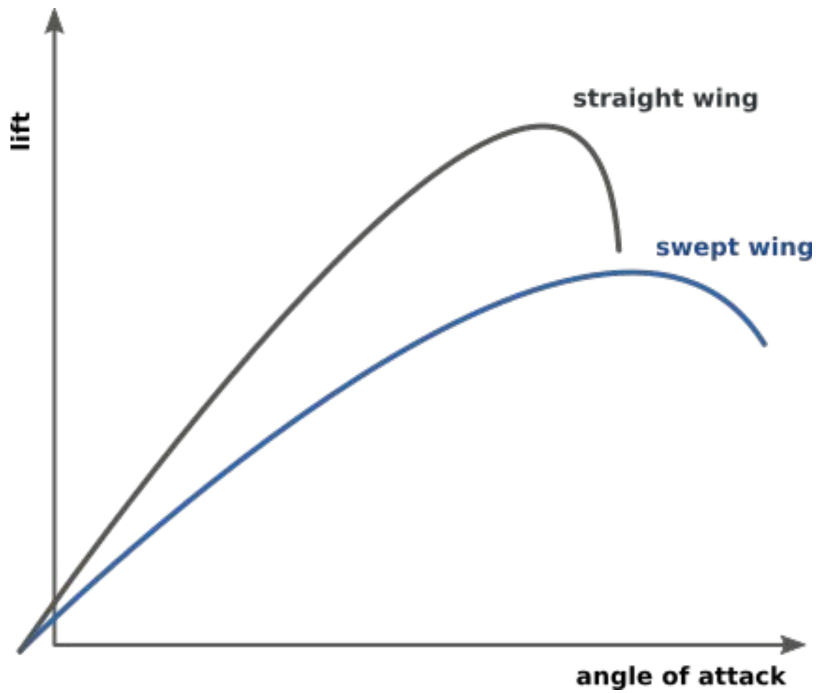
- A/R Effect on Lift Curve Slope
  - Infinite A/R has slope of 2*PI
  - Lower A/R - lower slope
  - Always want front wing (ON ANY PLANE) to have **lower LCS** than rear wing (for pitch stability)
  - **BUT** we want **higher LCS** than rear wing for deep stall resistance
  - Designer's job is to balance the two opposing needs



Wing Sweep

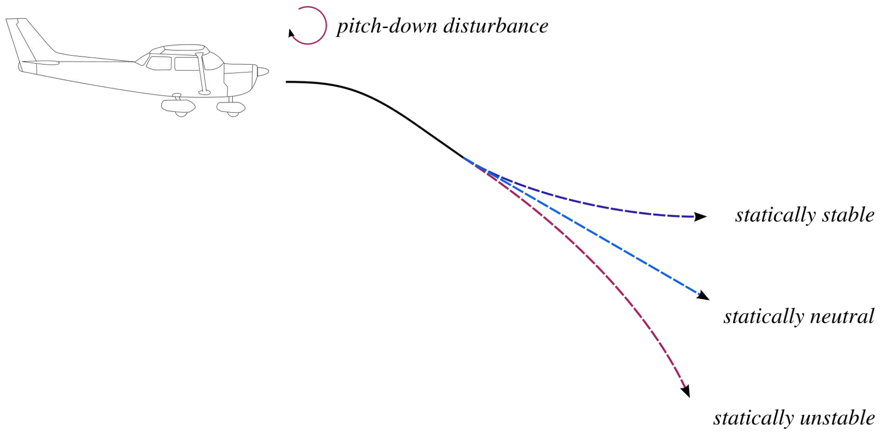
- Three types:
  - Sweep back
  - Sweep forward
  - Straight
- Lift Curve Slope decreases with sweep
- Works in concert with Aspect Ratio to ensure stability of aircraft
- Aft swept wings structurally stable
- Forward swept wings structurally unstable (may be heavier to ensure stiffness - avoid divergence/flutter)



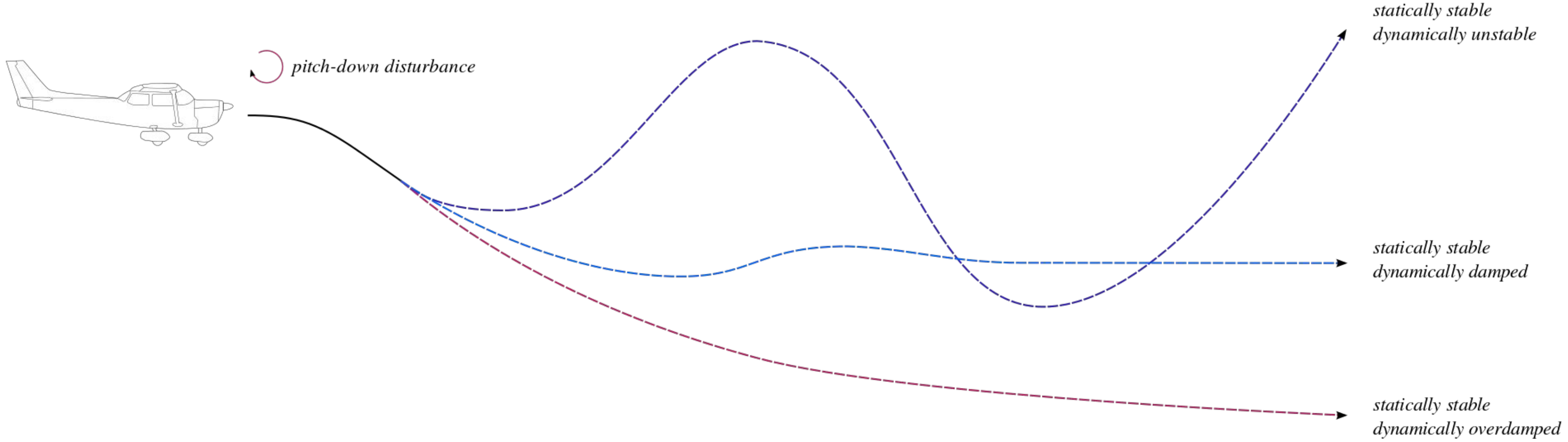


Pitch Stability

- Static
  - Does the plane want to return to it’s trimmed airspeed?

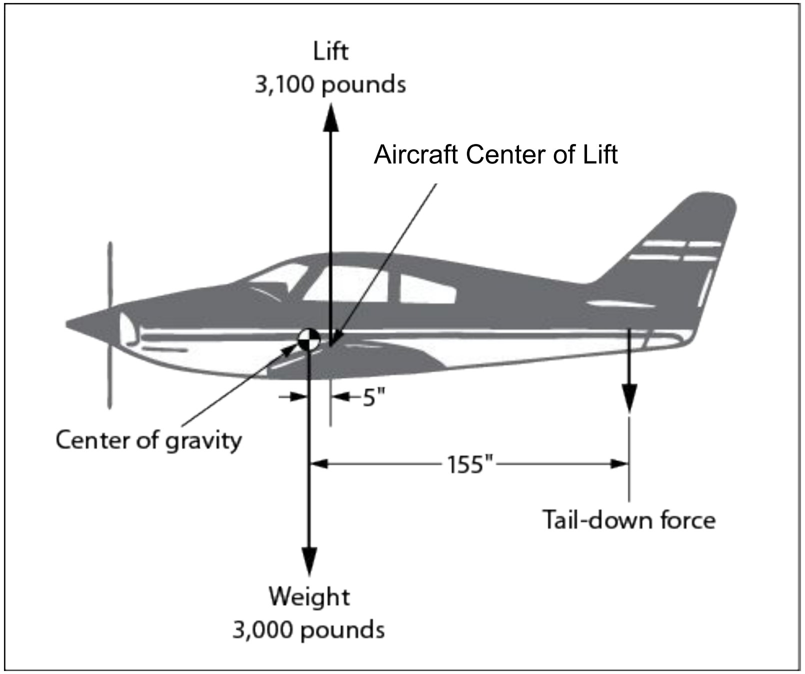


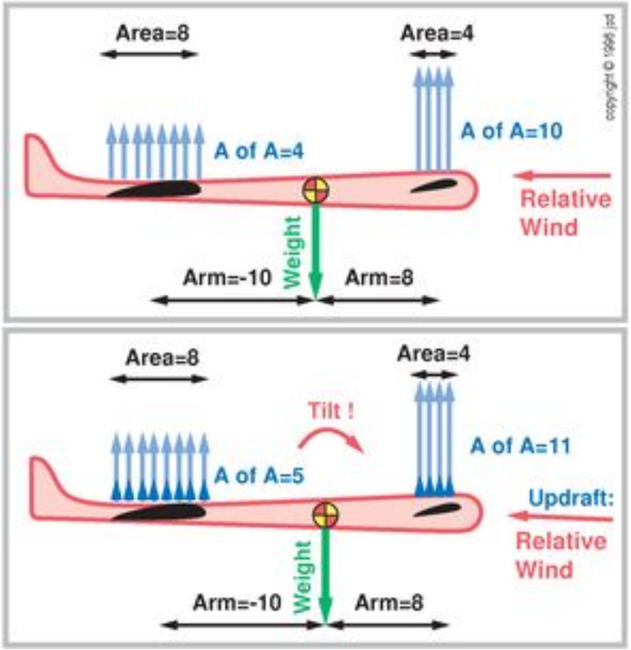
- Dynamic
  - Do the oscillations after a disturbance get smaller or bigger?



Pitch Stability

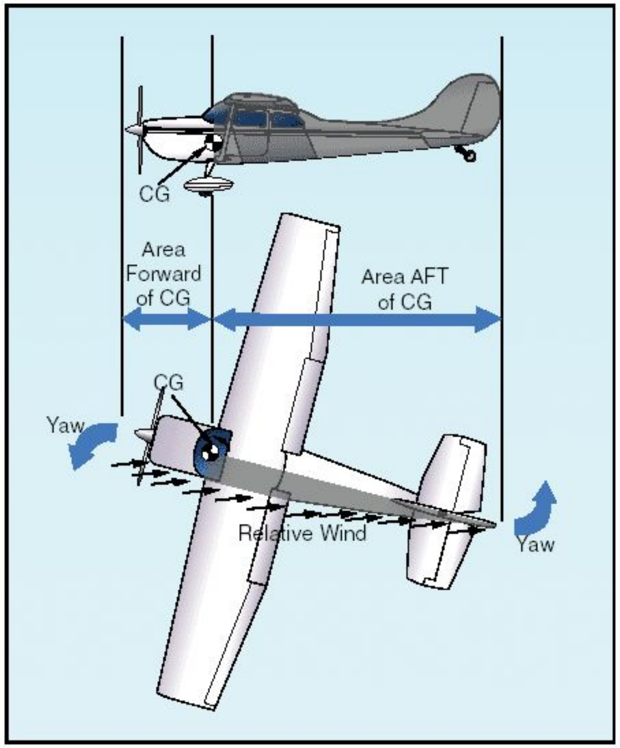
- Aircraft is statically pitch stable when rear wing provides restoring force opposite to perturbation
  - Rear wing needs to be more effective than forward wing (higher LCS)
  - Front wing needs to be more heavily loaded
  - Center of Gravity (CG) **MUST** be ahead of the Center of Lift
- Example - canard airfoils on our planes are only 15% or so of total wing area, but carry 25% - 33% of total weight of aircraft





Roll (Directional) & Yaw Stability

- Static
  - Does the plane want to return to the direction it's pointing after a yaw perturbation?
  - Does it want to return to level after a bank perturbation?



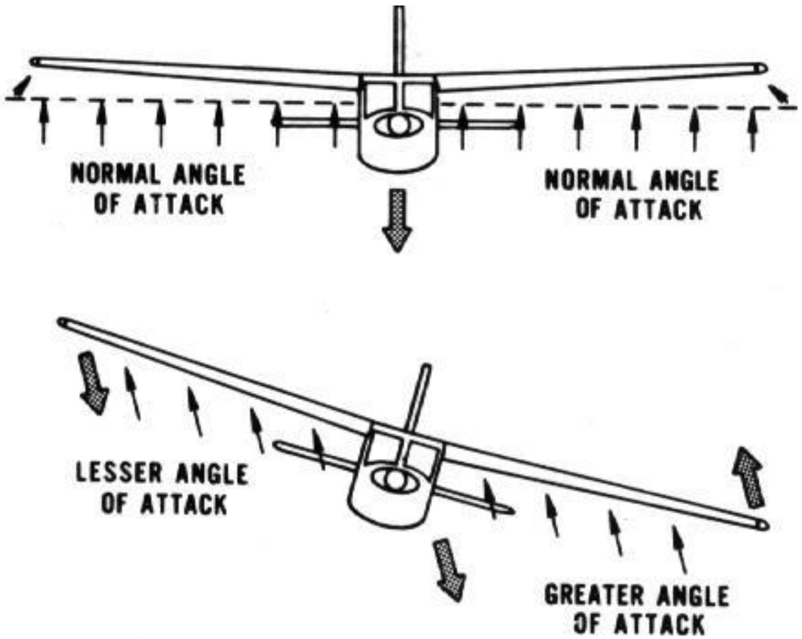
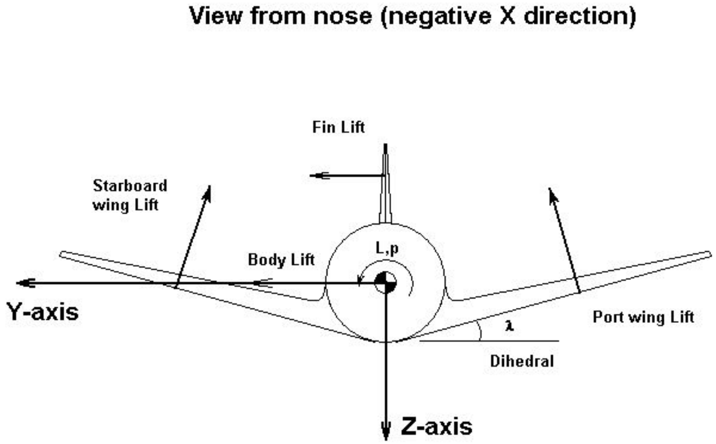


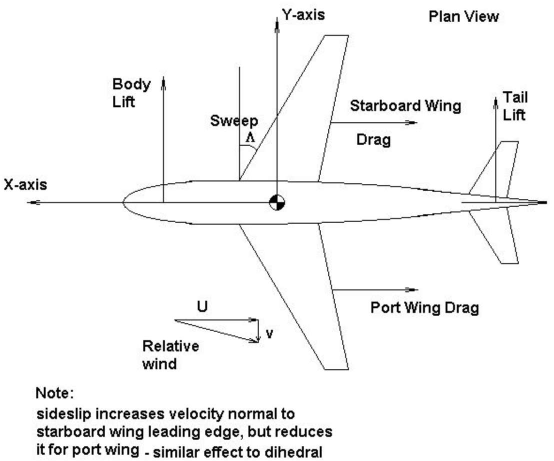
Figure 17–29 Dihedral for Lateral Stability

Roll (Directional) & Yaw Stability

- Dynamic
  - Do the oscillations after a disturbance get smaller or bigger?
  - Roll and Yaw are interconnected - results in “Dutch Roll” effect, and/or Spiral Instability. Generally, you get one or the other - it’s **VERY** hard to be stable in both
- Dihedral effect and sweep both contribute to stability



Lateral Stability - Main Sources of Stabilising Forces and Moments



Additional Contributions to Lateral Stability

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  - *Wing Sweep*
  - *Stability - Pitch / Roll / Yaw*
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- *Incomplete List of Aerodynamic Modifications*
  - *With Pictures*
    - *Long Nose*
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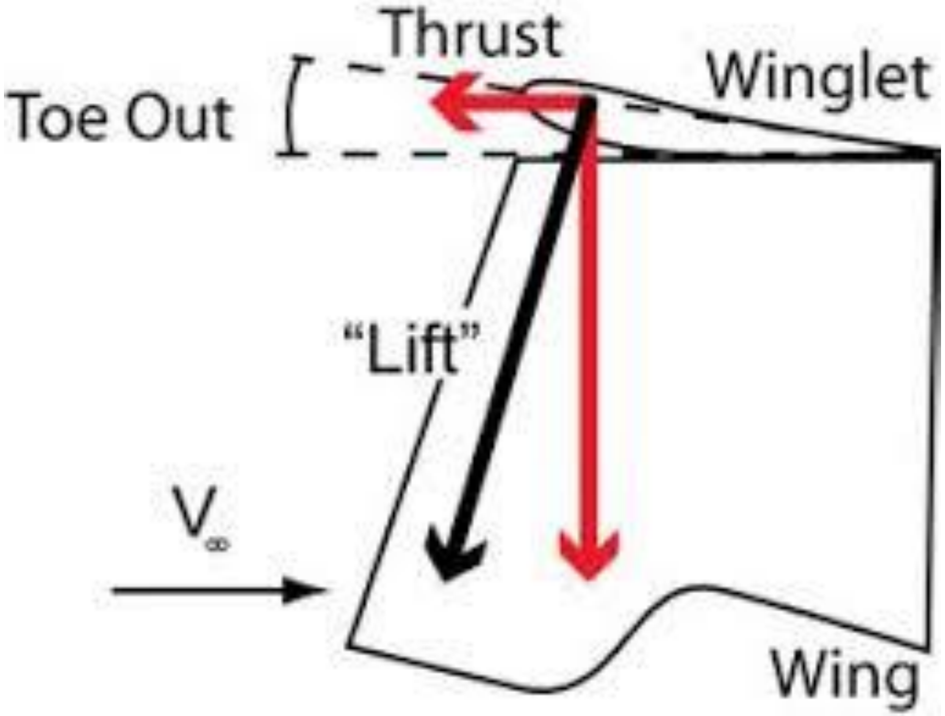
- *Questions and Answer – until done (ANY topic)*

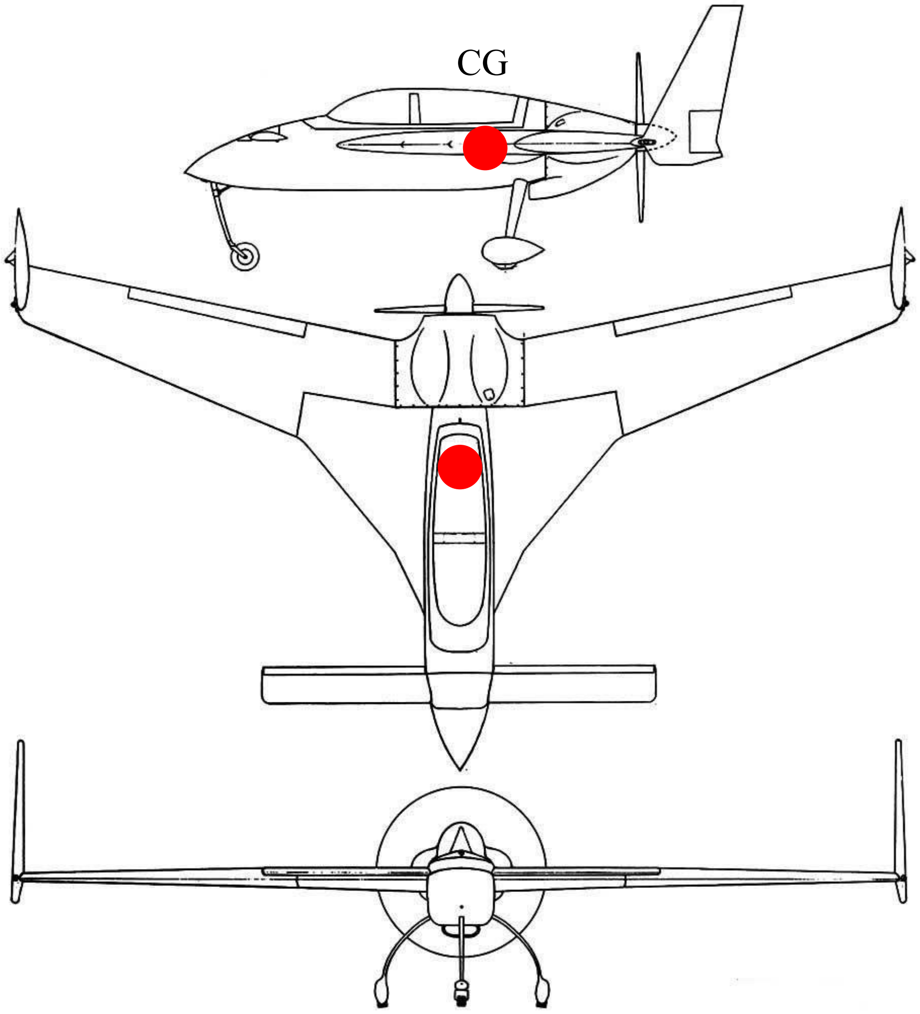
Winglets - Operation

- Original Purpose (Whitcomb) - decrease induced drag without increasing span (re: A/R effects on efficiency)
- Essentially a wingtip extension, bent up - reduces additional bending moments on wing, saving spar weight while providing about ⅓ of longer wing effect on efficiency
- With proper orientation, winglet can produce a slight amount of "thrust", which reduces overall induced drag - Generally, this will be in the 1% - 3% range when at best L/D speed - less to zero anywhere else (Best L/D speed for our planes is ~85 KIAS)
- Do **NOT** produce weight counteracting lift - only inward lift



Winglets - Actual Usage

- Directional Stability - Vertical Stabilizer
- Add little if anything to efficiency or drag reduction, if for no other reason than that we almost never cruise around at best L/D speed, which for these planes is ~ 85 KIAS
- Wings are swept to add dihedral effect, but mostly to get the winglets far enough aft to be effective without being huge
- Original flight testing of Long-EZ used Varieze winglets - way too small - had very poor directional stability. Mike/Dick tested > 5 versions to get to current size - previously, plane was happy to fly sideways



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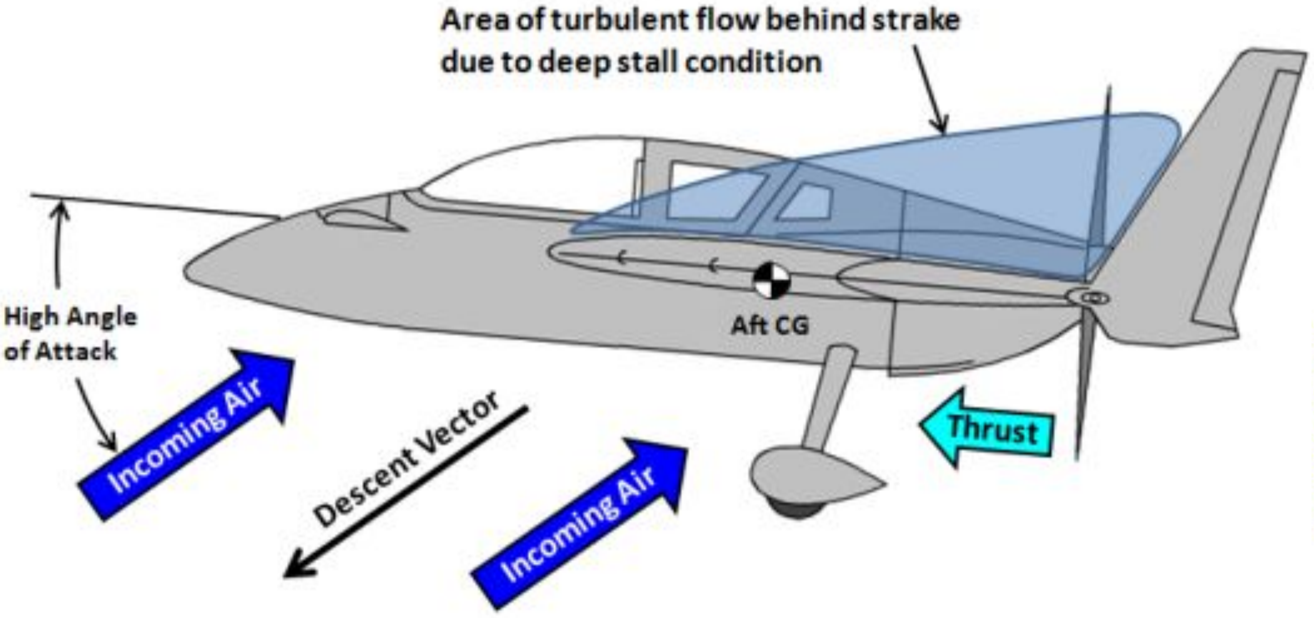
Relative Efficiency / Performance / Capability

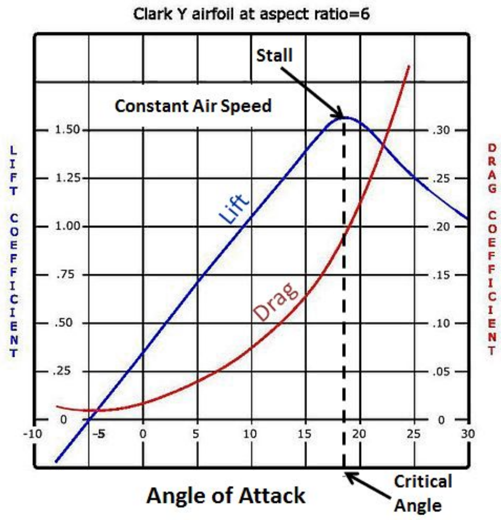
- All Else Being Equal?
- What's "All Else"?
  - Fuselage size/shape (side-by-side vs. tandem, sit up vs. lay down, etc.)
  - Wing Size / Area
  - Gear type (fixed vs. retractable)
  - Engine power
  - Propeller type (fixed pitch vs. C/S)
- Need to evaluate like vs. like:
  - Long-EZ vs. Glasair I thru III, Lancair 0-235 through O-360, Legacy, Tango II, RV-4/8
  - COZY MKIV vs. RV-10, Wheeler Express 2K, Lancair IV/IVP

- Canards **ARE** high performance, efficient aircraft
- But more / better?
  - To the extent we can measure and compare like vs. like, no substantive differences in efficiency / performance
- What are overall advantages over other high performance aircraft?
  - Stall / Spin resistance
  - Not much else

Relative E / P / C

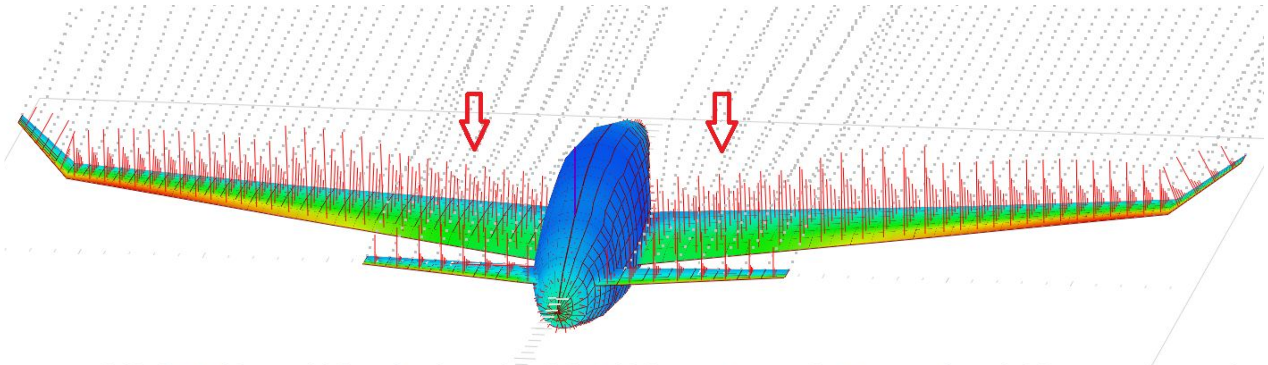
- Deep Stall Resistance - Main Wing Larger Than Optimal
- Canard (forward wing) **MUST** stall first to prevent "deep stall" condition
- Requires that Main Wing **NEVER** reach critical AOA, even at aftmost CG position
- This criteria requires main wing area to be larger than if critical AOA was achievable
  - $L = \frac{1}{2} \rho V^2 C_l A$



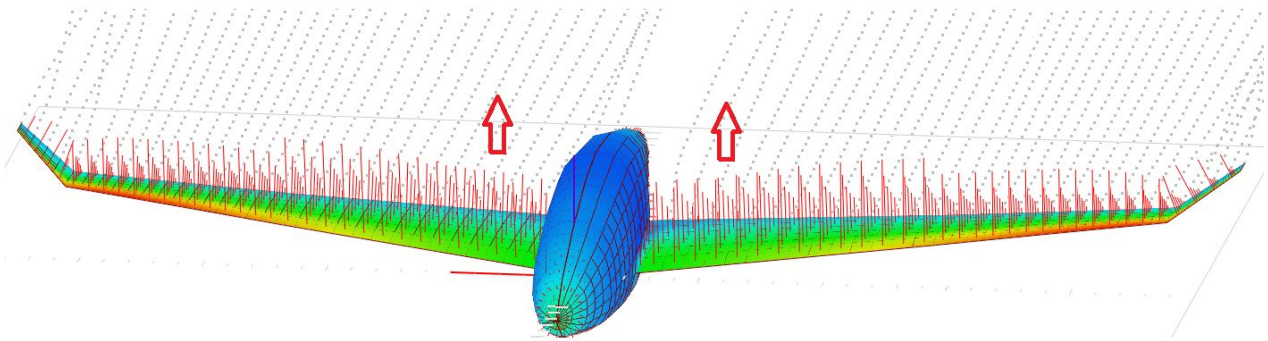


Relative E / P / C

- Canard Downwash Effect on Main Wing
  - Reduces lift in center of main wing
  - Requires larger main wing / sub-optimal lift distribution (non-elliptical) tip to tip
  - Both lead to increased drag

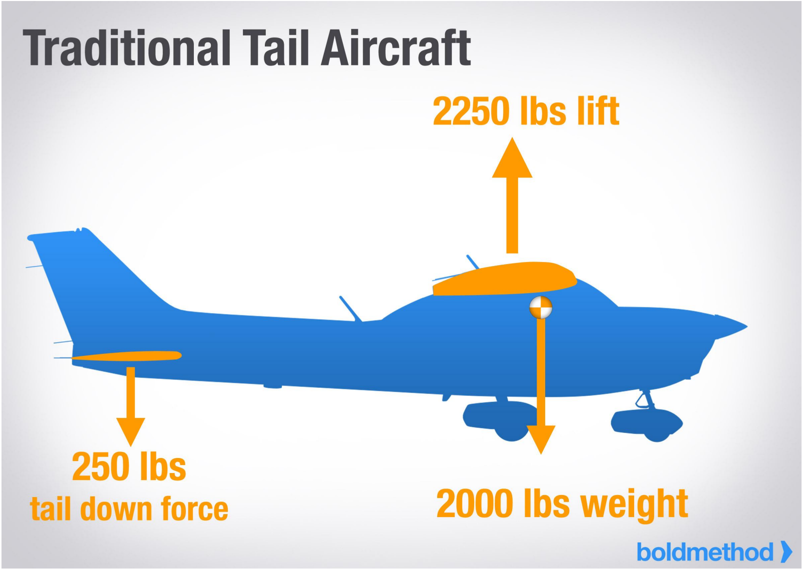


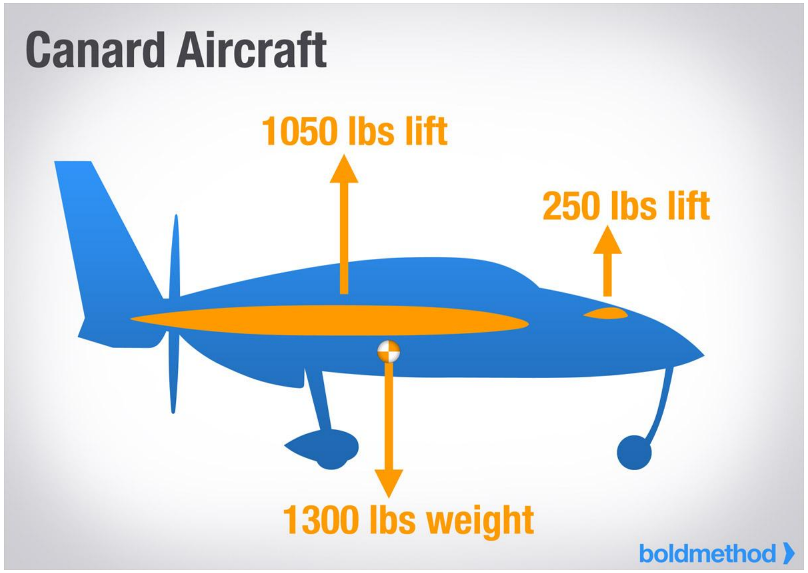
Effect of the Canard on the main wing



Relative E / P / C

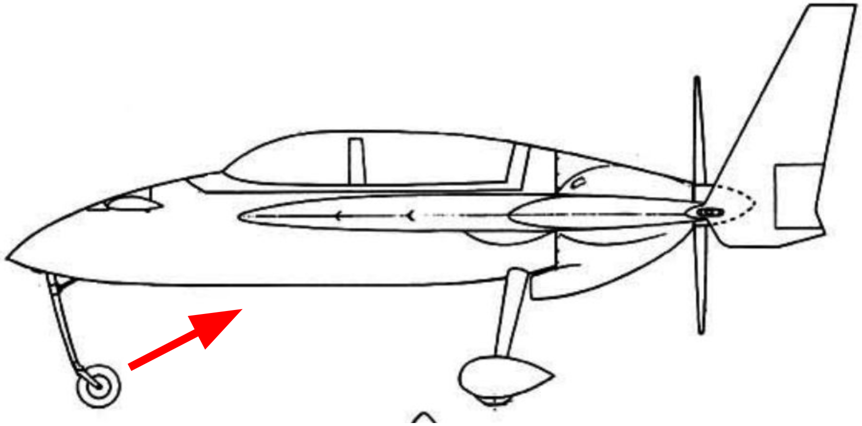
- But Both Wings Lifting - Why isn't this a huge advantage? On Conventional plane, more lift = more drag, no?
- Back to "all else equal"...
  - Downwash from canard requires larger main wing / sub-optimal lift distribution
  - Requirement for canard stall first leads to larger main wing
- End up ~ in same place, overall drag-wise





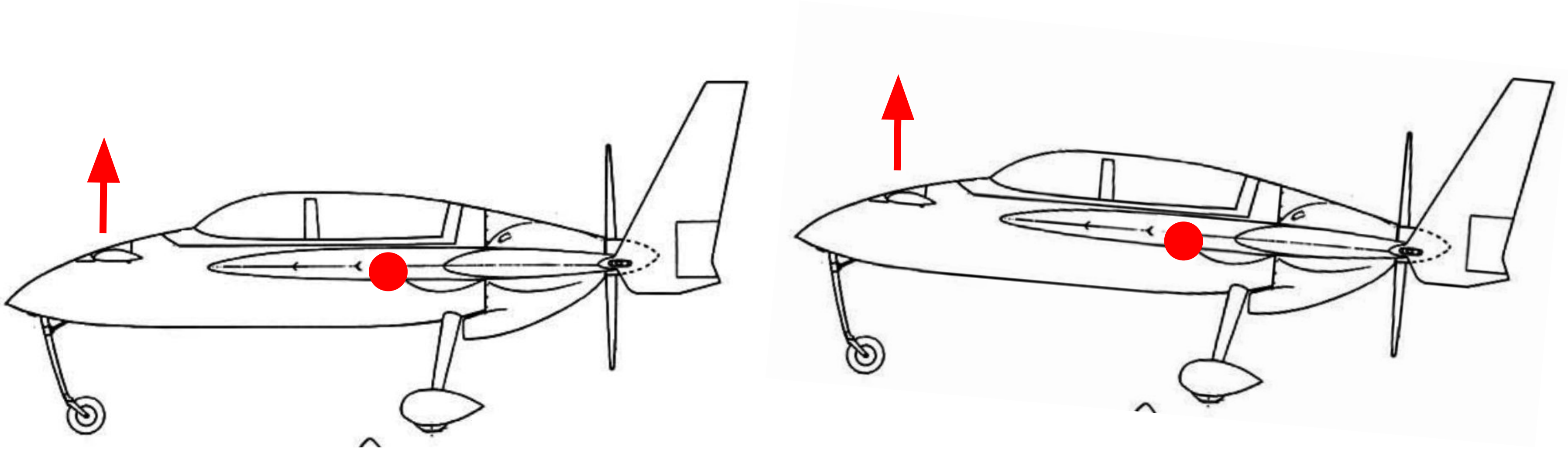
Relative E / P / C

- Short / Soft Field Performance
- All high performance planes suffer in these areas - canards more than most
- Landing:
  - Small main tires - susceptible to bumps/ruts
  - Tiny nose tire / same issues
  - Relatively weak nose gear strut/connectivity
  - VE/LE main gear - mounting sub-optimally robust
- Takeoff:
  - No propwash over horizontal tail to assist rotation
  - Small nose gear - poor nose gear geometry - reduces incidence angle with drag forces - difficult rotation
  - Can canards operate off grass fields?
  - Sure - IF field is hard packed, low drag short grass and long “enough”



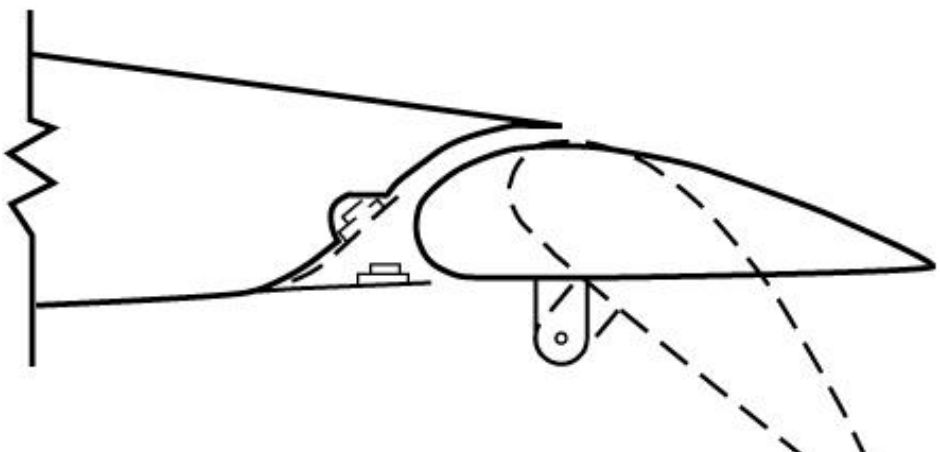
Relative E / P / C

- Relative Field Length - Rotation on Takeoff
- Again, all high performance planes use more runway than slower planes - wings are smaller, have higher stall speeds
- Added disadvantage - canard must create substantial lift (more than flying loads) to rotate around main axle (rather than around CG) - this is what leads to Pilot Induced Oscillations (PIO's) on takeoff with less experienced canard pilots - need more speed to get to point where canard can lift nose
- Example - Mike M. moved main gear aft 1" on N26MS to allow sitting on ground without nose gear retraction - but somewhat more difficult rotation

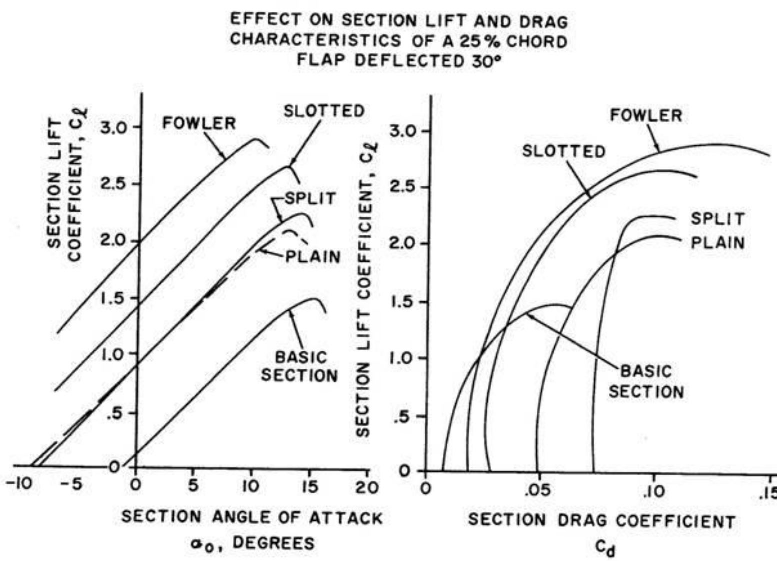


Relative E / P / C

- AOA Indicator - Why not?
  - “Elevator” on either GU or Roncz canard is actually just a slotted flap
  - Flap downward deflection moves Lift Curve Slope and increases Lift Coefficient (also changes drag coefficient)
  - Movement of canard then affects main wing AOA / Airspeed
  - Can measure **MAIN WING AOA** to prevent deep stall, but would need to calibrate AOA indicator **BY STALLING MAIN WING** (that’s not going to happen in any reasonable world and deep stalls can easily be prevented just by keeping CG in the approved range)

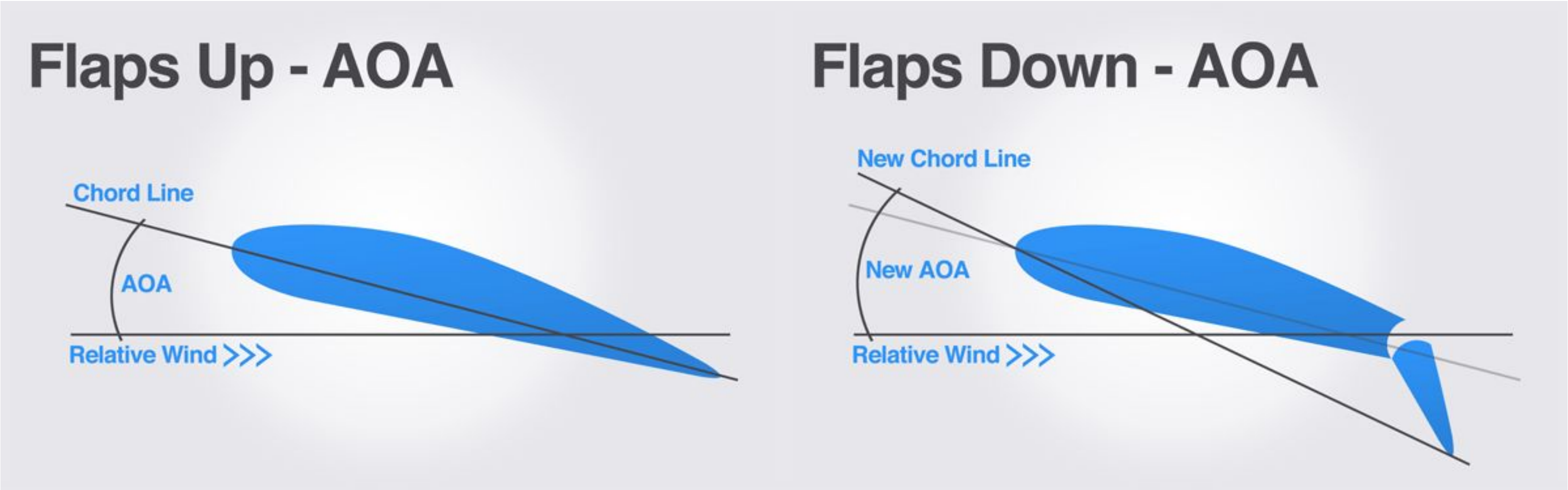


slotted flap



Relative E / P / C

- AOA Indicator - Why Not?
- Deflection of flap/elevator changes chord line - changes camber / AOA of canard airfoil
- Deflection required on flap/elevator is heavily dependent upon Gross Weight and Center of Gravity location
- Measuring AOA of canard airfoil has no one reference frame, since every GW/CG combination will have a different AOA reference - unless the AOA indicator can take into account the current GW/CG, the indication will be meaningless



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Aerodynamic Modifications

- Long Nose - (extreme example - many others of varying proportions)
  - Lower directional stability - area ahead of CG (verified via flight testing on other aircraft)
  - Lower pitch stability
  - Lower deep stall resistance

Aerodynamic Modifications

- Smaller / Removed Lower Winglets
  - Lower directional stability (verified via flight testing)
  - Lower deep stall resistance due to lower span-wise flow resistance

Aerodynamic Modifications

- Smaller Upper Winglets
  - Lower directional stability
  - Verified via flight testing

Aerodynamic Modifications

- Blended Winglets
  - Done for drag reduction purposes - only one successful instance w/ A-B comparison
  - Always in concert with lower winglet removal, as described on previous slide - same effects

Aerodynamic Modifications

- Dihedral Canard
  - No idea why people do this - maybe looking for roll stability increase?
  - No measurable differences to stability, speed, drag, or anything else

Other Aero. Modifications

- Canard Tip Plates
  - Area ahead of CG - lower directional stability
  - Possible deep stall issue due to increased effectiveness of canard - somewhat equivalent to increasing span or area
- Canard Span Changes
  - GU / Roncz on Long-EZ / COZY III
    (~10" difference [shorter] when moving to Roncz airfoil)
  - Roncz on COZY MKIV - Mandatory Changes
    (6" span decrease after deep stall testing)
  - Increased span moves Aerodynamic Center forward, which:
    - decreases pitch stability
    - decreases deep stall resistance
    - Requires moving CG range forward (1" - 1.5" estimate)
- Semi-Symmetric Winglet Airfoil
  - Unknown effect - no "A" to "B" comparisons
    (Scaled aerodynamicist said it could go either way when queried)
- COZY MKIV Wider Fuselage
  - Decreased pitch stability
  - Decreased deep stall resistance
  - How much? No test results available from existing aircraft

References

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Questions? (& Answers)

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- Websites: http://www.cozybuilders.org
  http://www.burnside-aerospace.com

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