Aero 101 for R/C Pilots
Part 1

Brian D. Kelly

June 2017

Common Questions from RC Pilots

Part 1 (June 2017)

Before takeoff

- Will this plane be stable?

Takeoff

- How does the prop affect the airplane?
- Do I need right thrust?
- Wind
- Is the “downwind turn” a myth?

Cruise

- How to fine-tune the cg
- Do I need down thrust?

General Handling

- Plane snaps out of a tight turn
- Does dihedral help or hinder me?
- Won’t respond to aileron when slow
- Unstable or too sensitive?

Part 2 (Feb 2018)

Approach

- How can I slow down safely?
- Should I re-trim for approach?
- Use elevator or thrust?
- What will flaps do?

Judge what a new plane will be like

- Wing Loading and stall speed
- Power loading
- Aspect Ratio
- Servo size

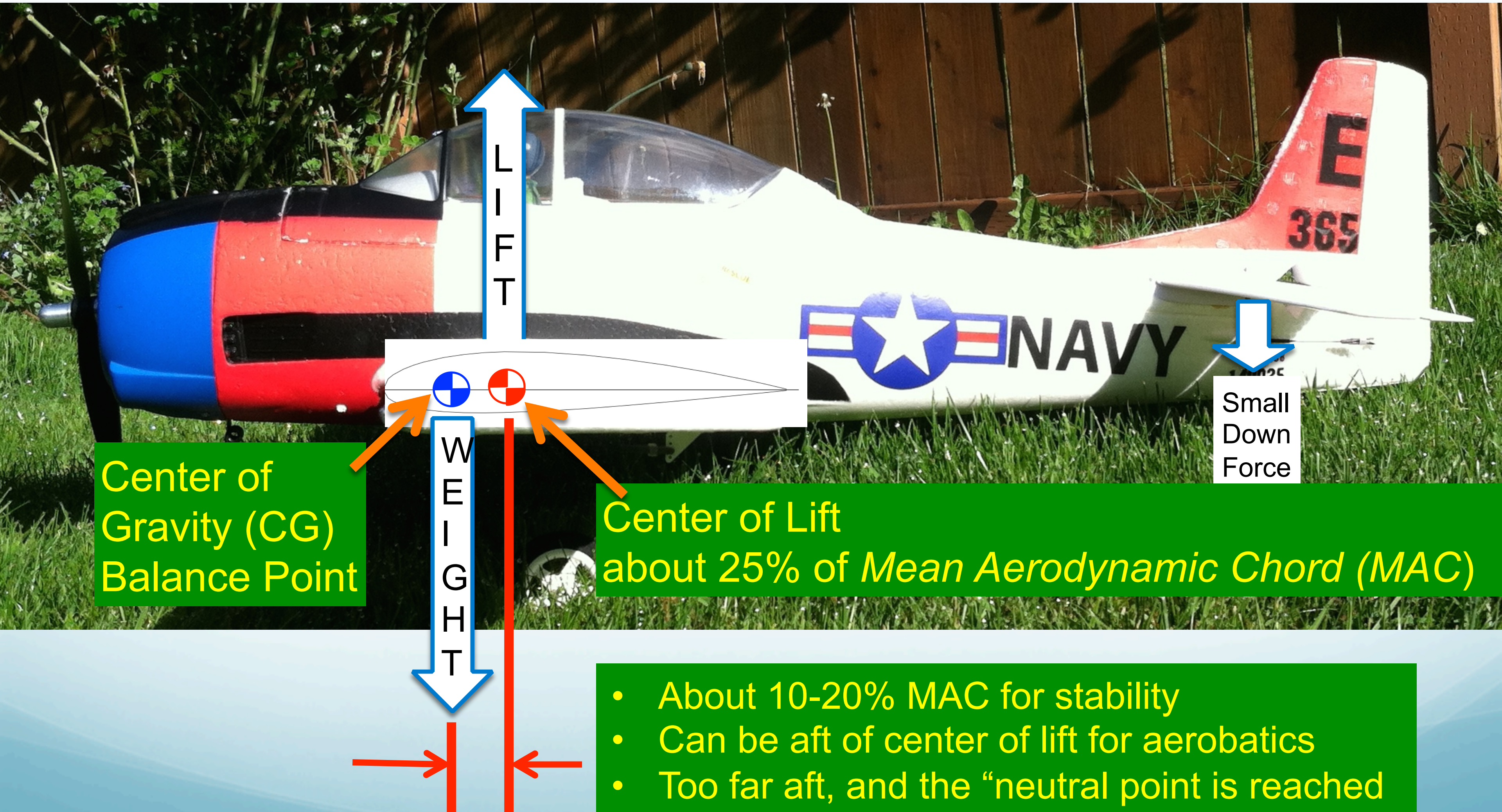
Part 3

- How can I use my computer transmitter to make the airplane more enjoyable or easier to fly?

Before takeoff
Will this new plane be stable?

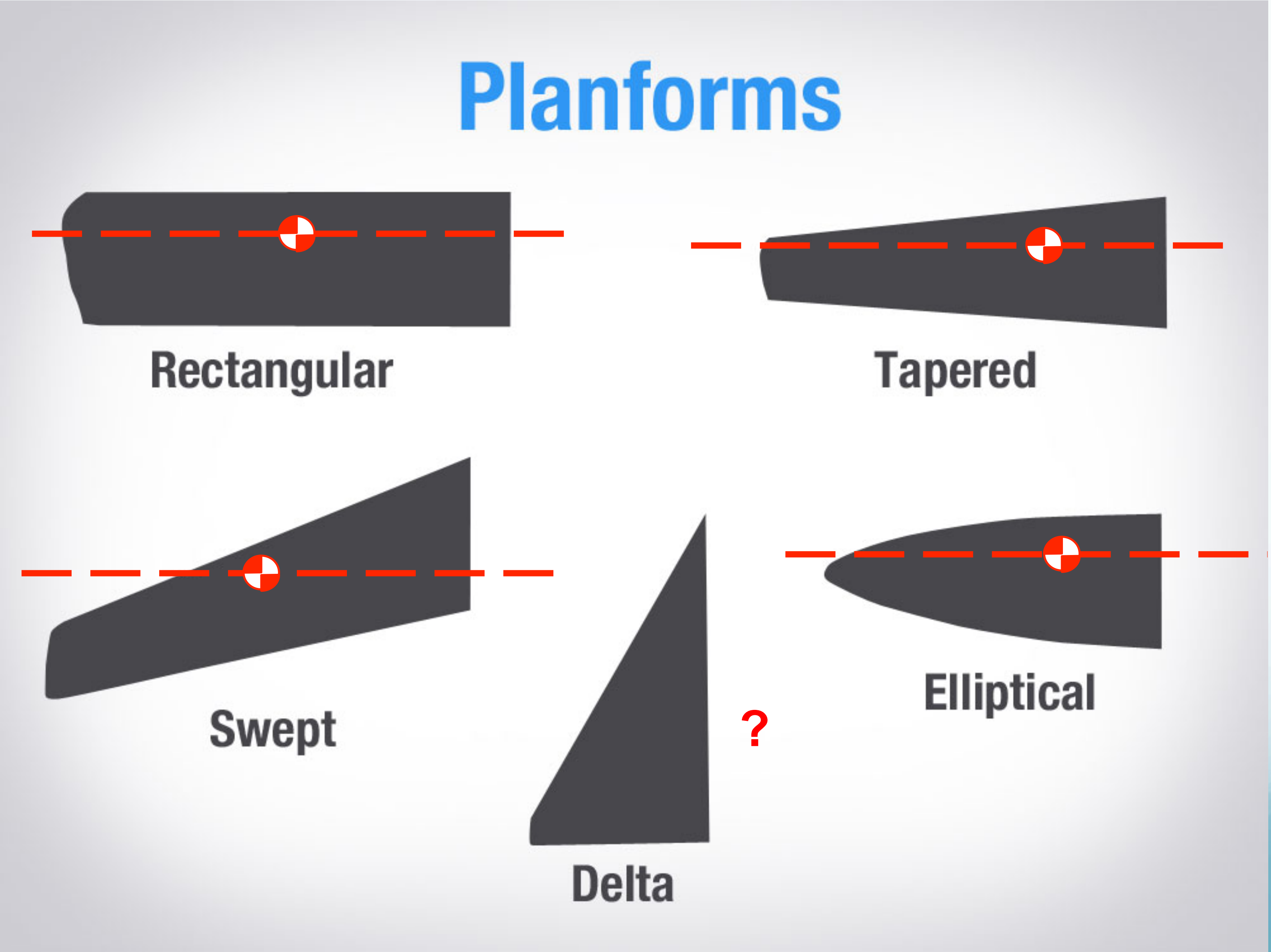
- Where should I put the cg?
  - Ahead of the center of lift.
  - Where is the center of lift?
  - How *much* ahead of the center of lift?
- Is the tail big and/or long enough?

Centers of Lift and Gravity Determine Pitch and Speed Stability



- About 10-20% MAC for stability
- Can be aft of center of lift for aerobatics
- Too far aft, and the “neutral point is reached (truly unstable)

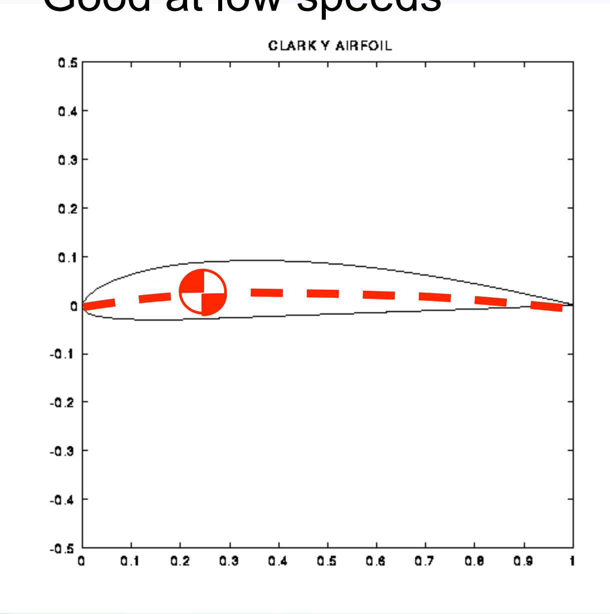
Where's the Center of Lift?



Airfoil Shapes

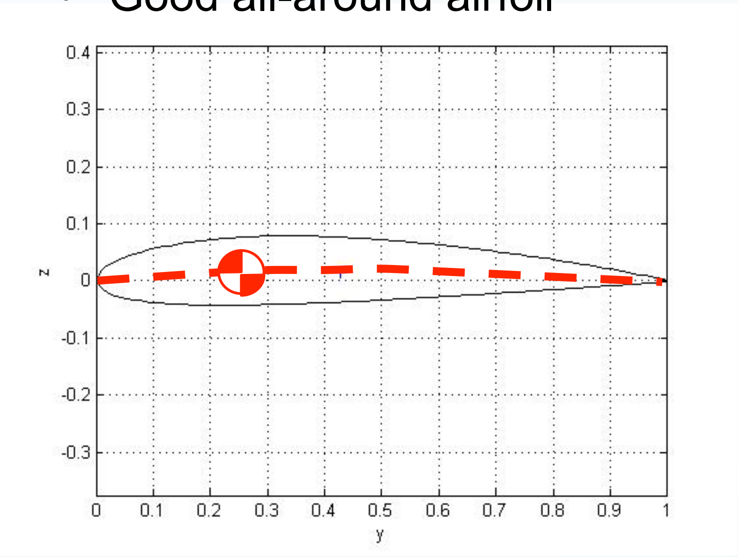
Flat bottom airfoil

- More camber (mid-line is curved)
- Trainers and Cubs (Clark Y)
- Good at low speeds



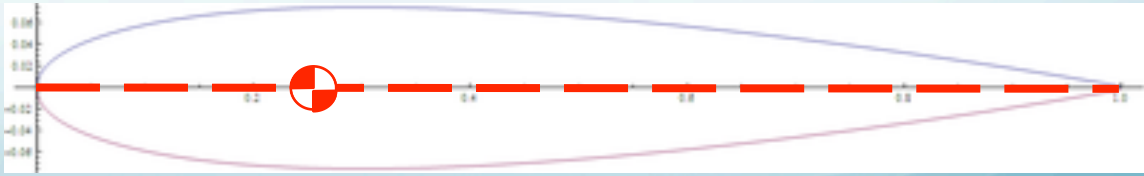
"Semi-symmetrical" airfoil

- has some camber
- sometimes used on trainers
- Good all-around airfoil



Symmetrical airfoil

- Zero camber - mid line is straight
- Used on aerobatic airplanes



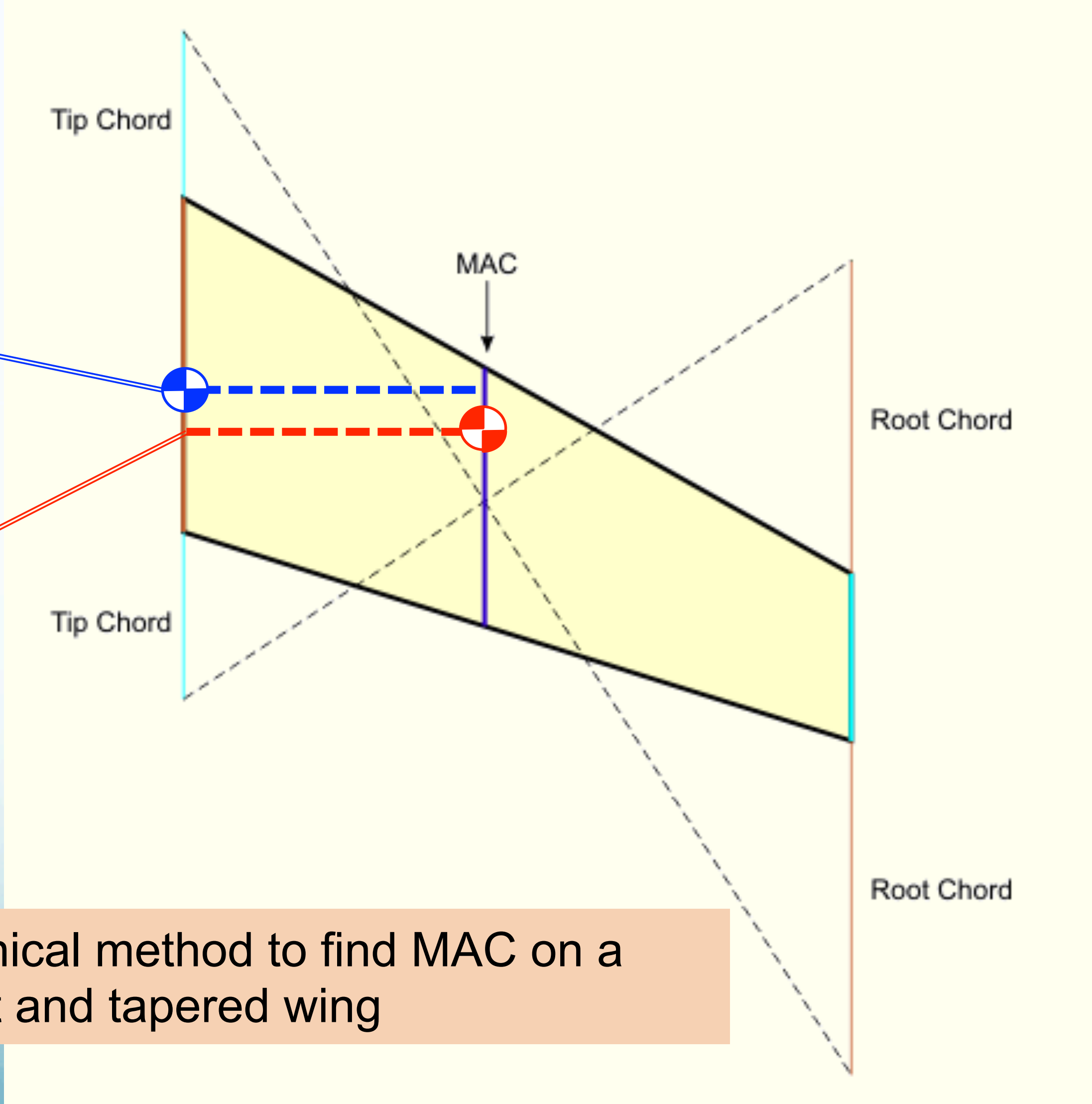
Center of lift is very close to 25% chord for almost any airfoil (subsonic)
-- usually near max thickness, best place to put the spar.

Mean Aerodynamic Chord (MAC)

- A chord location equivalent to a rectangular wing of the same area

- Center of Gravity (balance point) should be 10-20% of MAC ahead of the Center of Lift *

- Center of lift is at 25% of MAC from leading edge



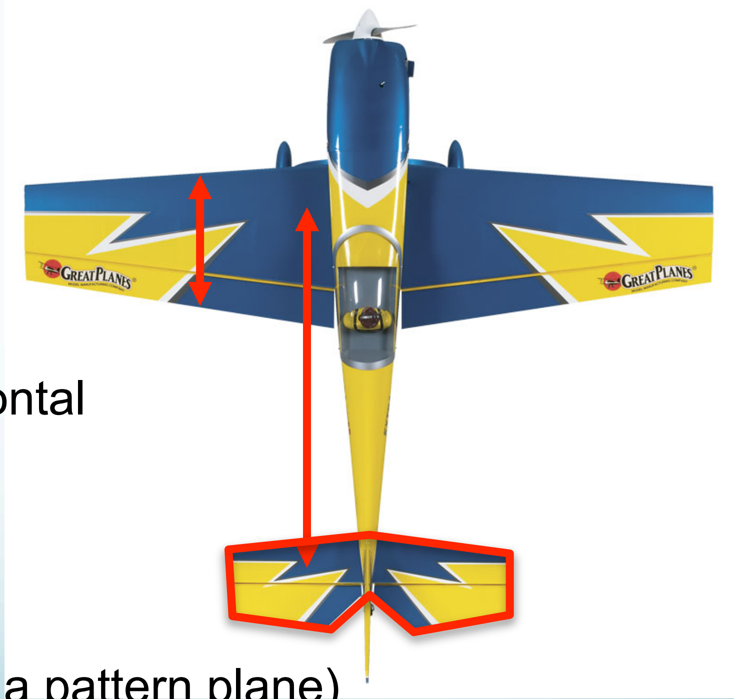
Graphical method to find MAC on a swept and tapered wing

* with fuel tank empty if fuel tank is forward of CG

Is the horizontal tail big or long enough?

- Even if CG is right, too small or too short tail:
  - difficult to fly
  - sensitive to CG position
- ***Tail Volume*** takes tail length and area into account

$$V_h = \frac{S_h L_h}{S c}$$



V_h horizontal tail volume
S_h horizontal tail area (includes elevator)
L_h tail length: .25 mac wing to to .25mac of horizontal
S wing area
c is mean aerodynamic chord (mac)

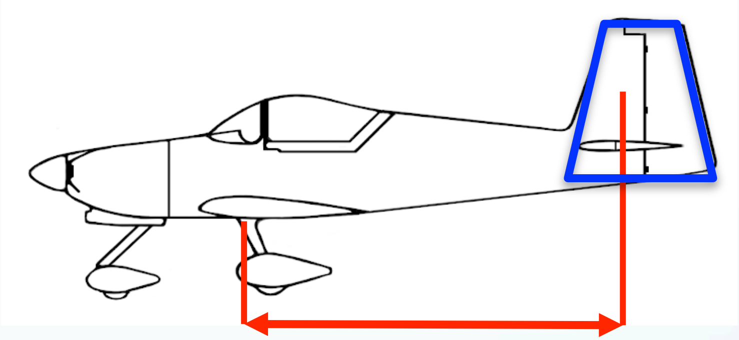
V_h should be from 0.3 to 0.6 for full scale planes
(generally more for RC planes, much more for a pattern plane)

Compare your plane to one of similar size with known flying characteristics

Is the vertical tail big or long enough?

- Even if CG is right, too small or too short tail:
  - difficult to fly
  - sensitive to CG position
- ***Tail Volume*** takes length and area into account

$$V_v = \frac{S_v L_v}{S\, b}$$



V_v vertical tail volume
S_v vertical tail area (includes rudder)
L_v tail length: .25 mac wing to to .25mac of vertical area
S wing area
b wing span

V_v should be from 0.02 to 0.05 for full scale planes (generally more for RC planes)

Compare your plane to one of similar size with known flying characteristics

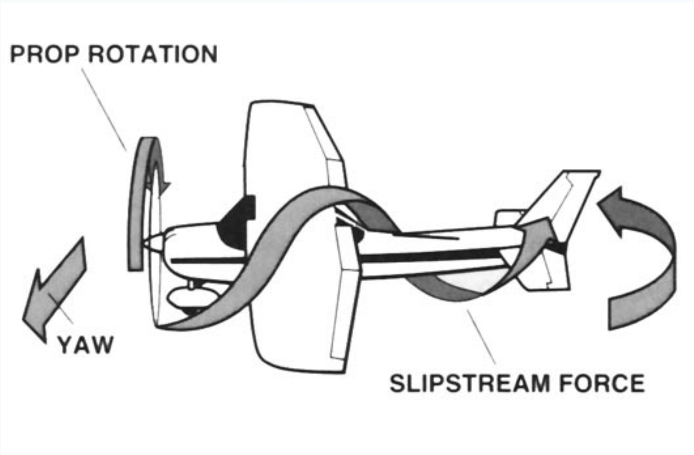
https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-01-unified-engineering-i-ii-iii-iv-fall-2005-spring-2006/systems-labs-06/spl8.pdf

Takeoff

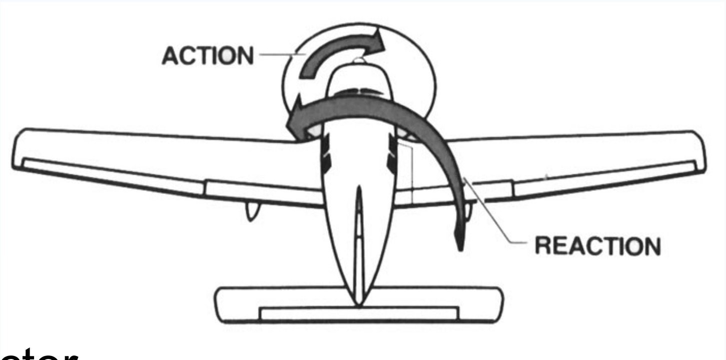
- How does the prop affect the airplane?
- Do I need right thrust?
- Wind
- Is the “downwind turn” a myth?

Propeller effects in Roll and Yaw

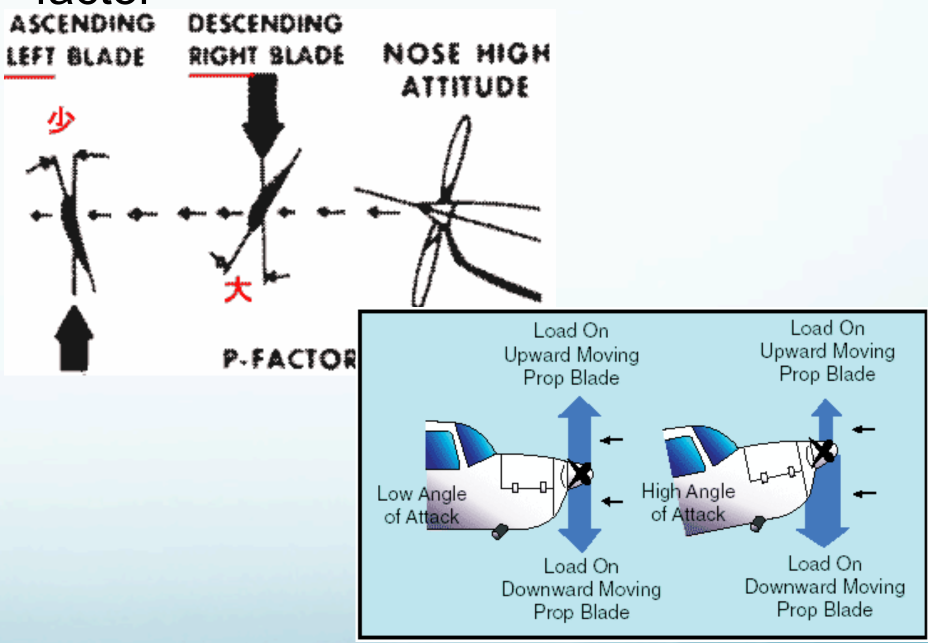
Slipstream (Likely the largest effect)



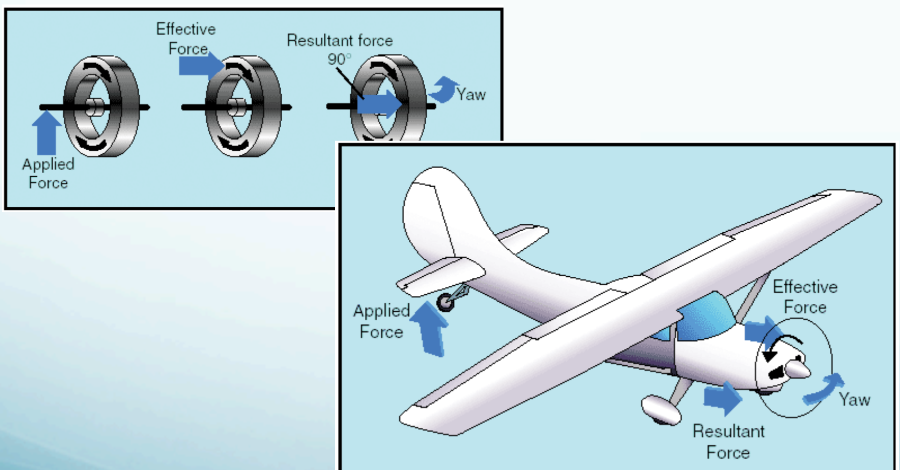
Torque



P-factor



Gyroscopic Precession



http://www.free-online-private-pilot-ground-school.com/propeller-aerodynamics.html

https://www.aircraftspruce.com/catalog/pdf/13-09032.pdf

Propeller Effects

What the pilot experiences

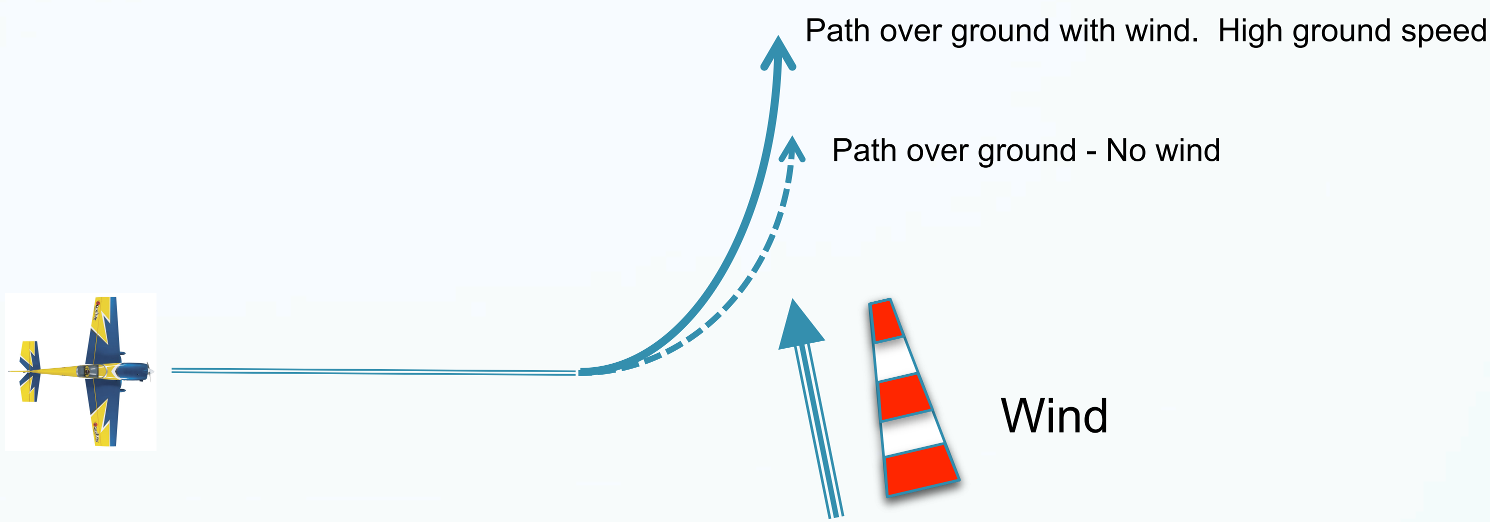
Swirling slipstream hits vertical fin	Yaw Left*	- noticeable on early takeoff roll
Gyroscopic effects	Yaw Left*	- Early takeoff when taildragger lifts up tail
Torque	Roll left	- large prop and short span - Torque roll hanging from prop - not noticeable if gear on the ground
"p-factor"	Yaw left*	- noticeable in the air with aoa - on ground for taildragger in tail-down position

* Sudden left yaw in the air will also cause left roll if airplane has dihedral

Right Thrust

- Helps!
- Must experiment for your airplane
- Most ARF’s come with the right thrust built in
- Start with a couple washers under the left engine mount bolts
- Do the experimenting before final mounting of your cowl

The Downwind Turn



- The airplane doesn't "feel" a steady wind
- If pilot controls by reference to the ground (not instruments) can pitch up too much and stall by perceiving ground speed
- RC pilots stand on the ground and therefore tend to reference their airplane control relative to the ground
- Down-wind turn hazards are a real thing for RC pilots

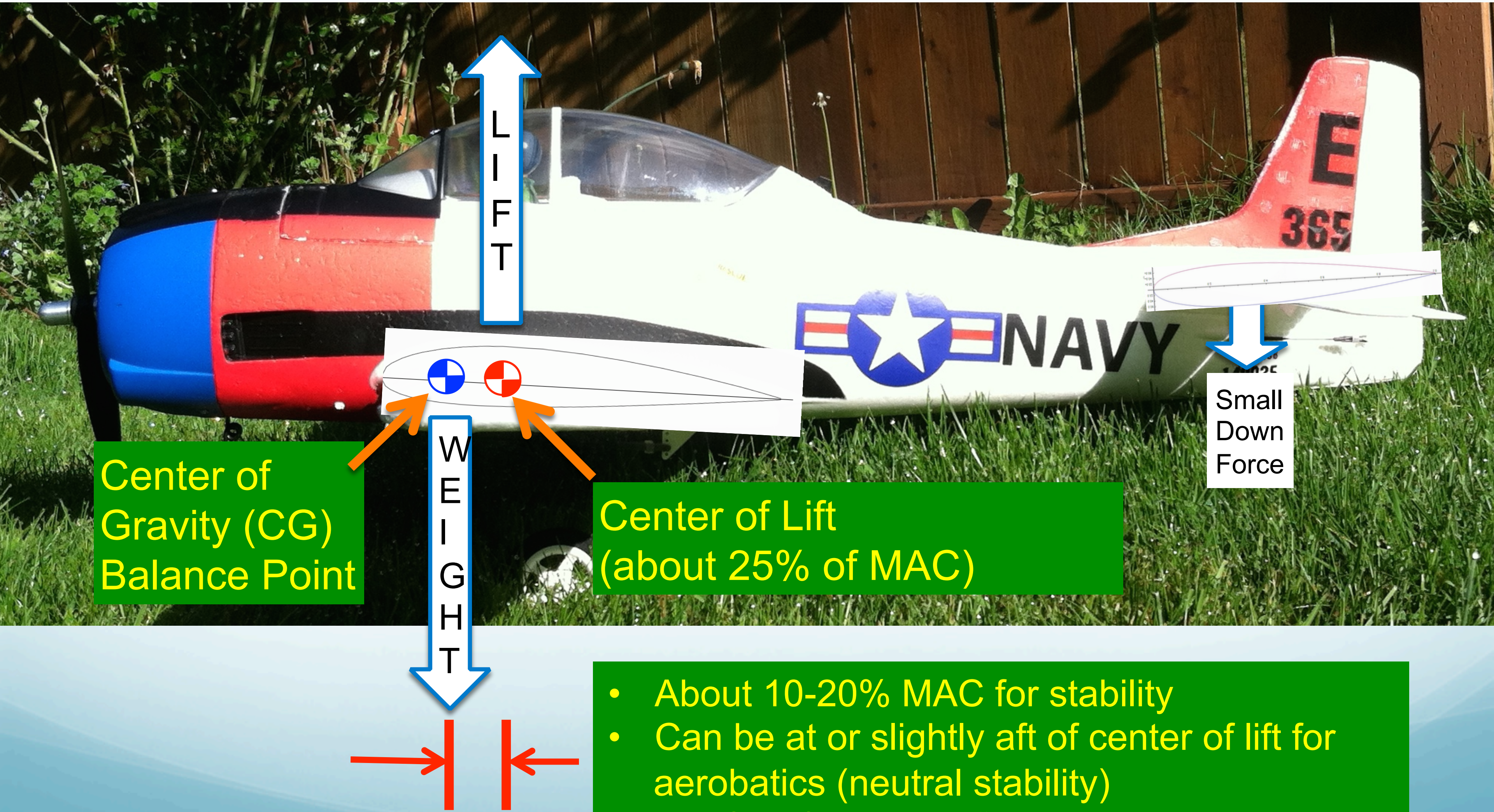
Wind on Takeoff

- Takeoff into the wind….of course!
- Crosswind will cause:
  - Yaw into the wind
  - Upwind wing to pick up, esp for high wing with dihedral
- Example: Crosswind from the right
  - Causes right yaw initially
  - Causes left roll as you rotate into the air (if dihedral)
  - Prop effects also cause left turn
  - Can lead to a downwind turn at low altitude

Cruise

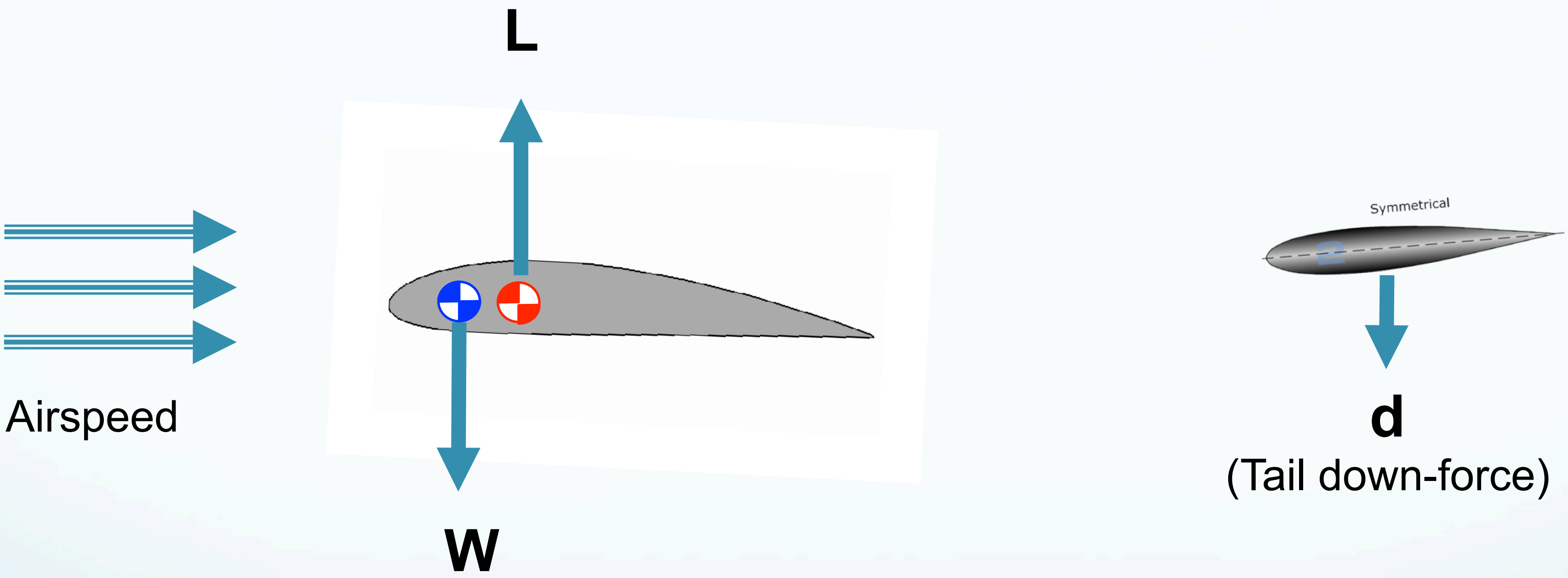
- How to fine-tune the cg
- Do I need down thrust?

Centers of Lift and Gravity Determine Pitch and Speed Stability

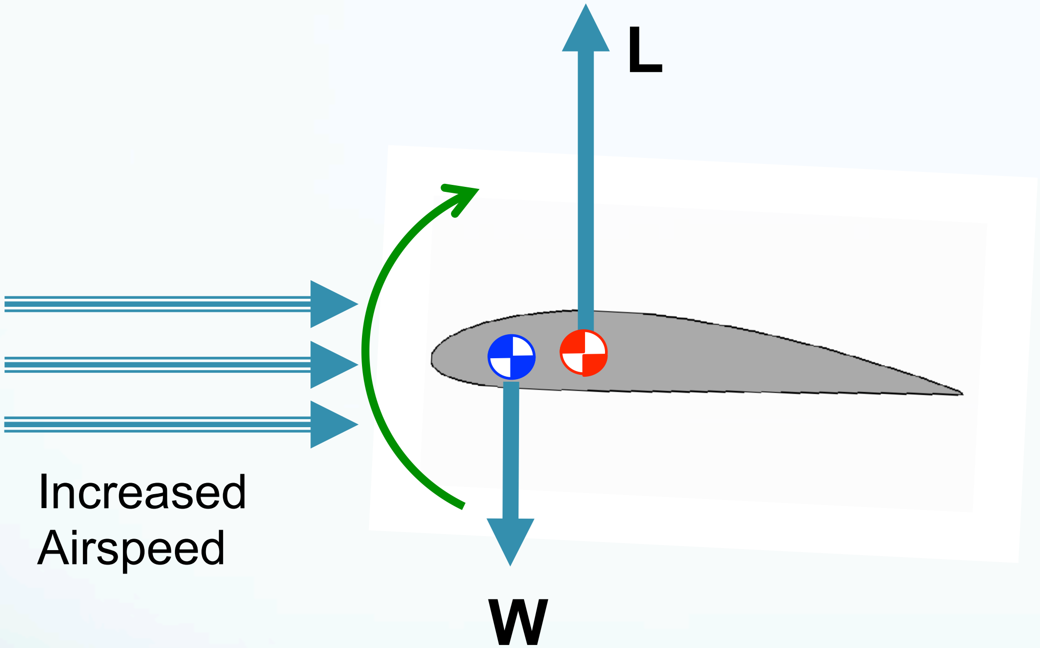


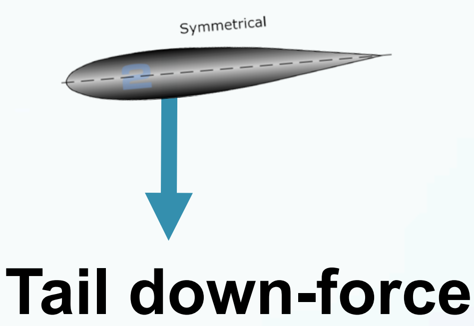
- About 10-20% MAC for stability
- Can be at or slightly aft of center of lift for aerobatics (neutral stability)
- Too far aft, and the “neutral point” is reached (truly unstable)

Trimmed



Now, increase speed without re-trimming





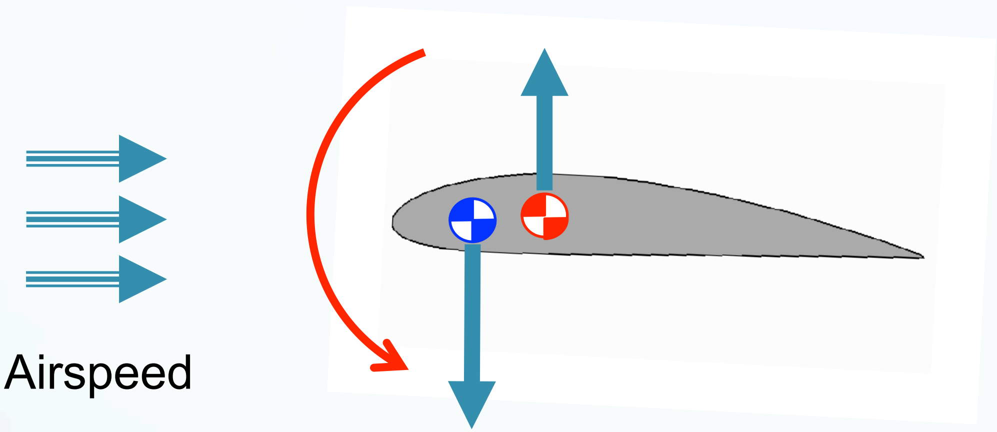
- More lift
- More tail down-force
- Weight stays the same

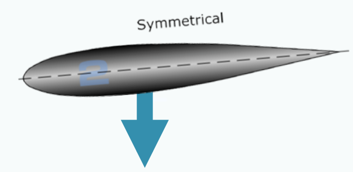
Airplane climbs, and pitches UP

… airplane begins to decelerate

Speed decreases ...

Decrease speed from trimmed state





- Less lift
- Less tail down-force
- Weight stays the same

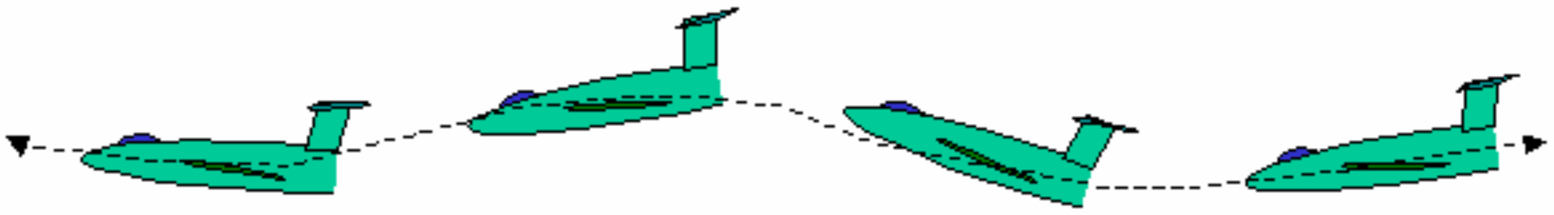
Descends and pitches down

… Airplane begins to accelerate

... Speed increases

... Cycle begins again

Result? Phugoid

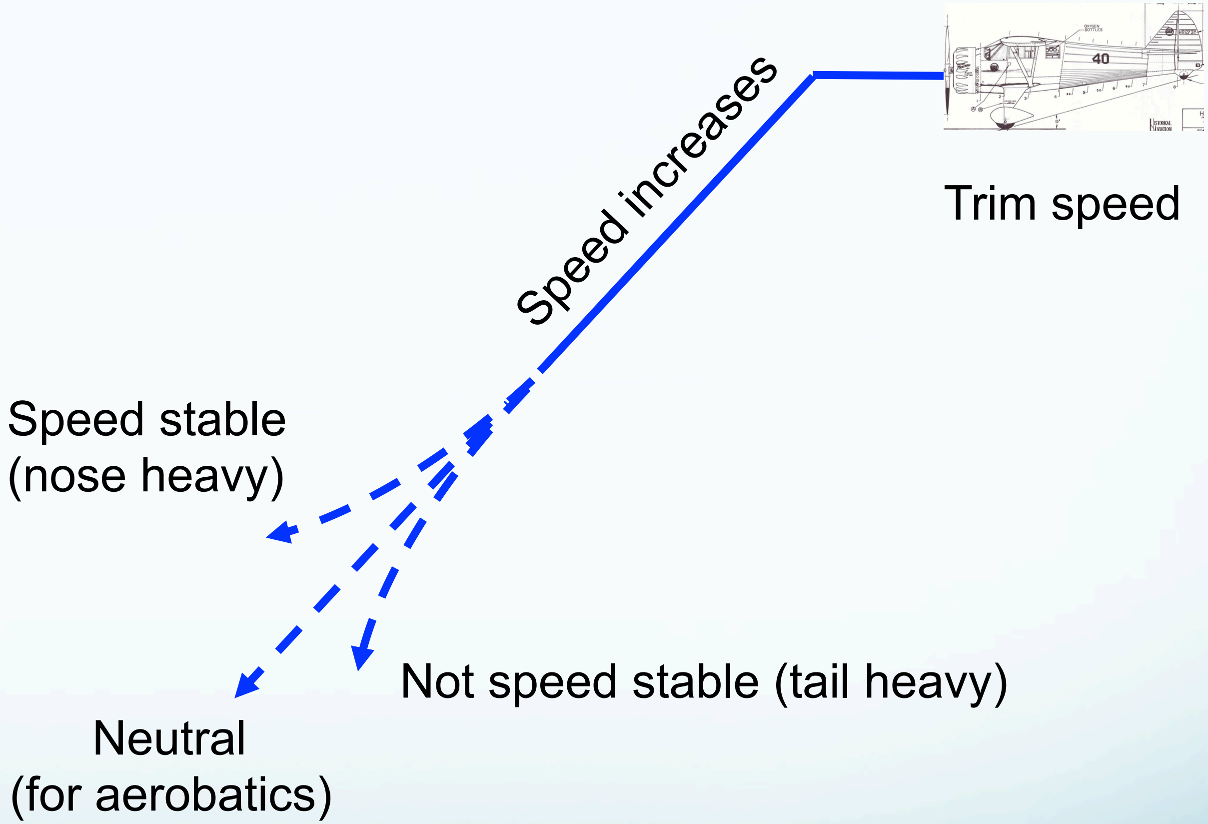


- Airplane is seeking the trimmed speed – “speed stable”
- Small, relatively slow changes. Pilot corrects without knowing
- Undesirable for aerobatics

https://en.wikipedia.org/wiki/Aircraft_dynamic_modes

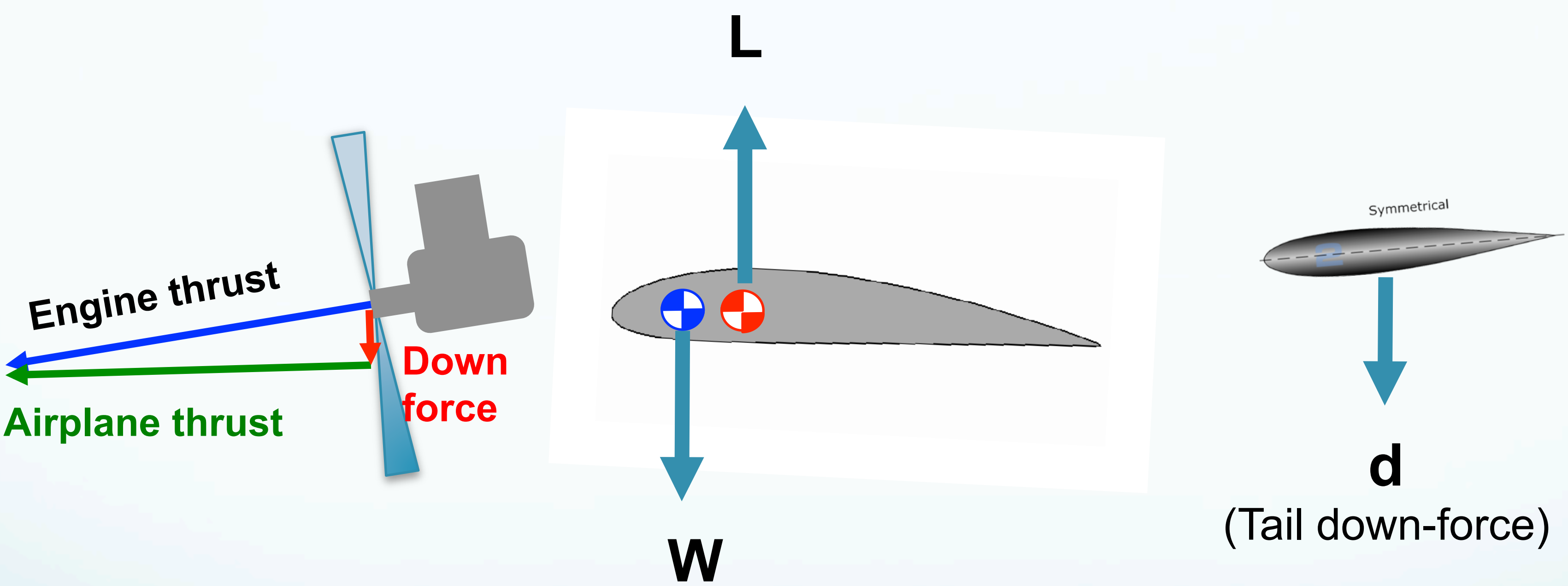
Fine-Tuning the CG
(Choosing your Speed Stability)

- Trim for mid-power
- Fly high and level
- Nose down about 45^{o}
- Hands off controls
- Let airplane accelerate



Another way:
http://www.flyrc.com/aerobatic-trimming/

Down-Thrust compensates for pitch changes due to increase in speed from throttle



… and reduces the need to re-trim at approach speed

General Handling

- Snaps or spins out of a tight turn
- Does dihedral help or hinder me?
- Won’t respond to aileron when slow
- Unstable or too sensitive?

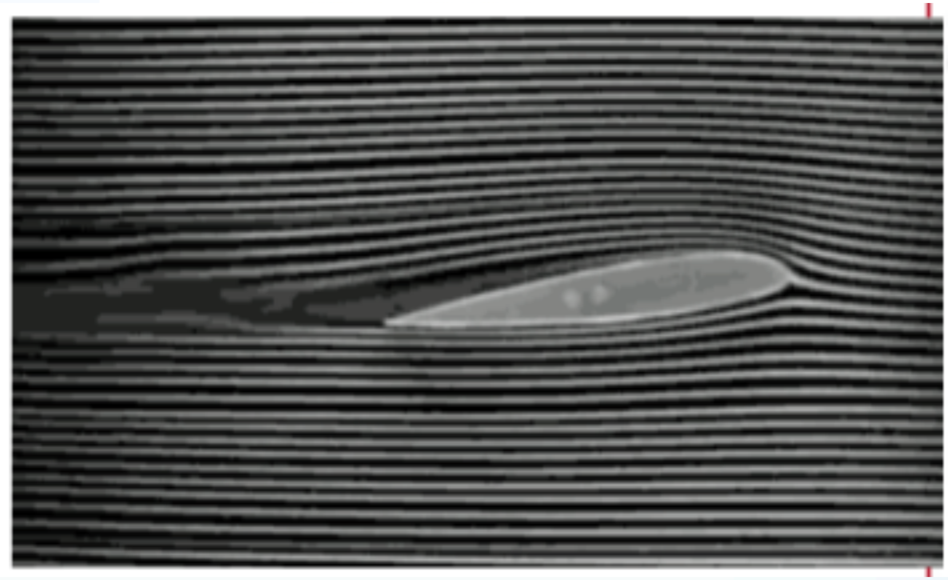
Snaps or Spins out of a Tight Turn

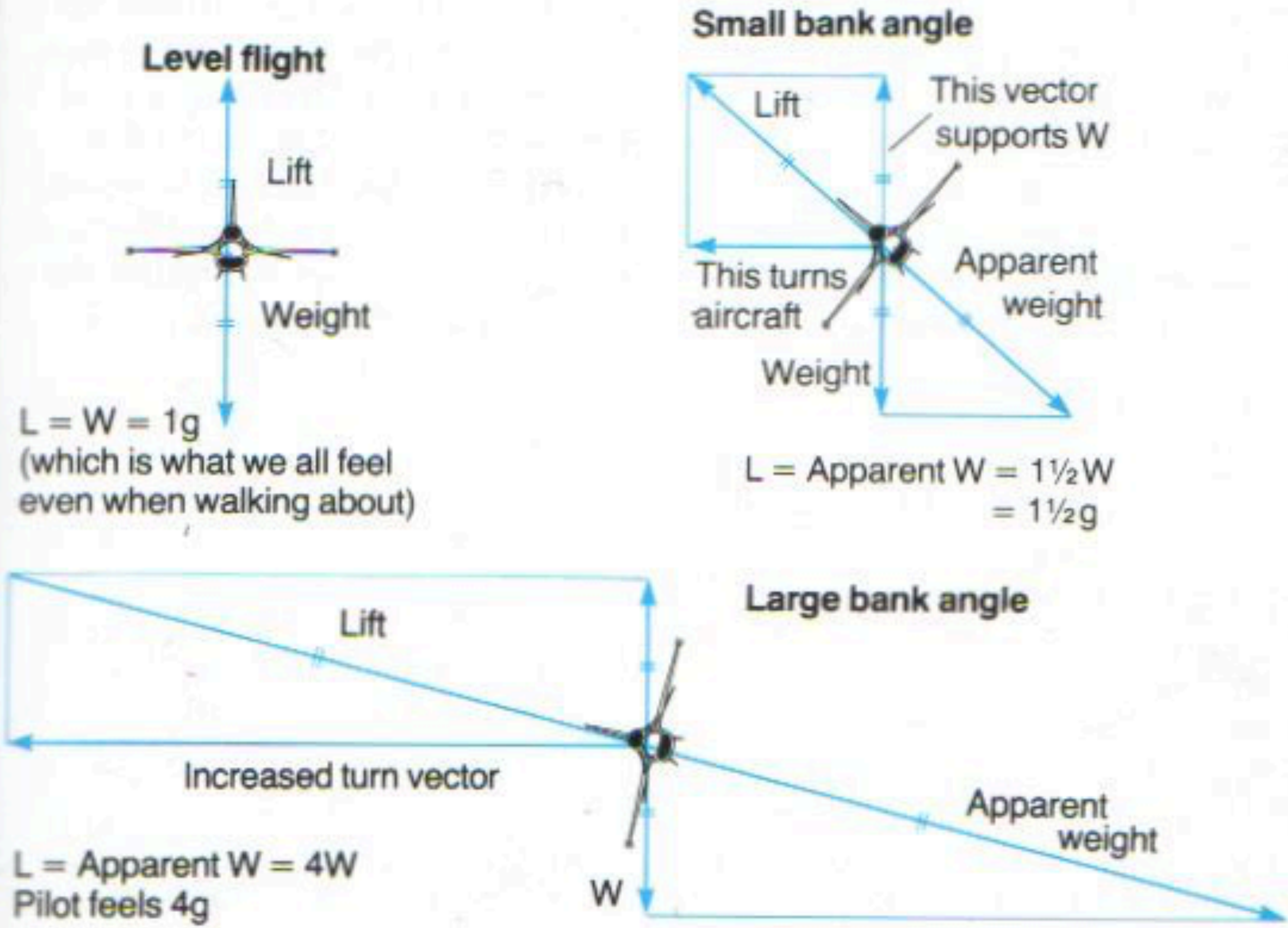
- Stall
  - Stall with G's
  - How many G's in a turn?

- Why does it Snap? (one wing stalls first)
  - Wings at different incidence
  - Torque (if highly powered)
  - Wing planform stall characteristics
  - Airfoil stall characteristics
  - Reynolds number
  - Washout and other preventive measures

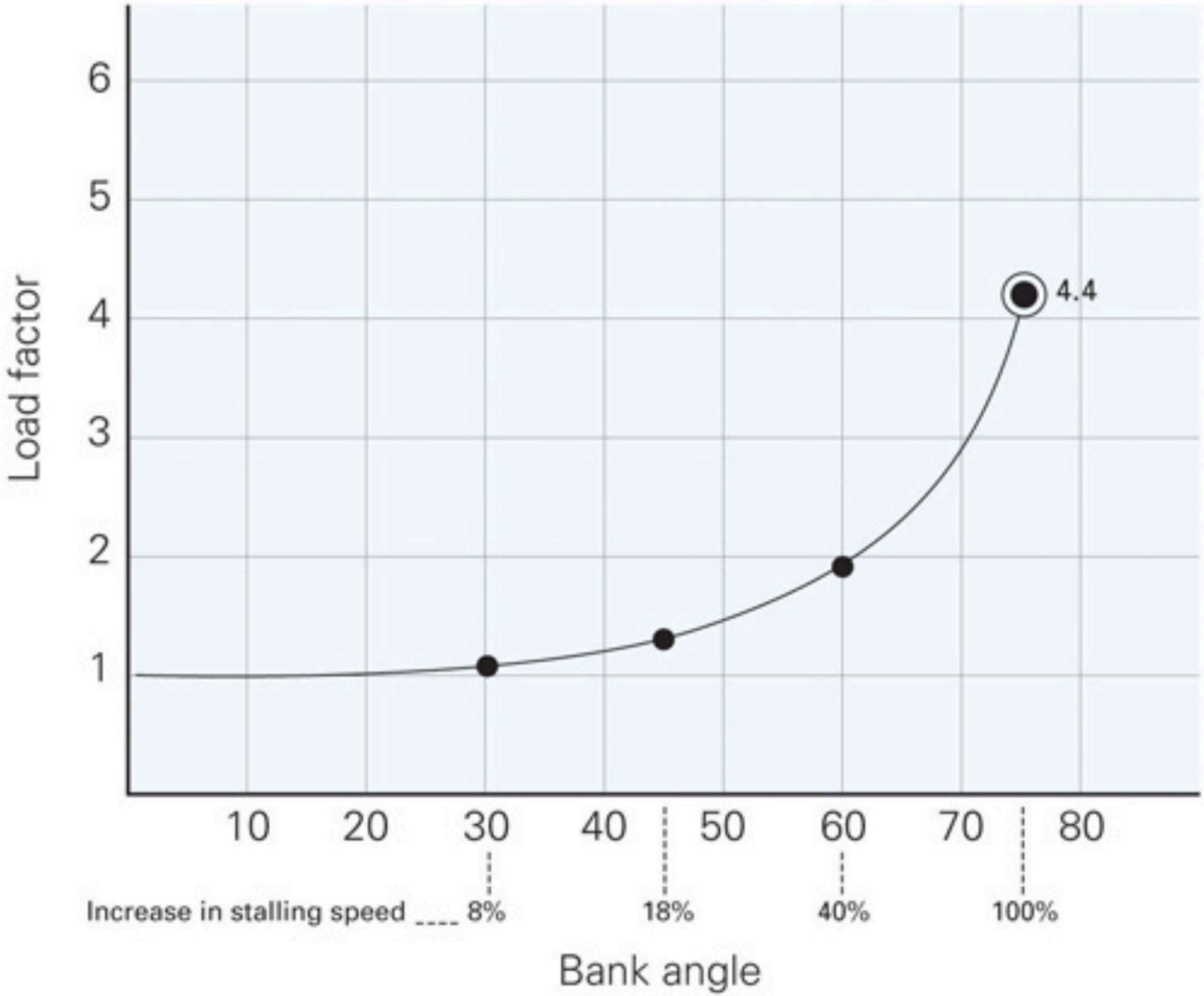
Lift is reduced when the Wing Stalls

- Flow separation occurs at the *critical angle of attack,* around15 degrees, depending on
  - thickness
  - camber
  - LE radius
  - wing planform
- Critical angle of attack can occur when:
  - Too slow
  - Too many g's
  - Or both
  - …in any attitude





Effect of apparent weight and bank angle on 1g flight, 1.5g flight, and 4g flight



https://www.caa.govt.nz/fig/advanced-manoeuvres/steep-turns/

Stall progression for different planforms

(perfectly built wings with no twist)

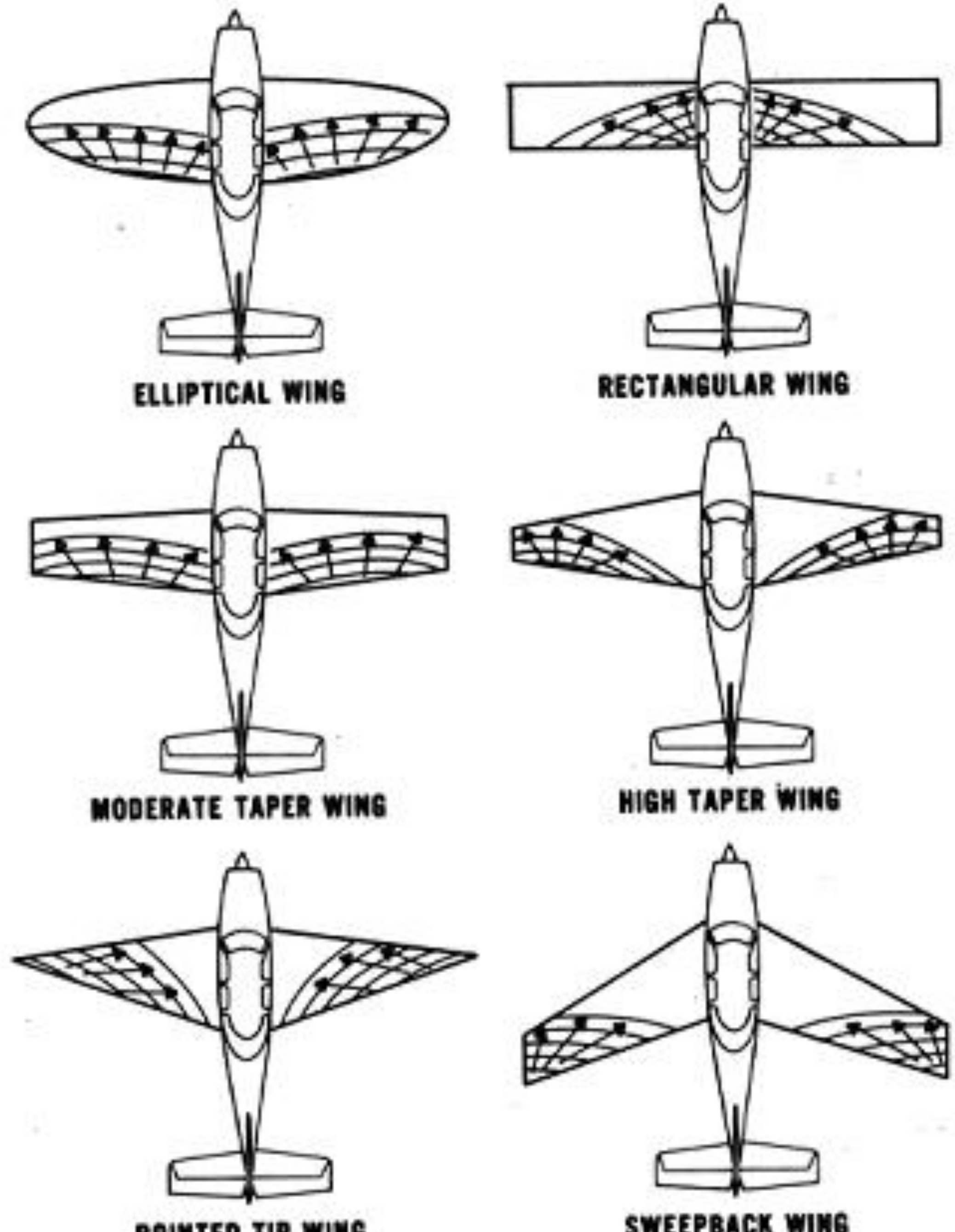
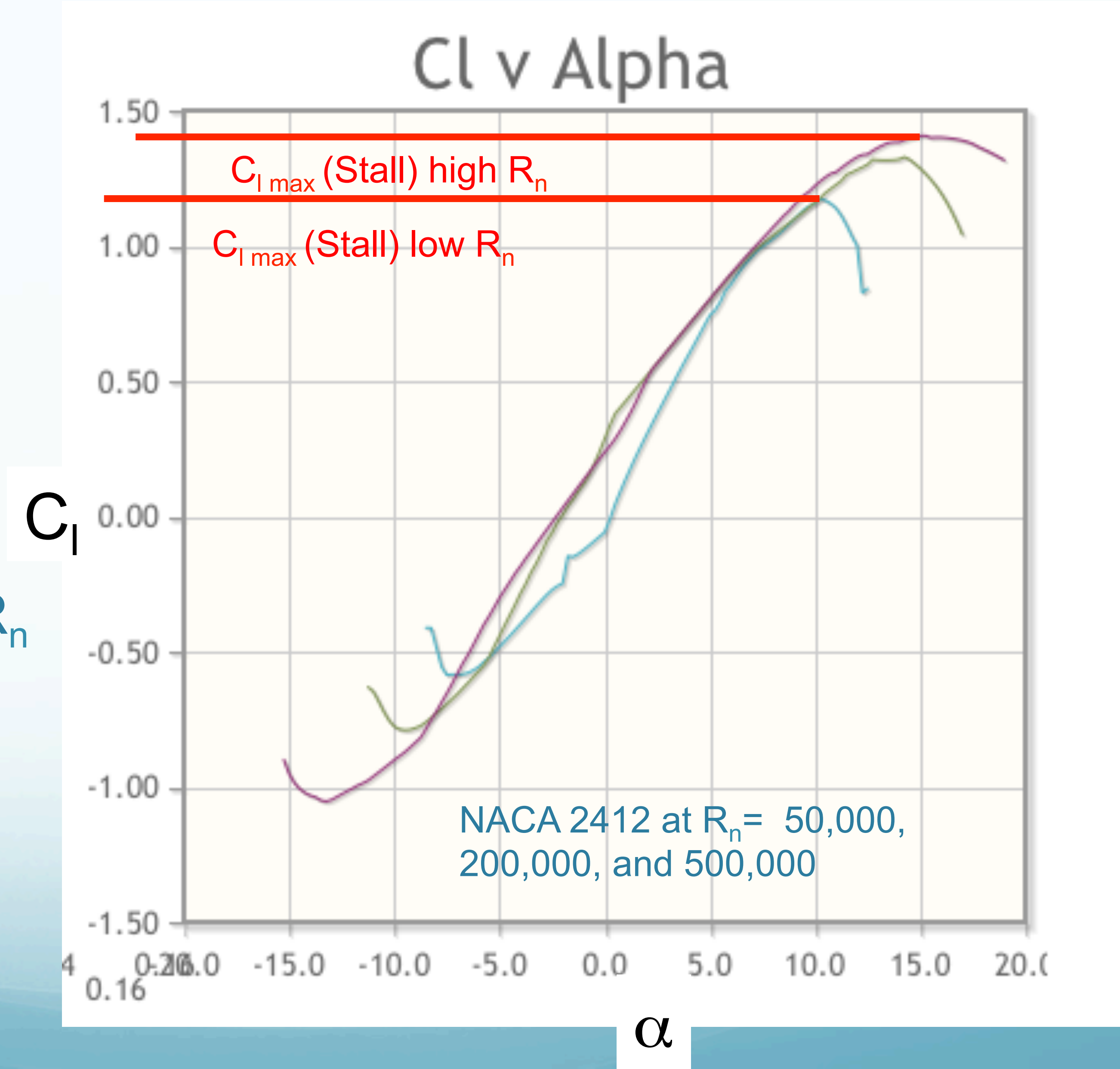


Figure 17–13 Wing Planforms (Exaggerated)

Tip may stall first on a tapered wing

Shorter chord results in lower Reynolds Number R_n

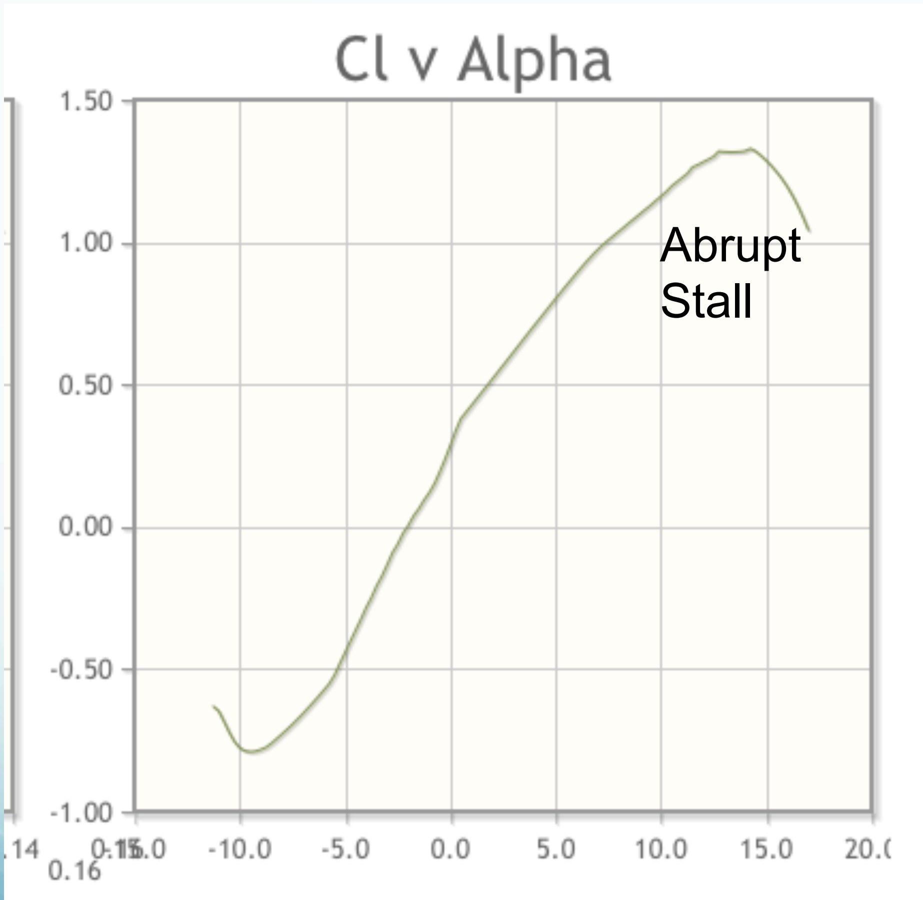


The Reynolds Number

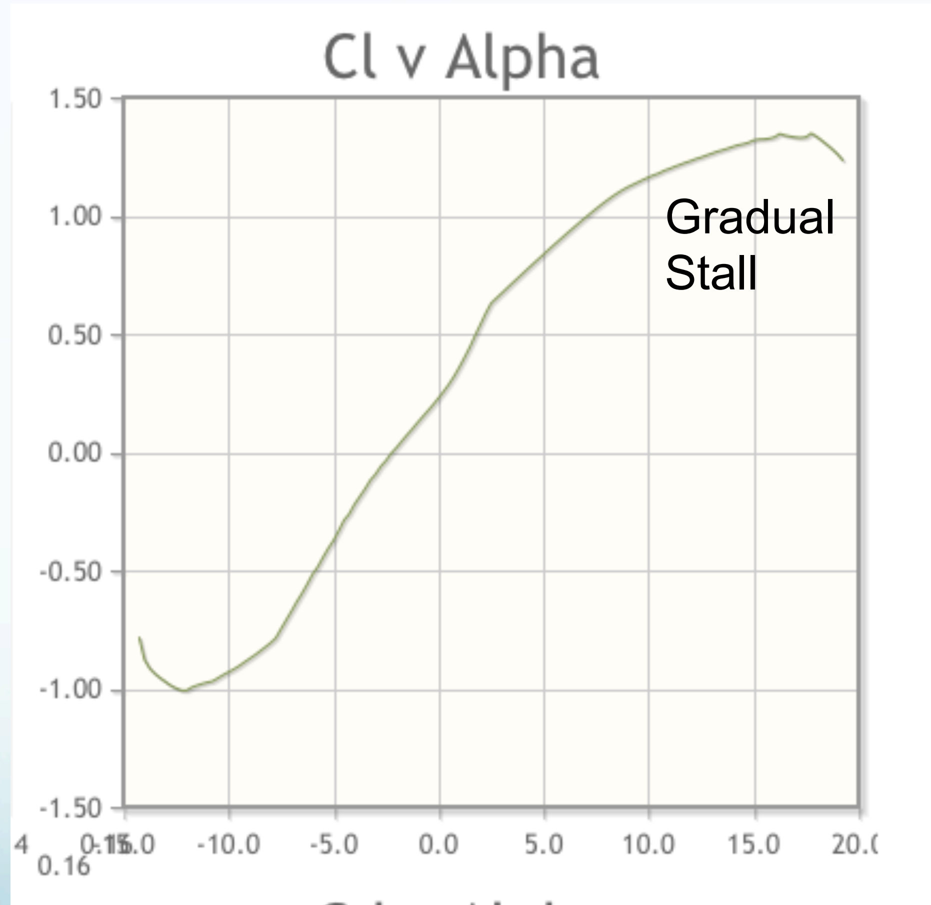
- $R_n = \rho V x / \mu$
  - The ratio of *inertial* forces to *viscous* forces
  - ρ is density of air
  - V is speed
  - x is a reference length, usually the chord of a wing section
  - μ is the viscosity coefficient of air
- Correlates with boundary layer behavior
- We fly at low R_n and there is little wind tunnel data for us
- There is computed data for airfoils – airfoiltools.com
- For small, slow models and park flyers, a flat plate is almost as good as an airfoil
- In some 3D models, thin airfoils with sharp leading edges are used, and yet the stall is still gentle and controllable. Opposite what is expected for a full scale airplane

Airfoils Stall Differently

NACA 2412

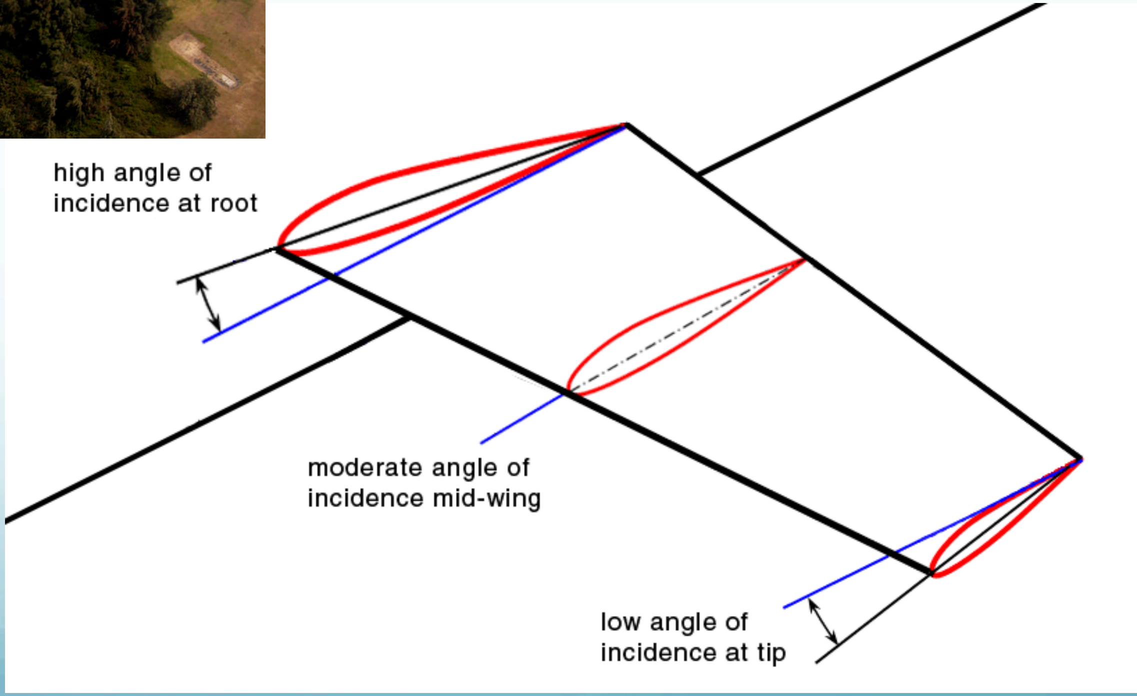


NACA 2415



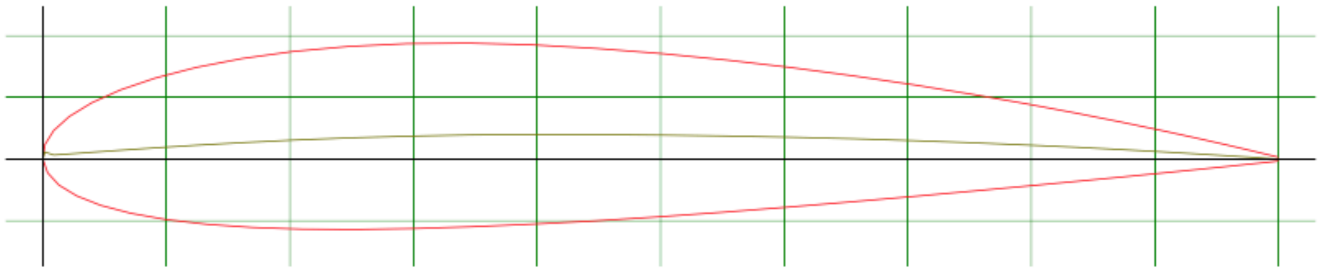
Prevent tip stall

- Washout
- Stall strips
- Different airfoil at tip
  - Thicker
  - Rounder LE



NACA 2415 (n2415-il)

NACA 2415 - NACA 2415 airfoil



Details

(n2415-il) NACA 2415
NACA 2415 airfoil
Max thickness 15% at 29.5% chord.
Max camber 2% at 39.6% chord
Source UIUC Airfoil Coordinates Database
Source dat file
The dat file is in Selig format

Dat file

```
NACA 2415
 1.00000  0.00157
 0.99740  0.00223
 0.98930  0.00419
 0.97590  0.00739
 0.95733  0.01172
```

Parser

No parser warnings

Send to airfoil plotter
Add to comparison
Lednicer format dat file
Selig format dat file

Similar airfoils

NACA 2415	Preview	Details
GEMINI (smoothed)	Preview	Details
S2027	Preview	Details
AVISTAR	Preview	Details
RAF-48 AIRFOIL	Preview	Details
USA 48 AIRFOIL	Preview	Details
MB253515 15.0% smoothed	Preview	Details
EPPLER 715 AIRFOIL	Preview	Details
MH 104 15.28%	Preview	Details
NACA 2414	Preview	Details

Polars for NACA 2415 (n2415-il)

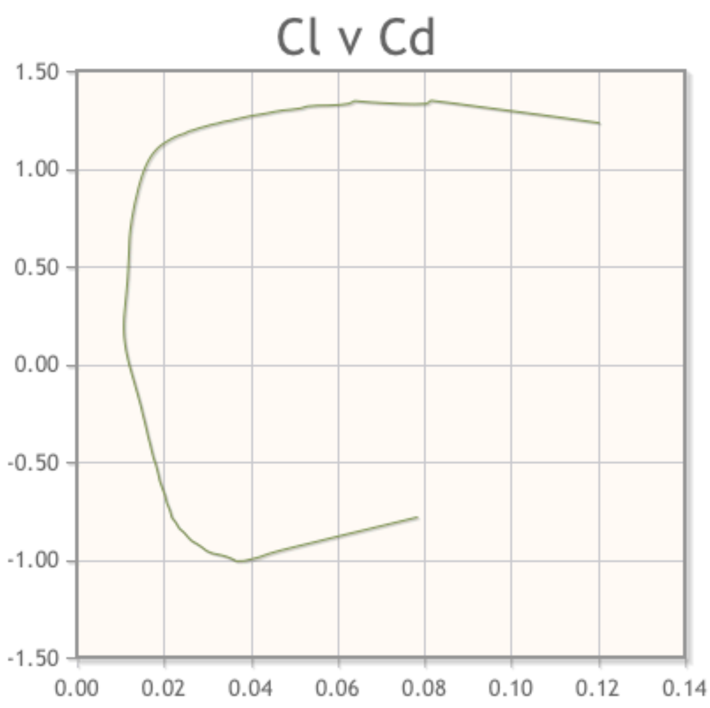
Plot	Airfoil	Reynolds #	Ncrit	Max Cl/Cd	Description	Source	
☐	n2415-il	50,000	9	26.3 at α=9.5°	Mach=0 Ncrit=9	Xfoil prediction	Details
☐	n2415-il	50,000	5	31.6 at α=7.5°	Mach=0 Ncrit=5	Xfoil prediction	Details
☐	n2415-il	100,000	9	46.6 at α=7.5°	Mach=0 Ncrit=9	Xfoil prediction	Details
☐	n2415-il	100,000	5	47.2 at α=6.75°	Mach=0 Ncrit=5	Xfoil prediction	Details
☑	n2415-il	200,000	9	64.2 at α=6.75°	Mach=0 Ncrit=9	Xfoil prediction	Details
☐	n2415-il	200,000	5	61.5 at α=6°	Mach=0 Ncrit=5	Xfoil prediction	Details
☐	n2415-il	500,000	9	87.1 at α=5.75°	Mach=0 Ncrit=9	Xfoil prediction	Details
☐	n2415-il	500,000	5	79.2 at α=5.5°	Mach=0 Ncrit=5	Xfoil prediction	Details
☐	n2415-il	1,000,000	9	103 at α=5.75°	Mach=0 Ncrit=9	Xfoil prediction	Details
☐	n2415-il	1,000,000	5	89.9 at α=6.25°	Mach=0 Ncrit=5	Xfoil prediction	Details

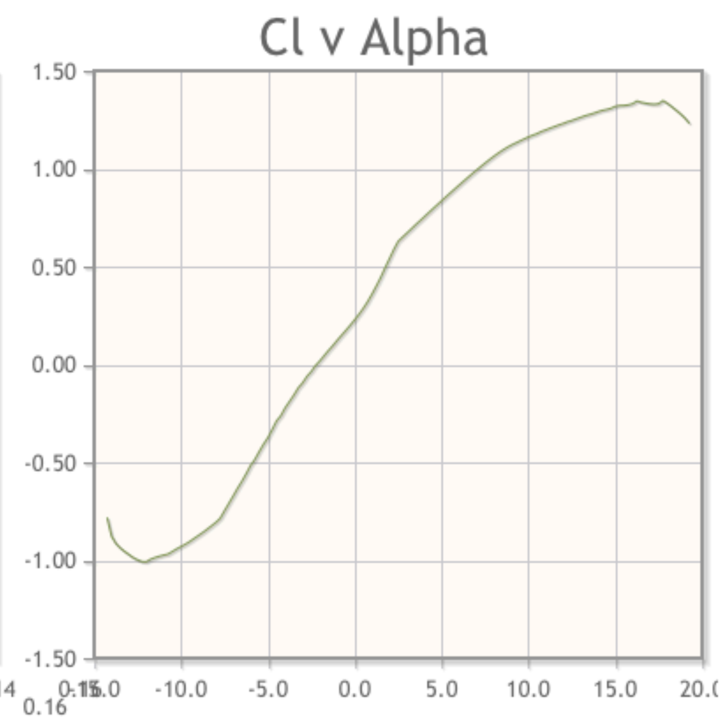
Update plots   Reynolds number calculator

Set Reynolds number and Ncrit range

Update Range

	Low	High
Reynolds Number	200,000	200,000
NCrit	7	7





Applications

- Airfoil database search
- My airfoils
- Airfoil plotter
- Airfoil comparison
- Reynolds number calc
- NACA 4 digit generator
- NACA 5 digit generator

Information

- Airfoil data
- Lift/drag polars
- Generated airfoil shapes

Searches

- Symmetrical airfoils
- NACA 4 digit airfoils
- NACA 5 digit airfoils
- NACA 6 series airfoils

Airfoils A to Z

- A a18 to avistar (88)
- B b29root to bw3 (22)
- C c141a to curtisc72 (40)
- D dae11 to du861372 (28)
- E e1098 to esa40 (209)
- F falcon to fxs21158 (121)
- G geminism to gu255118 (419)
- H hh02 to ht23 (63)
- I isa571 to isa962 (4)
- J j5012 to joukowsk0021 (7)
- K k1 to kenmar (11)
- L l1003 to lwk80150k25 (24)
- M m1 to mue139 (95)
- N n0009sm to nplx (174)
- O oa206 to oaf139 (9)
- P p51droot to pw98mod (16)
- R r1046 to rhodesg36 (63)
- S s1010 to supermarine371ii (174)

Reynolds number calculator

Velocity	20	m/s	44.739 mph	72 kph
Chord width	0.3	m	0.98425 ft	11.811 in
Kinematic Viscosity	1.4207E-5	m^2/s	1.529e-4 ft^2/s	
Reynolds Number	422,327			

Calculate

Reynolds number calculation

The Reynolds number is a dimensionless value that measures the ratio of inertial forces to viscous forces and descibes the degree of laminar or turbulent flow. Systems that operate at the same Reynolds number will have the same flow characteristics even if the fluid, speed and characteristic lengths vary.

The Reynolds number is calculated from:

$$Re = \frac{\rho v l}{\mu} = \frac{v l}{\nu}$$

Where:

v = Velocity of the fluid
l = The characteritics length, the chord width of an airfoil
ρ = The density of the fluid
μ = The dynamic viscosity of the fluid
ν = The kinematic viscosity of the fluid

Kinematic Viscosity

Example kinematic viscosity values for air and water at 1 atm and various temperatures.

Air

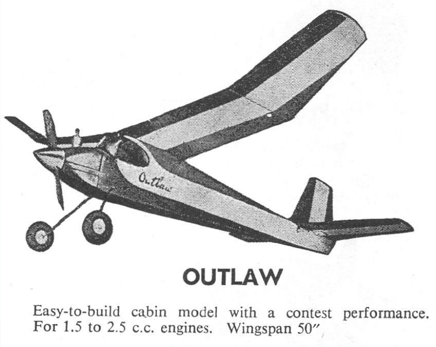
Kinematic Viscosity m^2/s	°C	°F	
1.2462E-5	-10	14	Use
1.3324E-5	0	32	Use
1.4207E-5	10	50	Use
1.5111E-5	20	68	Use

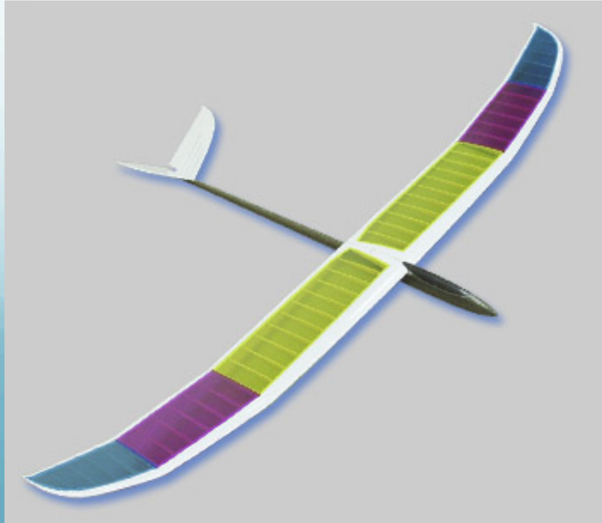
Water

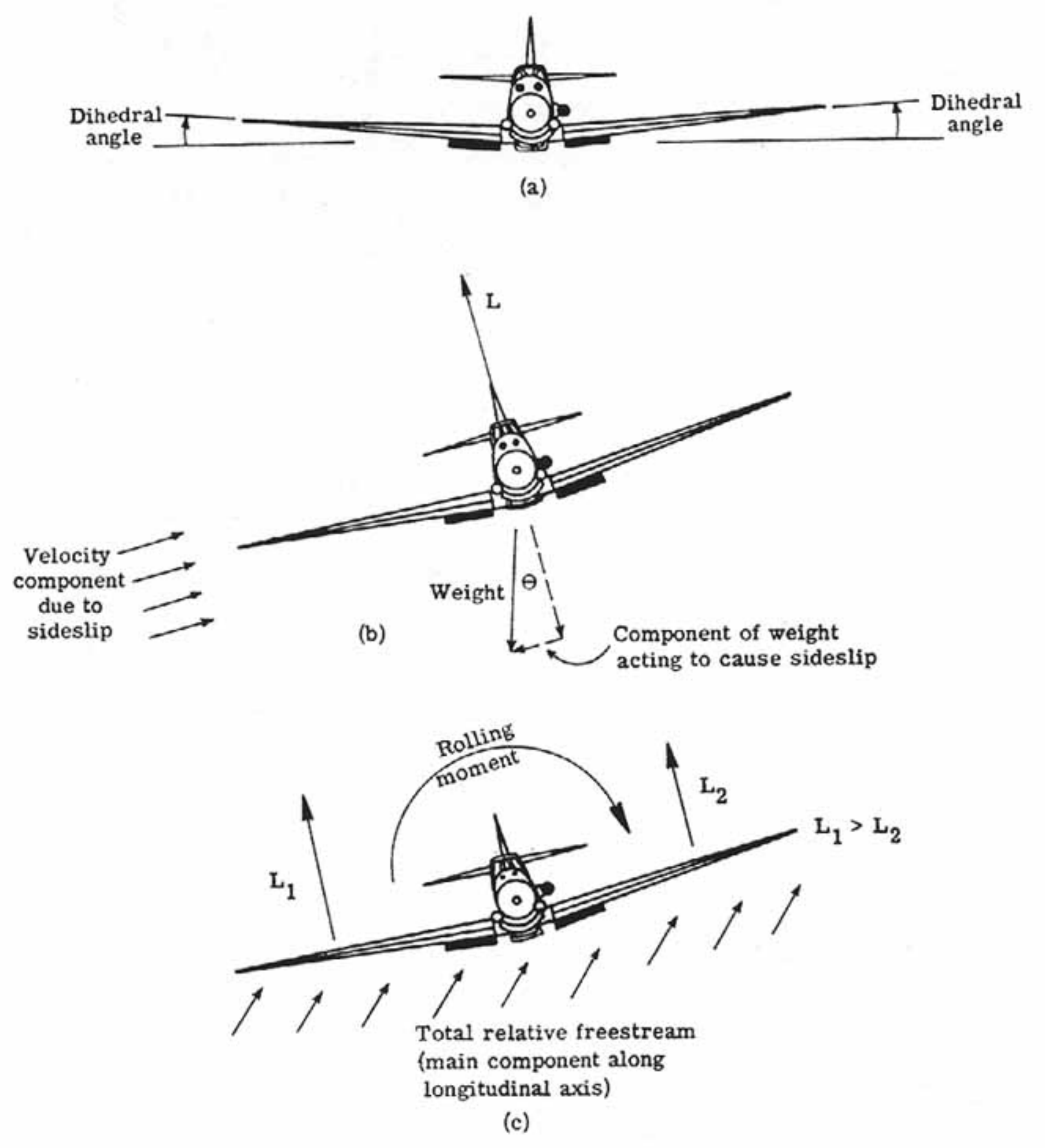
Kinematic Viscosity m^2/s	°C	°F	
1.6438E-6	1	33.8	Use
1.267E-6	10	50	Use
9.7937E-7	20	68	Use

Does Dihedral Help or Hinder?

- Tends to restore airplane to wings level

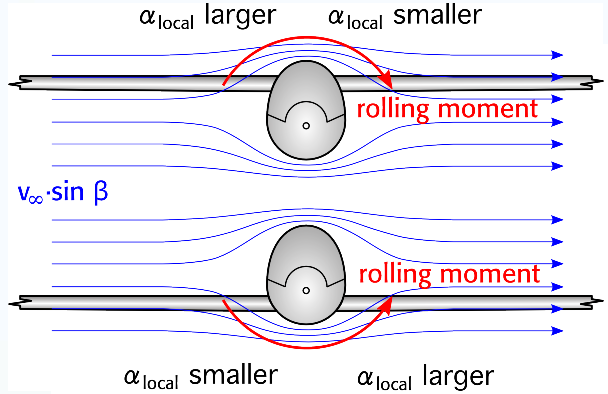


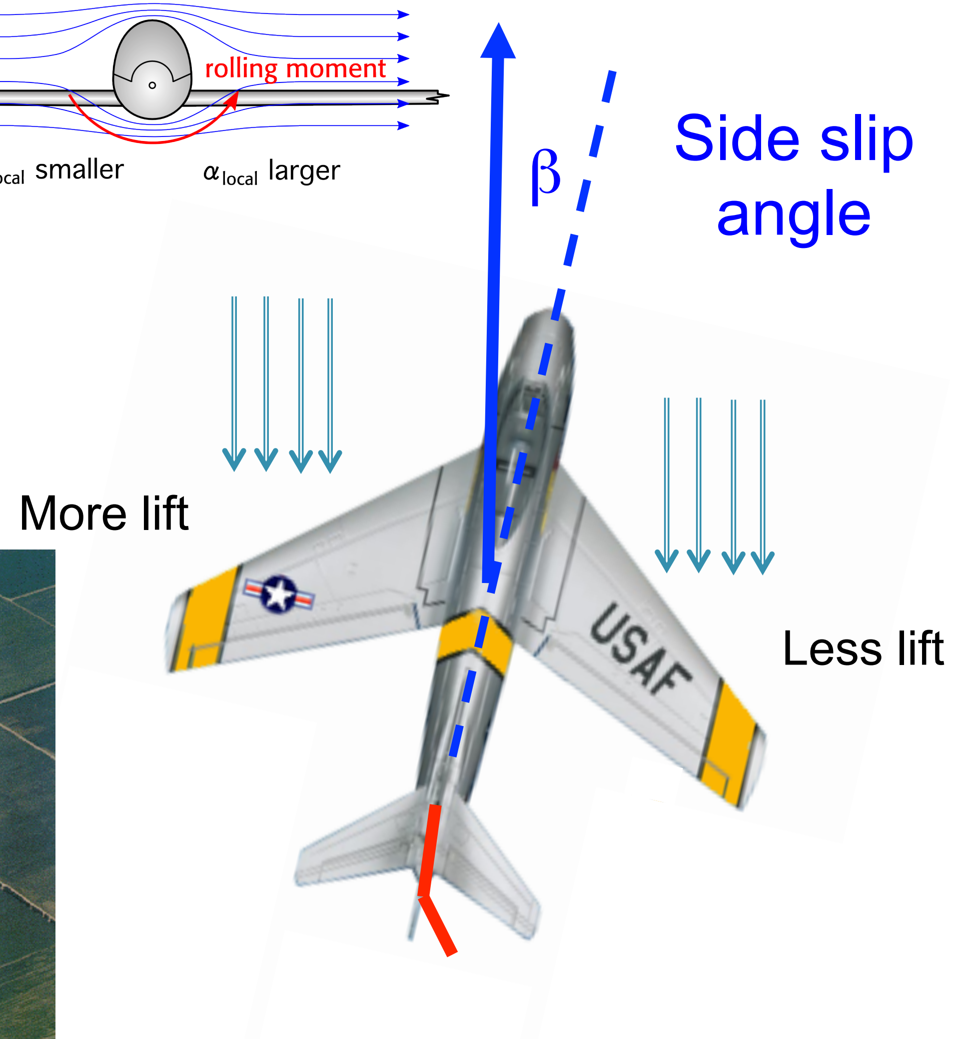




Dihedral Effect - Roll due to Sideslip

- High wing
- Sweep gives dihedral effect (roll stability) upright or inverted!
- Tall T-tail and butterfly tails will also add to dihedral effect





… so the F-104 has ***anhedral*** to compensate

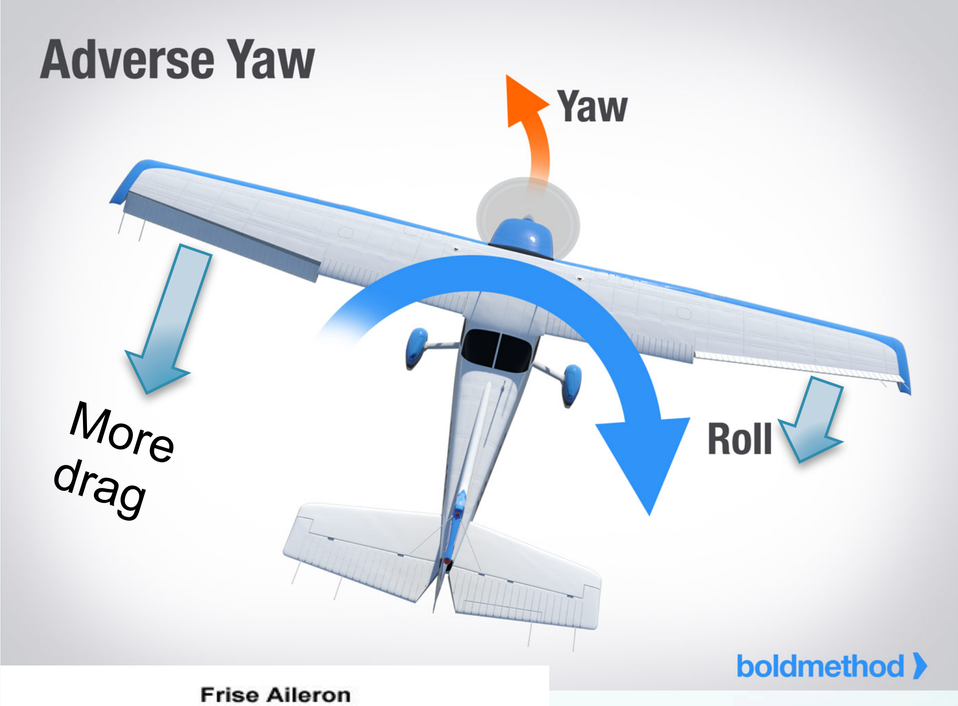
Zero Dihedral Effect

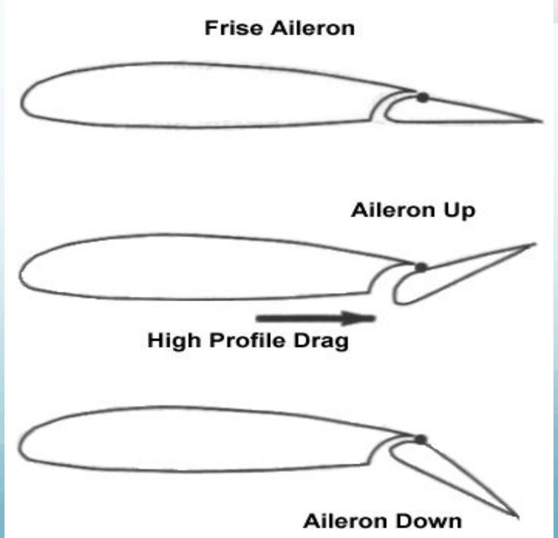
Mid-wing, no sweep

No rolling tendency in knife-edge flight (very high sideslip angle)

My Plane Won't Respond To Aileron

- "Adverse Yaw"
  - long wings
  - vertical fin too small
  - most noticeable when slow
- Fixes:
  - Use your rudder thumb!
  - Aileron > Rudder mix (about 50% for a trainer)
  - Differential Ailerons (more up travel than down)
  - Frise Ailerons





"My plane is hard to control."
Is it Unstable or Too Sensitive?

- Roll and Yaw:
  - Not likely to be "*unstable*" (unless it has anhedral) or fin and rudder too small
- Pitch:
  - If CG dive test is OK, then surfaces too sensitive or horizontal stabilizer is too small
  - If dive test is not OK, move CG forward
- First, reduce throws
  - Second, try expo…. Unless it's a 3D plane, then use for expo for sure
  - Last, try adding horizontal tail area