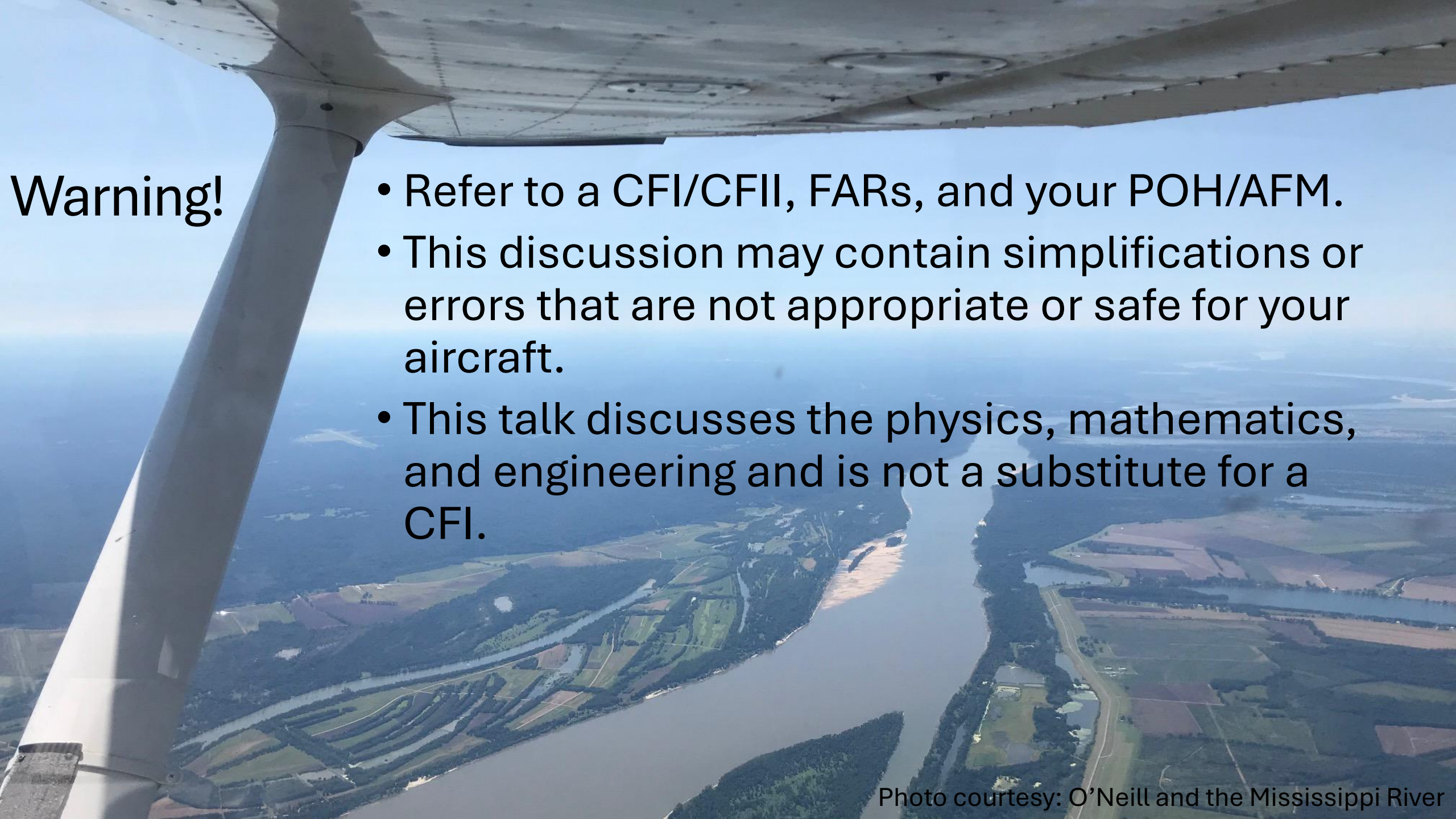
Eights on Pylons: Physics and Limitations

Charles O’Neill (Engineer)
Justus Milligan (CFI/CFII)
12 May 2025
Posted at: https://charles-oneill.com

How this discussion is structured:

1) Start with an interesting question or observation.
2) Dig into the physics, TTPs, and details.
3) Zoom out and give actionable knowledge.

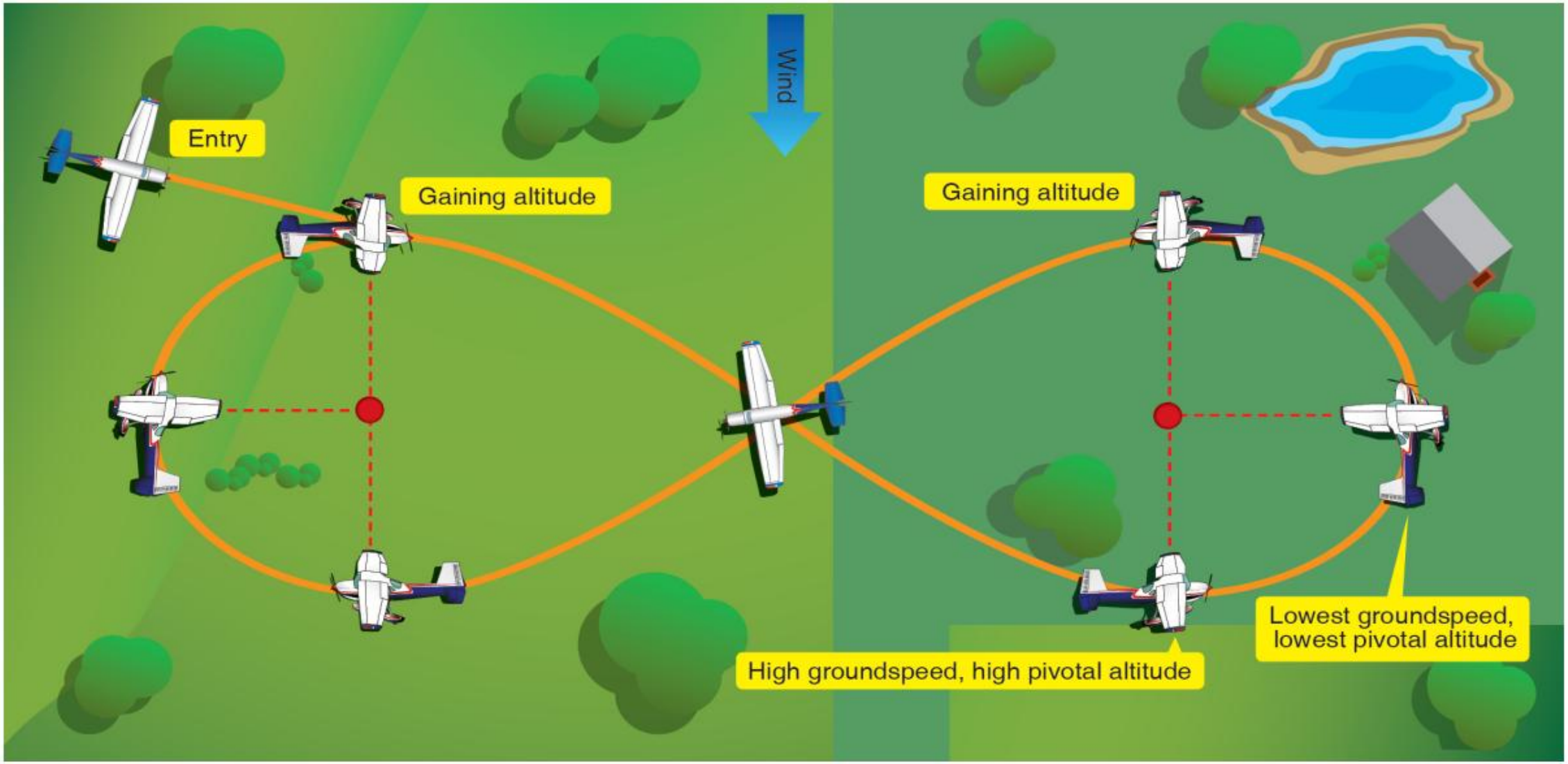


Warning!

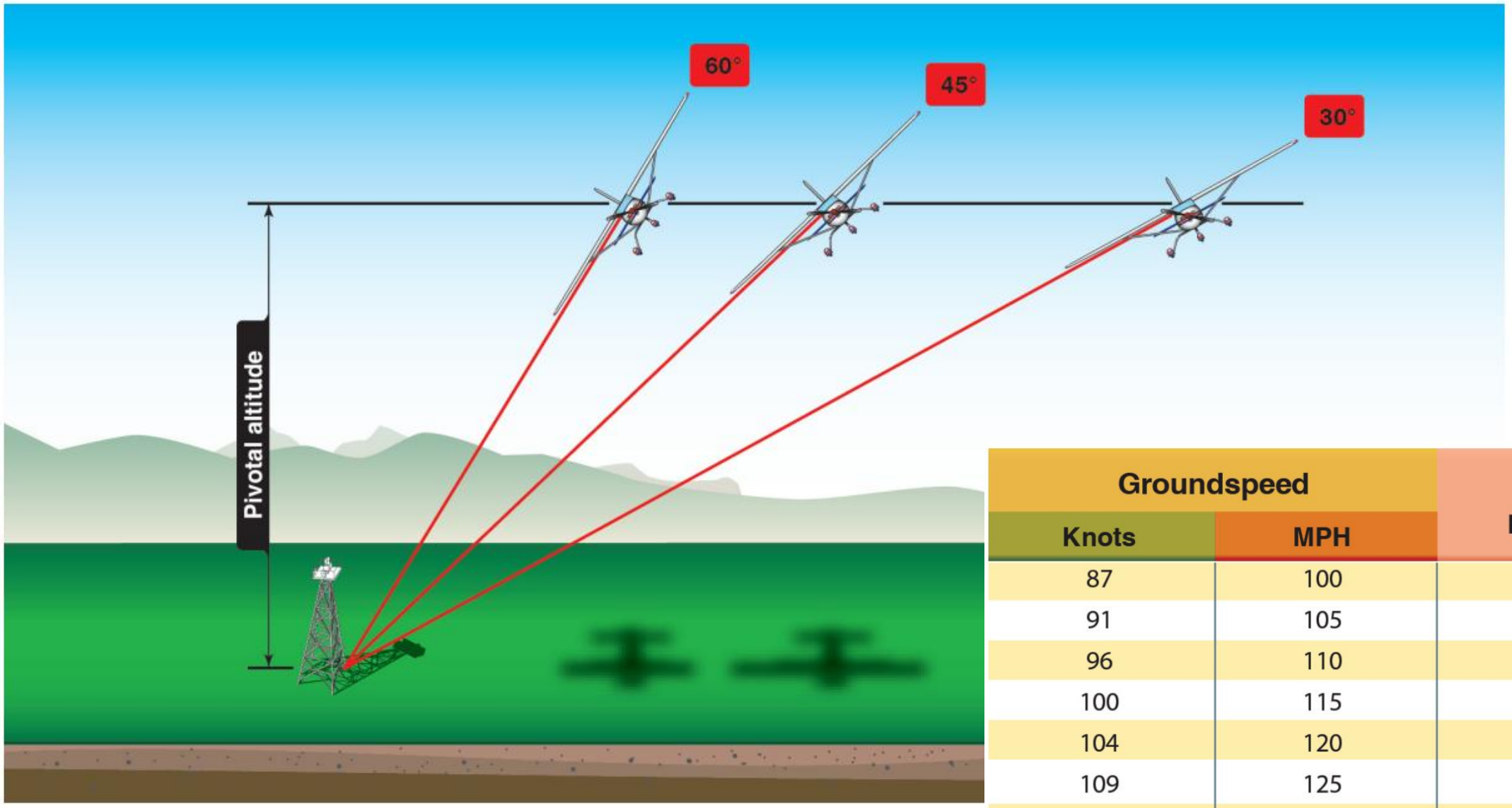
- Refer to a CFI/CFII, FARs, and your POH/AFM.
- This discussion may contain simplifications or errors that are not appropriate or safe for your aircraft.
- This talk discusses the physics, mathematics, and engineering and is not a substitute for a CFI.

Photo courtesy: O'Neill and the Mississippi River

8s on Pylons (Official FAA Figure)

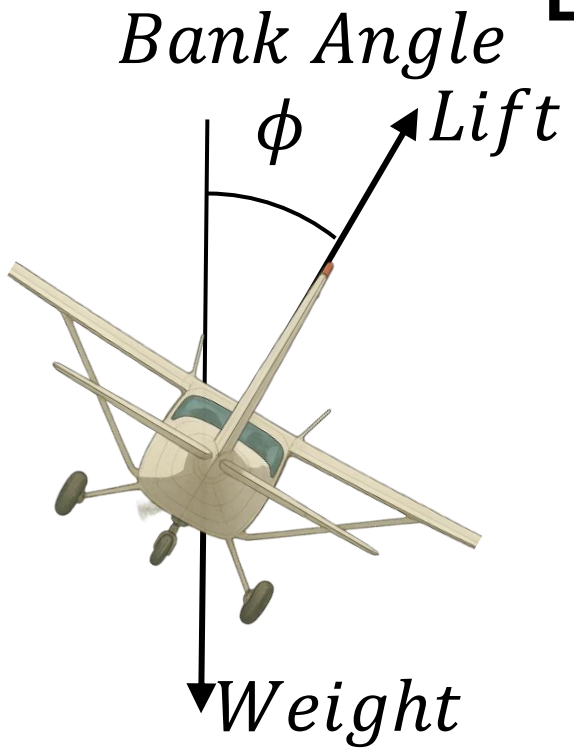


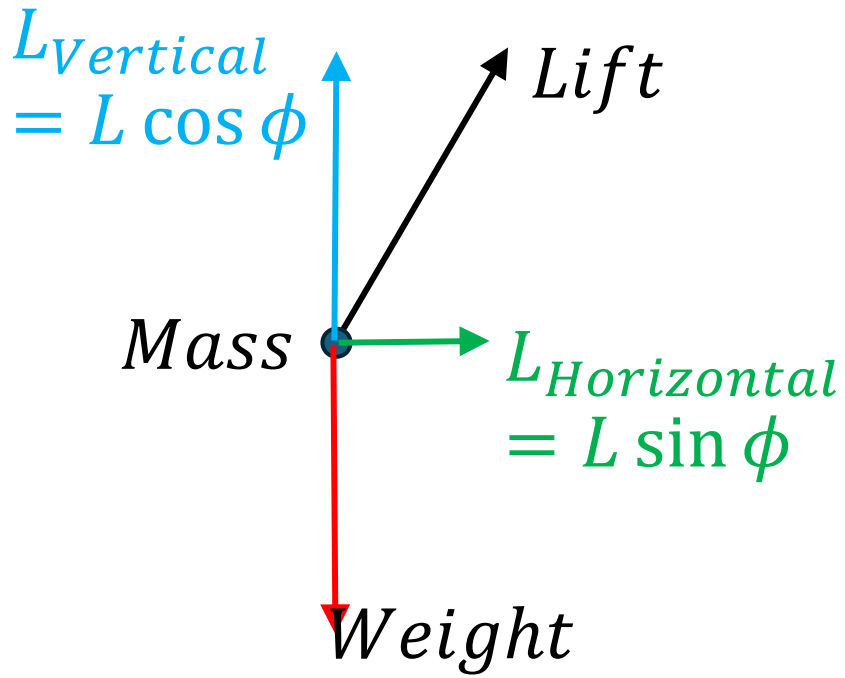
Pivotal Altitude (Official FAA Figure)



Groundspeed		Approximate Pivotal Altitude
Knots	MPH	
87	100	670
91	105	735
96	110	810
100	115	885
104	120	960
109	125	1050
113	130	1130

Level Banked Turn



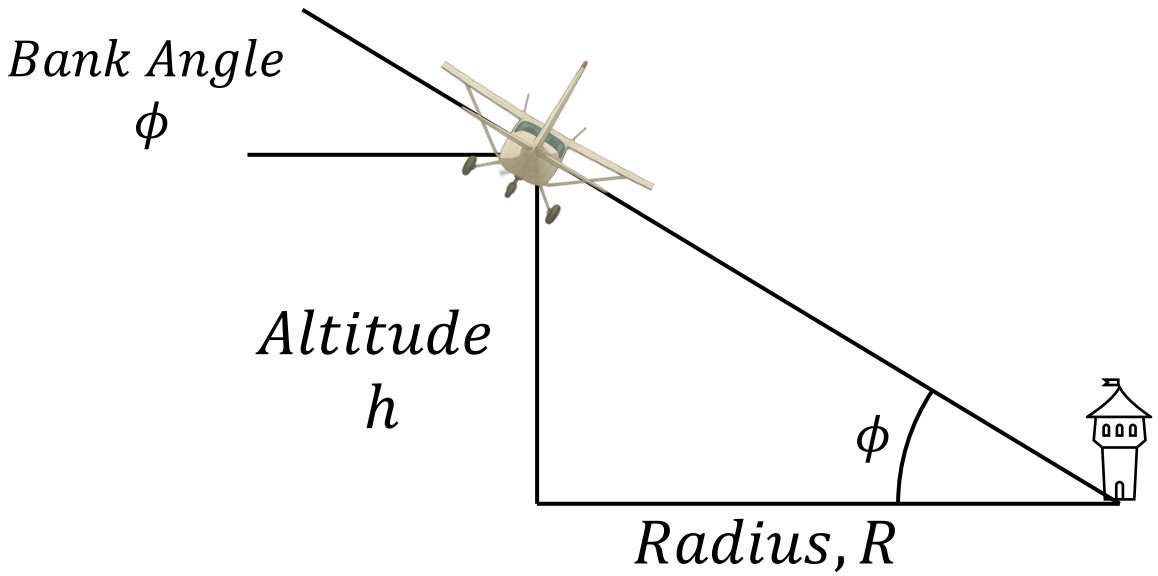


- The Vertical Lift equals the Weight.
- The Horizontal Lift accelerates the aircraft towards a central point.

$$a_{horz} = \frac{V^2}{R}$$

- The g-load depends on the bank angle. $n = \frac{1}{\cos\phi}$

Physics and Geometry of the Maneuver



- From the aircraft performance, the turn radius is:

$$R = \frac{V^2}{\mathrm{g}\tan\phi}$$

- From the geometry, the turn radius is:

$$\tan\phi = \frac{h}{R}$$

- Combine to give an 8s-on-pylons pivotal altitude equation:

$$\mathrm{h} = \mathrm{R}\tan\phi = \frac{V^2}{\mathrm{g}\tan\phi}\tan\phi$$

$$\mathrm{h} = \frac{V^2}{g}$$

Height is only a function of groundspeed! Radius only affects bank angle!

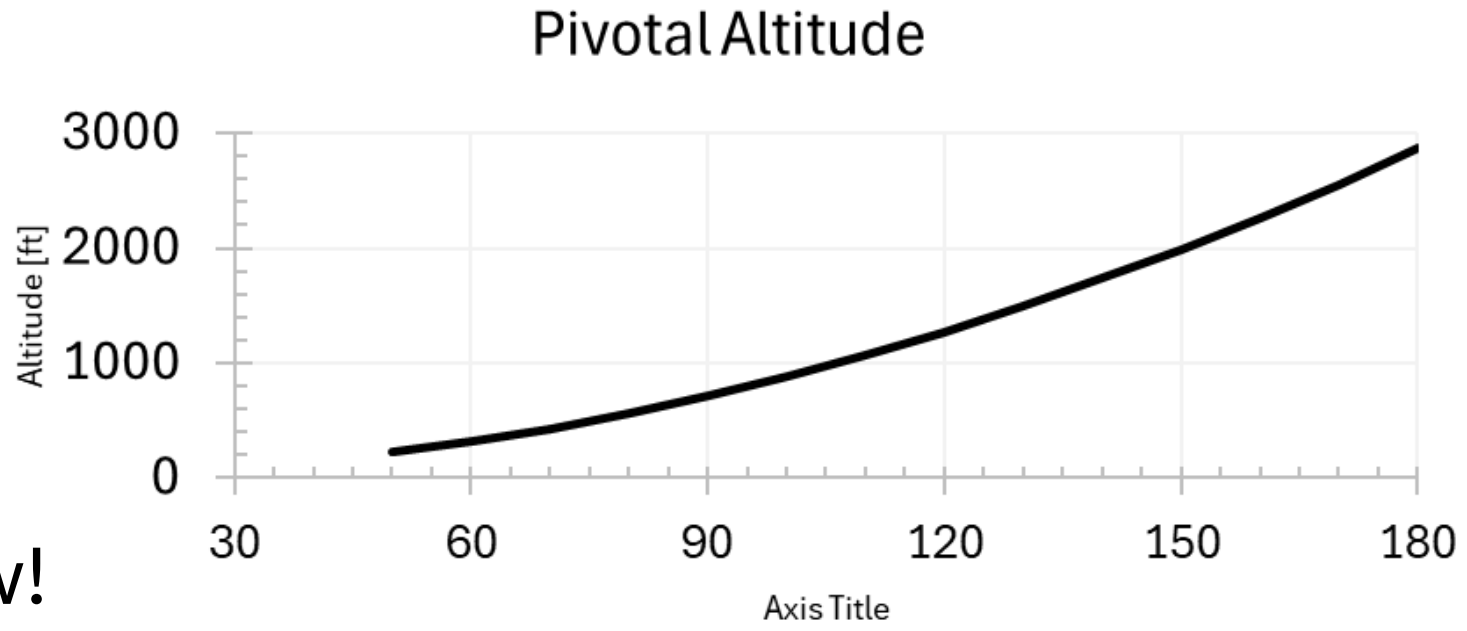
Generate Pivotal Altitudes from Scratch

- Engineering Units Conversion (Algebra Elves)

$$\mathrm{h} = \frac{V^2}{g} = \frac{[kt^2]}{1} \cdot \frac{[s^2]}{[32.2ft]} \cdot \frac{[nm^2]}{[kt^2][hr^2]} \cdot \frac{[hr^2]}{[3600s^2]} \cdot \frac{[6076^2 ft^2]}{[nm^2]}$$

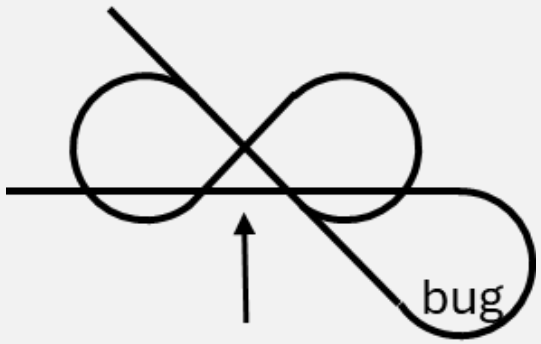
- Solution

$$\mathrm{h} = \frac{V^2}{g} = \frac{V_{kt}^2}{11.3}$$



Matches the FAA! Whew!

What does CO's flight notes show? Why?



Pivotal Altitude

75 – 500'
90 – 720'
100 – 890'
110 – 1070'

CFI Discussion Pause:

- Why this entry?
- Bug?
- Which ground reference points are better?
- FAR 91.119 and 91.13
- 75 kts groundspeed?

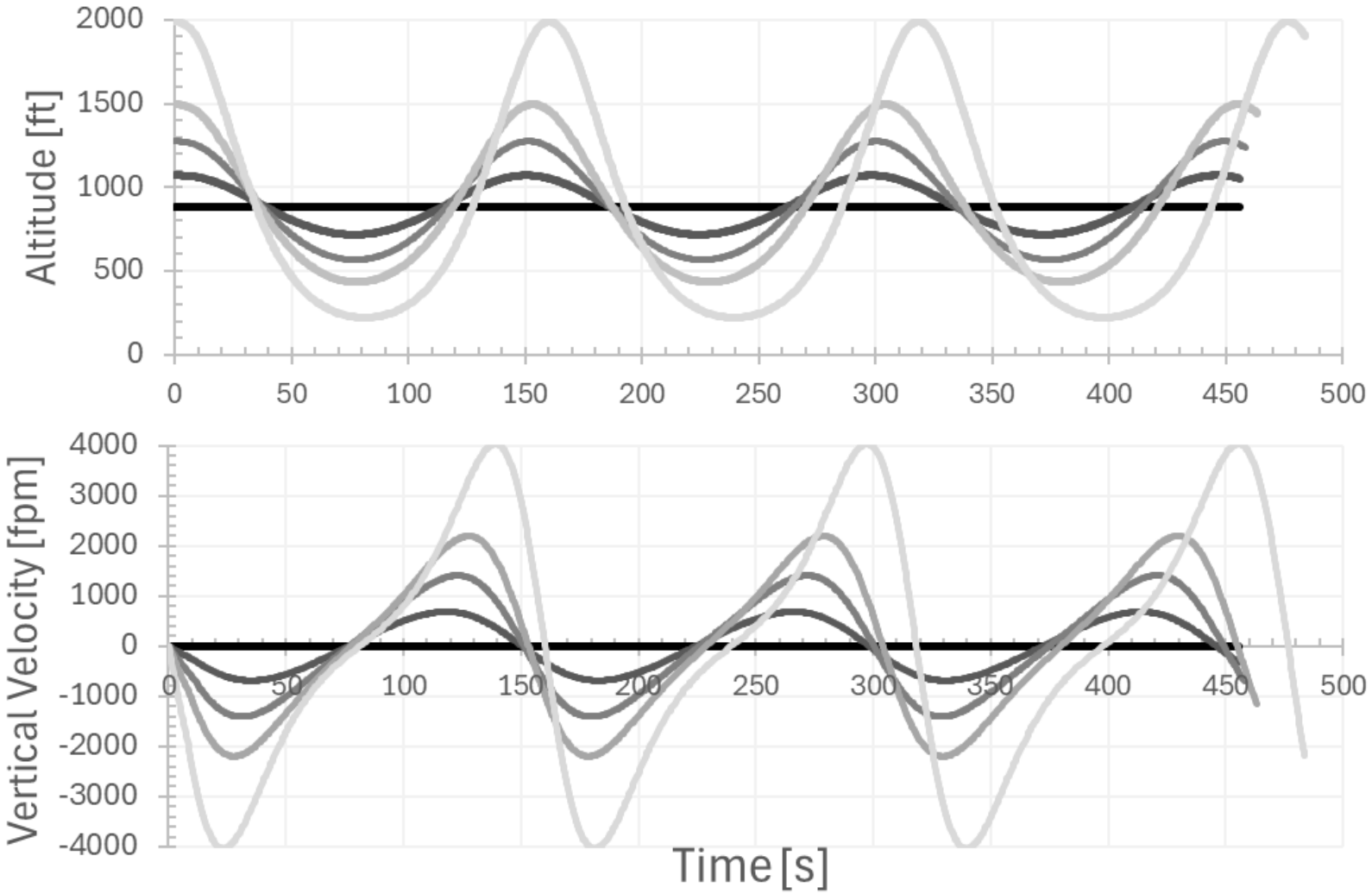
Q: Why can a Tri-Pacer in the Texas Panhandle NOT fly 8s on Pylons?

Observed by Justus, but why? We speculated:

- Lower power aircraft (150 hp @ SSL)
- Short wing Piper
- Wind (20+ kts)
- High density altitude
- Sight lines

How can this be fixed?

What does the vertical flight profile look like?

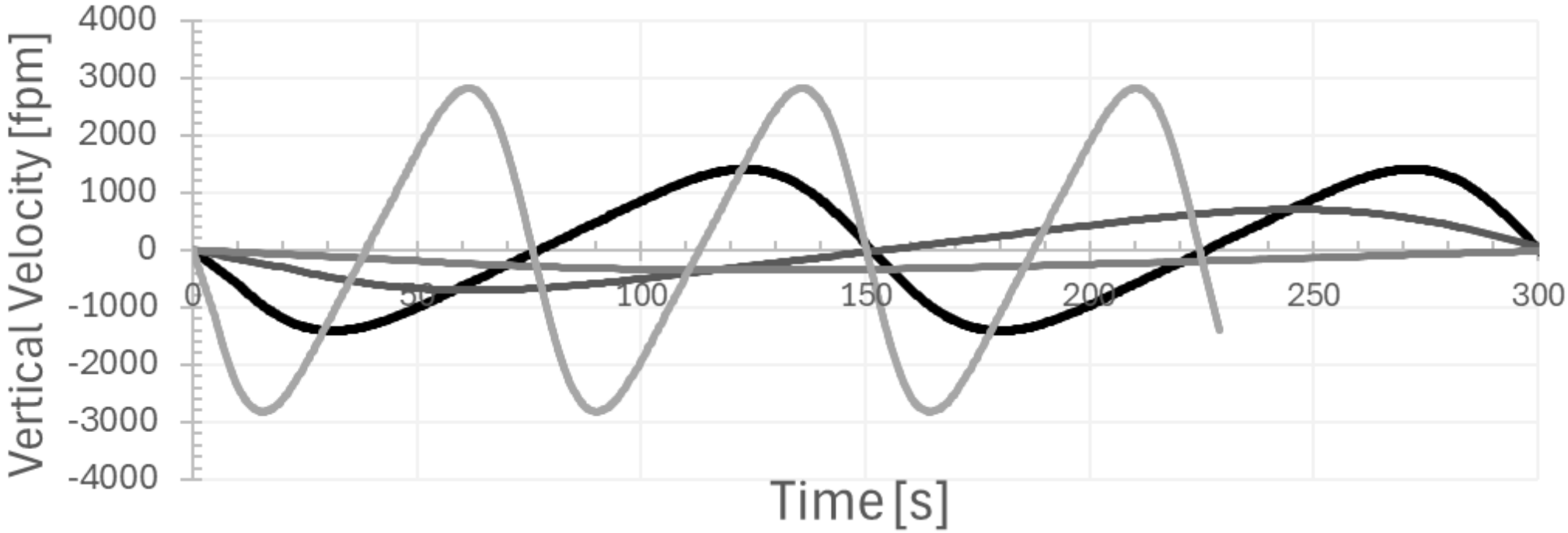


Comments:

- 100 KTAS
- Radius: ½ mile
- Wind: 0, 10, 20, 30, 50 kts.
- As wind increases, the vertical profile becomes asymmetrical.
- Performance and FARs limit feasible upper wind velocity.

1st Solution to Climb Rate Limits: Increase R

- If your aircraft isn't meeting the climb rate needed for 8s-on-pylons, increase the radius.
- For example, at 100 KTAS and 20 kts wind, a 0.25 radius needs 3000 fpm rate. But at 1 mile, the rate is only 750 fpm.



Radius Limit Equation

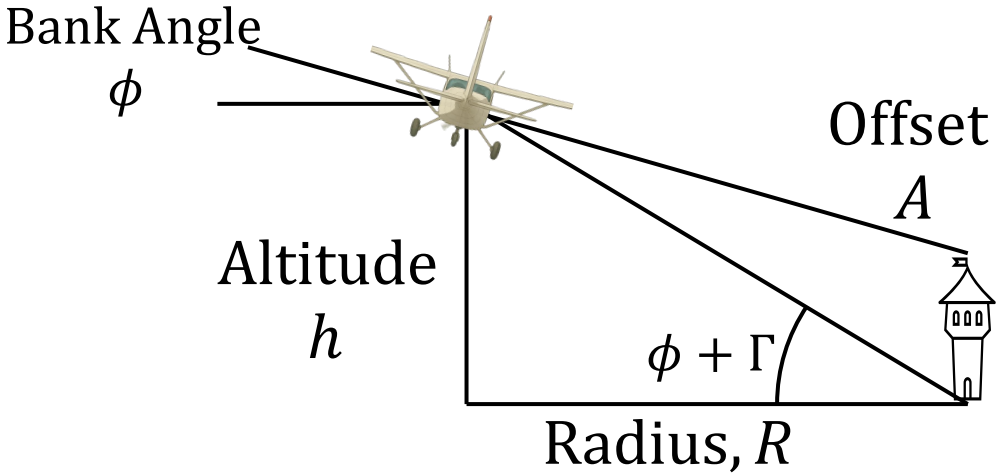
- Using some engineering analysis, a reasonable radius (R) given a zero-wind Pivotal Altitude (h), Wind (W_{kts}), and a maximum aircraft climb rate of VV_{fpm} is:

$$R_{sm} \geq \frac{h_{pivotal}}{VV_{fpm_{max}}} \frac{W_{kts}}{25}$$

- This strategy was tested by Justus and it works.

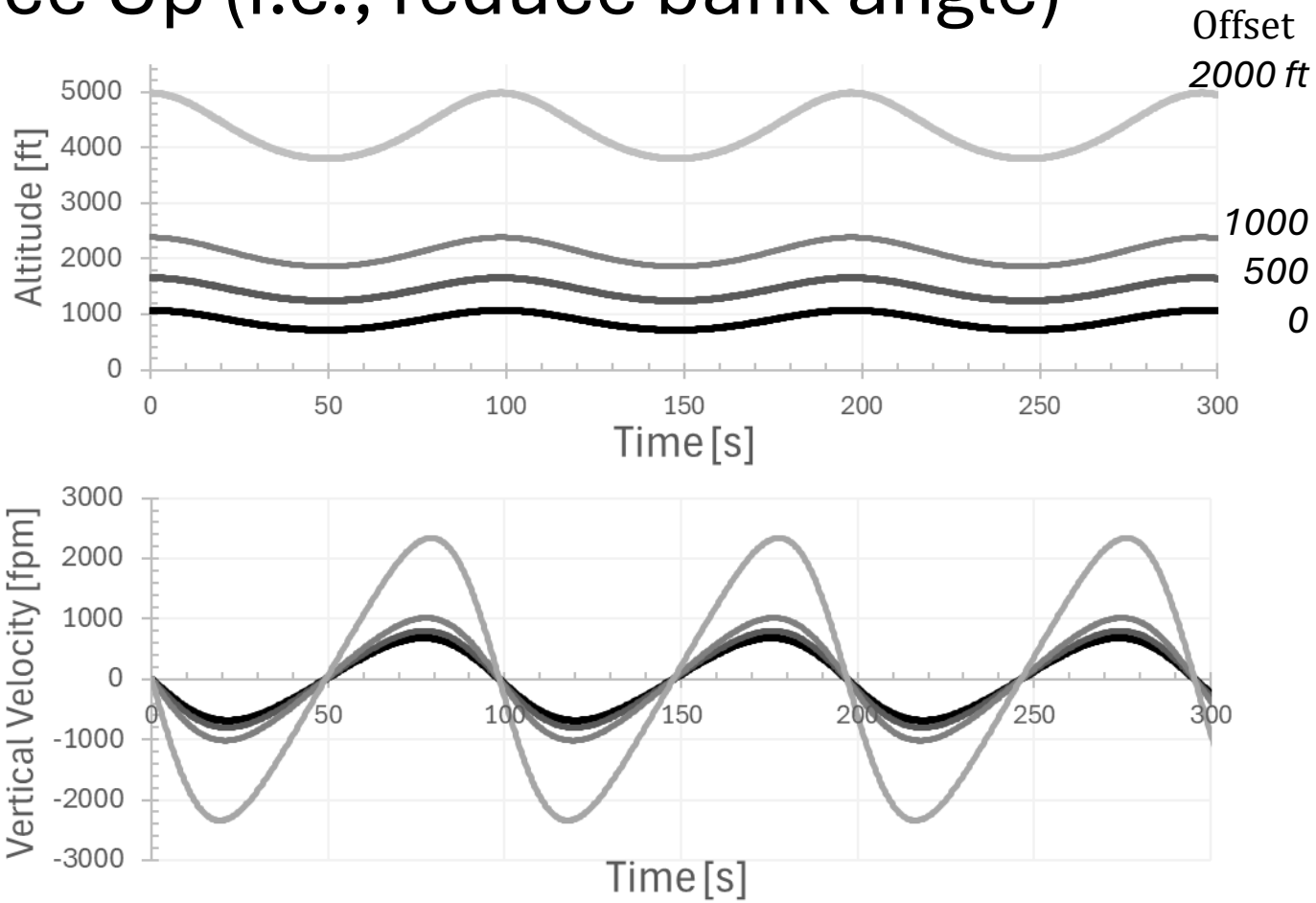
Strategy to Increase Altitude

- Offset the Ground Reference Up (i.e., reduce bank angle)



$$A = R \tan \Gamma$$

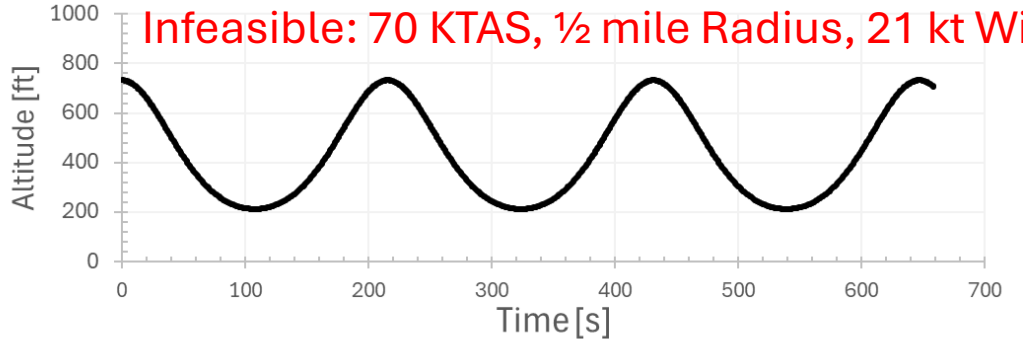
$$h = \frac{\frac{V_{gs}^2}{g} + A}{1 - \frac{V_{gs}^2}{R^2 g} A}$$



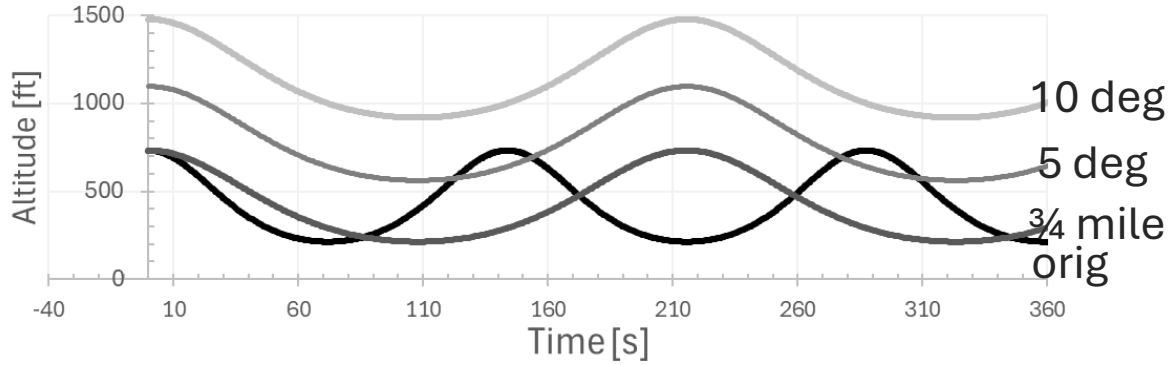
- Adding a vertical offset improves the low AGL limit at the expense of climb rate!

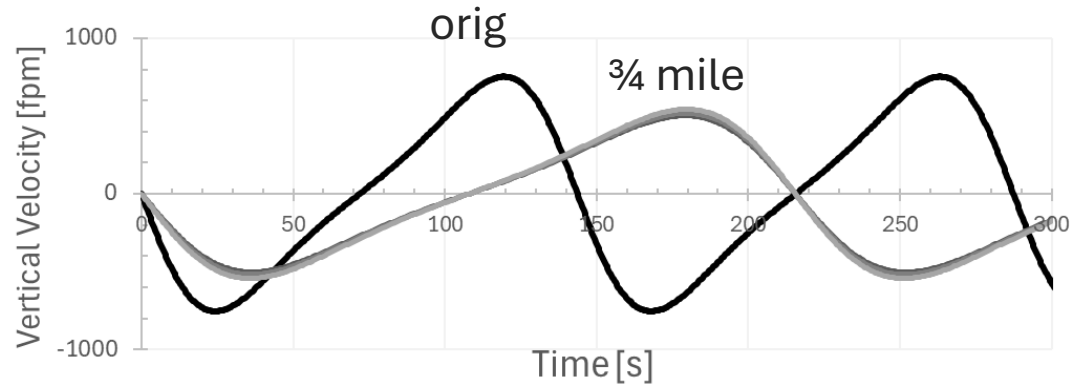
Does this help the TriPacer?

- 70 knot Airplane at +500 fpm
- Radius is 0.5 mile
- Wind is 21 knots.



1. Increase Radius to ¾ mile
   - Climb rate below 500 fpm
2. Add 350 to Ground Target
   - Lowest AGL > 500 ft
   - 5 degrees less bank
3. What if: Add another 5 degrees?
   - Lowest AGL ~ 1000 ft
   - Climb rate about 500 fpm





8s-on-pylons Takeaways:

Posted at: https://charles-oneill.com
Email at: oneill@aerofluids.com

1. Pivotal Altitude depends solely on groundspeed.

$$h_{ft} = \frac{V_{kt}^2}{11.3}$$

2. AGL should be above 500 ft to satisfy 91.119. This is a groundspeed of 75 knots.

3. Increase Radius to reduce the Maximum Climb Rate.

$$R_{sm} \geq \frac{h_{pivotal}}{VV_{fpm_{max}}} \frac{W_{kts}}{25}$$

4. Increase Ground Reference Altitude to improve AGL limit.