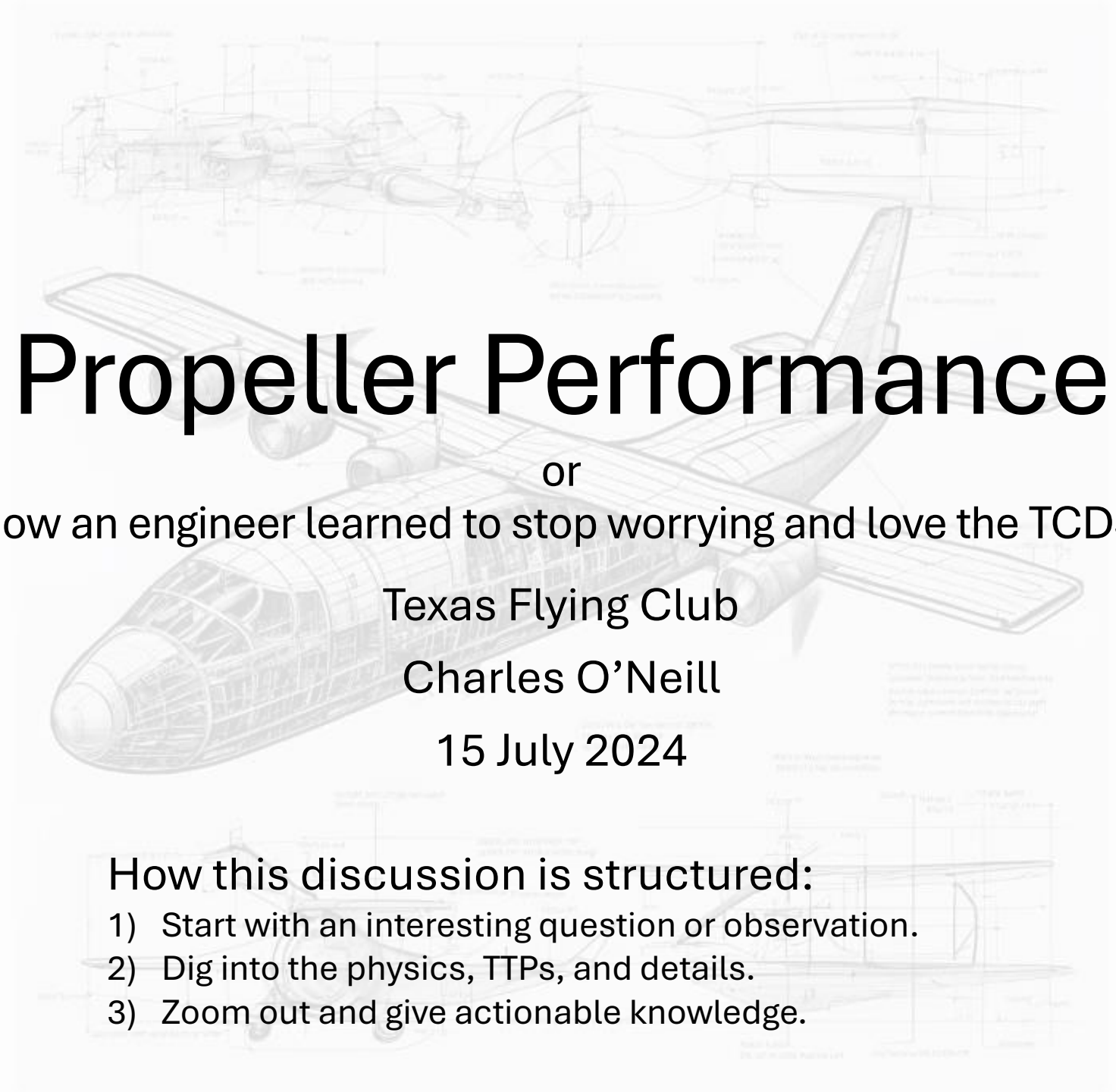


Propeller Performance

or

How an engineer learned to stop worrying and love the TCDS.

Texas Flying Club

Charles O’Neill

15 July 2024

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!

- I am not a CFI. Refer to a CFI and your POH/AFM.
- This discussion may contain simplifications or errors that are not appropriate or safe for your aircraft.
- Please do not fly at high elevations without an appropriate aircraft, high altitude instruction, and pleasant weather.
- Don’t be this guy.

Q: What prop RPM should you see during a runup?

POH/AFM

POWER PLANT LIMITATIONS

Engine Manufacturer: Avco Lycoming.
Engine Model Number: O-320-H2AD.
Engine Operating Limits for Takeoff and Continuous Operations:
Maximum Power: 160 BHP.
Maximum Engine Speed: 2700 RPM.

NOTE

The static RPM range at full throttle (carburetor heat off and full rich mixture) is 2280 to 2400 RPM.

Type Certificate Data Sheet

Search: "TCDS FAA" → Cessna 172 is Textron Aviation's "3A12"

https://drs.faa.gov/browse/TCDSMODEL/doctypeDetails

*Engine Limits	For all operations, 2700 rpm (160 hp)
Propeller and Propeller Limits	1. Propeller (a) McCauley 1C160/DTM 7557 Static rpm at maximum permissible throttle setting: Not over 2400, not under 2280 No additional tolerance permitted Diameter: not over 75 in., not under 74 in. (b) Spinner: Dwg. 0550320

So, the Type Certificate says 2280 to 2400 rpm.

Q: How much variation in power is this?

Q: How can pilots use this information?

Q: How does rpm and density altitude connect to propulsive performance?

Propeller Performance Theory

How much thrust does the propeller produce?

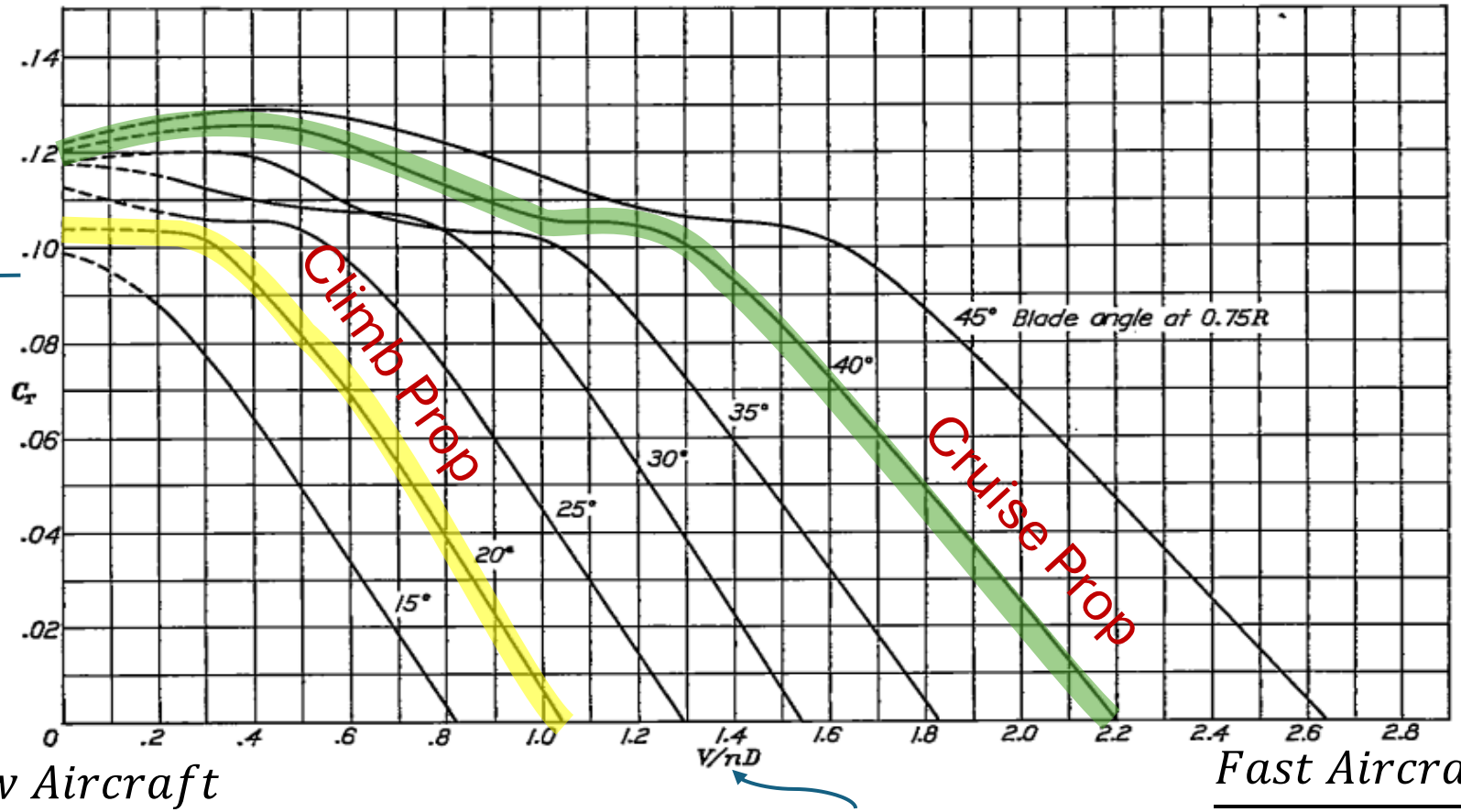
$$T = C_T \rho n^2 D^4$$

force

density

rev/sec

diameter



$\frac{Slow\ Aircraft}{Fast\ Prop}$

$\frac{Fast\ Aircraft}{Slow\ Prop}$

Advance Ratio

$$J = \frac{V}{nD} \approx \frac{Aircraft\ Travel}{Prop\ Travel}$$

All things equal:

10% higher rpm = 21% higher thrust;

10% larger prop = 50% more thrust.

Propeller Performance Theory

How much power does the propeller require?

$$P = C_P \rho n^3 D^5$$

All things equal:
Higher J → Unload Prop
10% higher rpm = 33% higher power
10% larger prop = 55% more power.

Aero Enthusiasts:
Q: Why third power for n? V^3
Q: Why fifth power for D?
Area, Velocity, Moment Arm

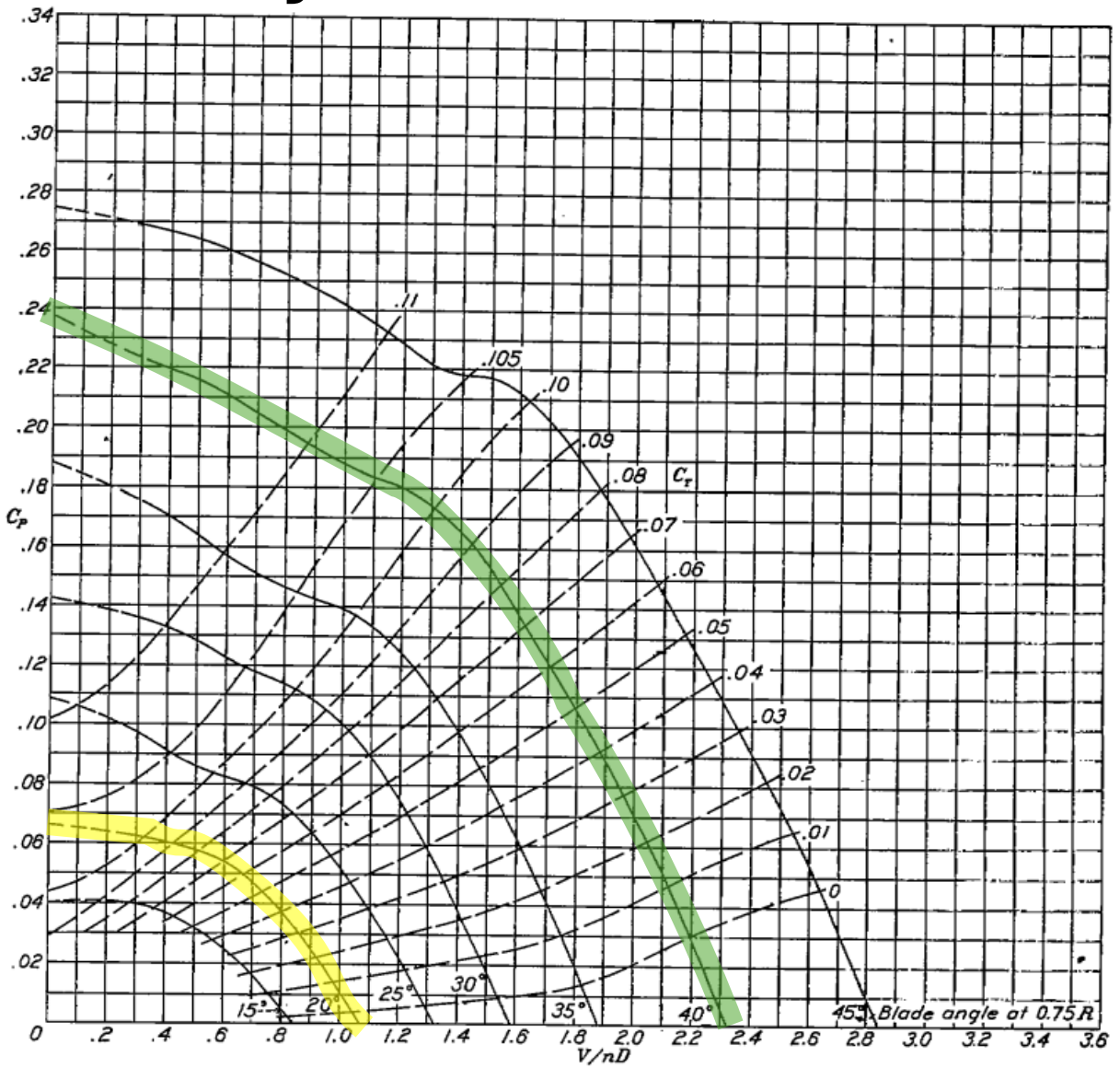


FIGURE 6.—Power-coefficient curves for propeller 5868-9, Clark Y section, 2 blades.

Efficiency

$$\eta = \frac{C_T \cdot V}{C_P} = \frac{Output\ Power}{Input\ Power}$$

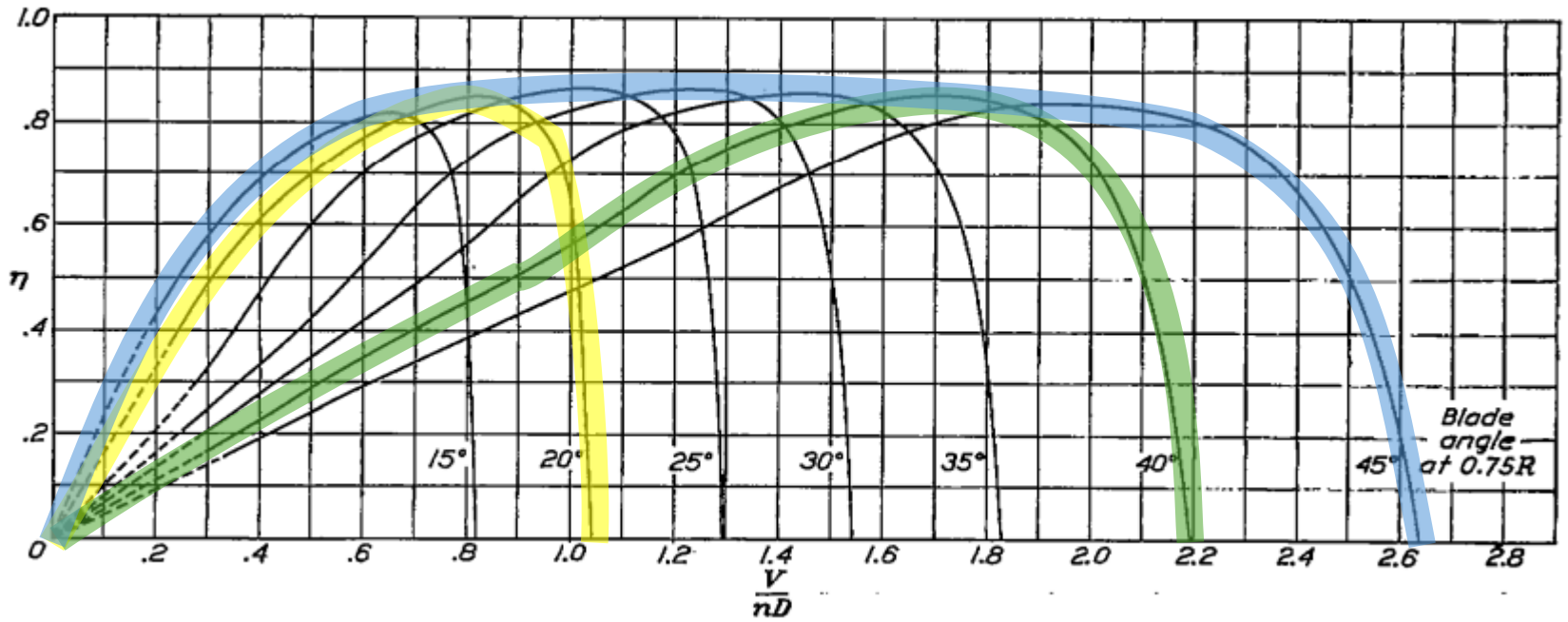


FIGURE 5.—Efficiency curves for propeller 5868-9, Clark Y section, 2 blades.

Climb Prop

Cruise Prop

Variable Pitch Prop

Great, but how can this help the pilot?

Q: Does static runup RPM vary with density altitude? Higher or lower?

How does prop RPM vary with density altitude?

Piston Engine Performance Model

$$HP = \frac{\rho}{\rho_{ssl}} HP_{SSL}$$

Combine Power and Engine Models.

$$HP = \frac{\rho}{\rho_{ssl}} HP_{SSL} = C_P \rho n^3 D^5$$

Solve for RPM (i.e. “n”)

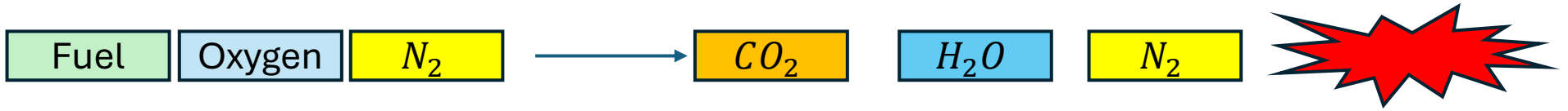
$$n = \sqrt[3]{\frac{HP_{SSL}}{C_P} \cdot \frac{1}{D^5} \cdot \frac{1}{\rho_{SSL}}}$$

No dependence on local density!
Static RPM will be the same!
Why doesn’t this match our observations?

Combustion

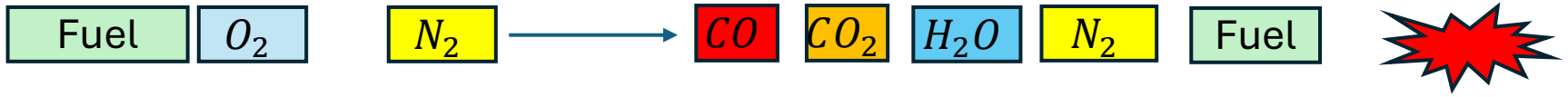
Stochiometric Combustion

$$C_8H_{18} + m(O_2 + N_2) \rightarrow n_1CO_2 + n_2H_2O + mN_2$$



Reality Combustion at a high-density altitude (i.e. lower oxygen density)

$$C_8H_{18} + m(O_2 + N_2) \rightarrow n_1CO_2 + n_2H_2O + mN_2 + n_3CO$$



Less heat, heat left over fuel, CO, lower HP

1. Reduced Static Runup RPM has more to do with combustion efficiency than propellers.
2. Lean at high DA.
3. Rich mixtures contain more Carbon Monoxide

If there is interest in these discussions, we could go through multiple engineering topics.

- Aerodynamics
- Water condensation ($$$) and DA
- Flight dynamics:
  - What is Dutch Roll really?
  - Vmca and Vmcg
- “Can I break the airplane at Va?”
- Aerostructures
- RF, Antennas, and NAV/COMM
- Performance
  - “What MP/RPM setting is ideal for the Pathfinder?”
- Flight Test Engineering
- Your (and my) questions here.