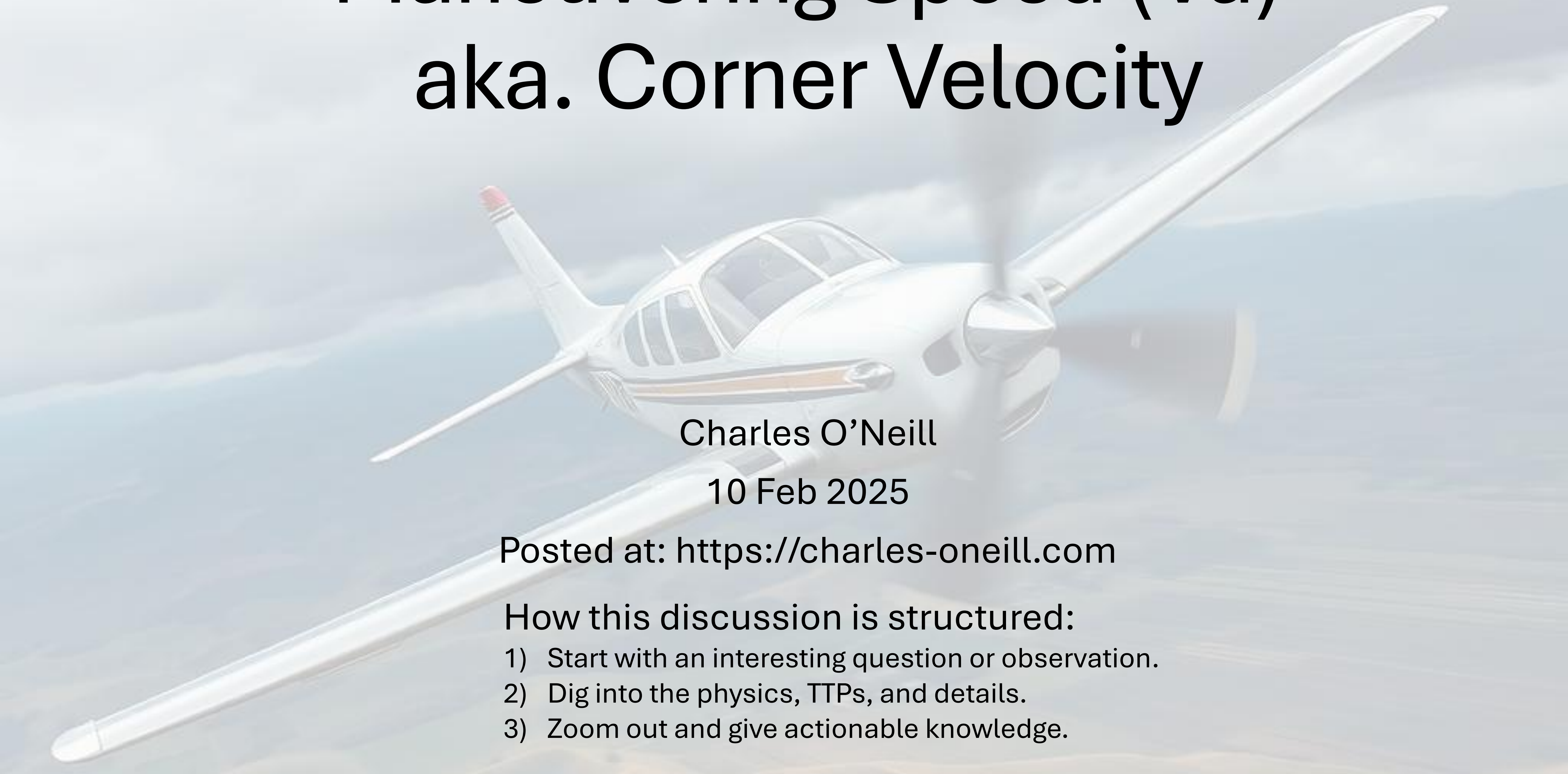


Maneuvering Speed (Va)
aka. Corner Velocity

Charles O’Neill

10 Feb 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! I’m an Aerospace Engineer.

- I am not a CFI/CFII or DER yet. 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.

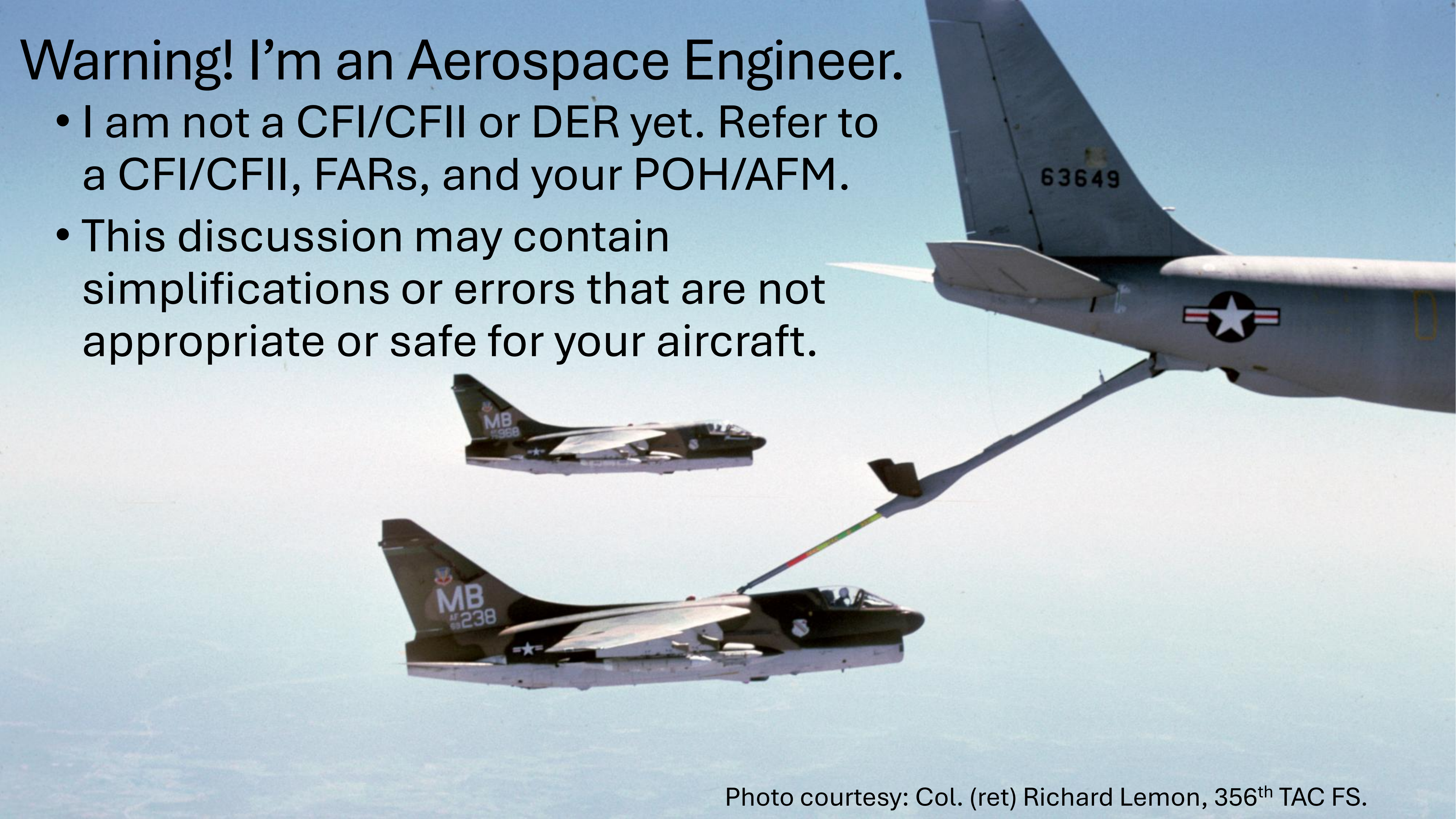


Photo courtesy: Col. (ret) Richard Lemon, 356th TAC FS.

Can you break an airplane at Va?

Va = Maneuvering Airspeed / Corner Velocity

How?

- CFIT (terrain & towers)
- Loss of Control
- Thunderstorms
- Midairs, Wakes & Birds
- Ikarus
- Landing? See right →

This is really NOT the relevant question. Rephrase.

Question 1: "*Given a calm atmosphere, no obstructions, and no traffic or wake, can control inputs structurally break an airplane at Va?*"

Fact #1: By 14 CFR 23 (or prior CAR 3) definition, Va ensures the wing stalls before the structure reaches the load limit.

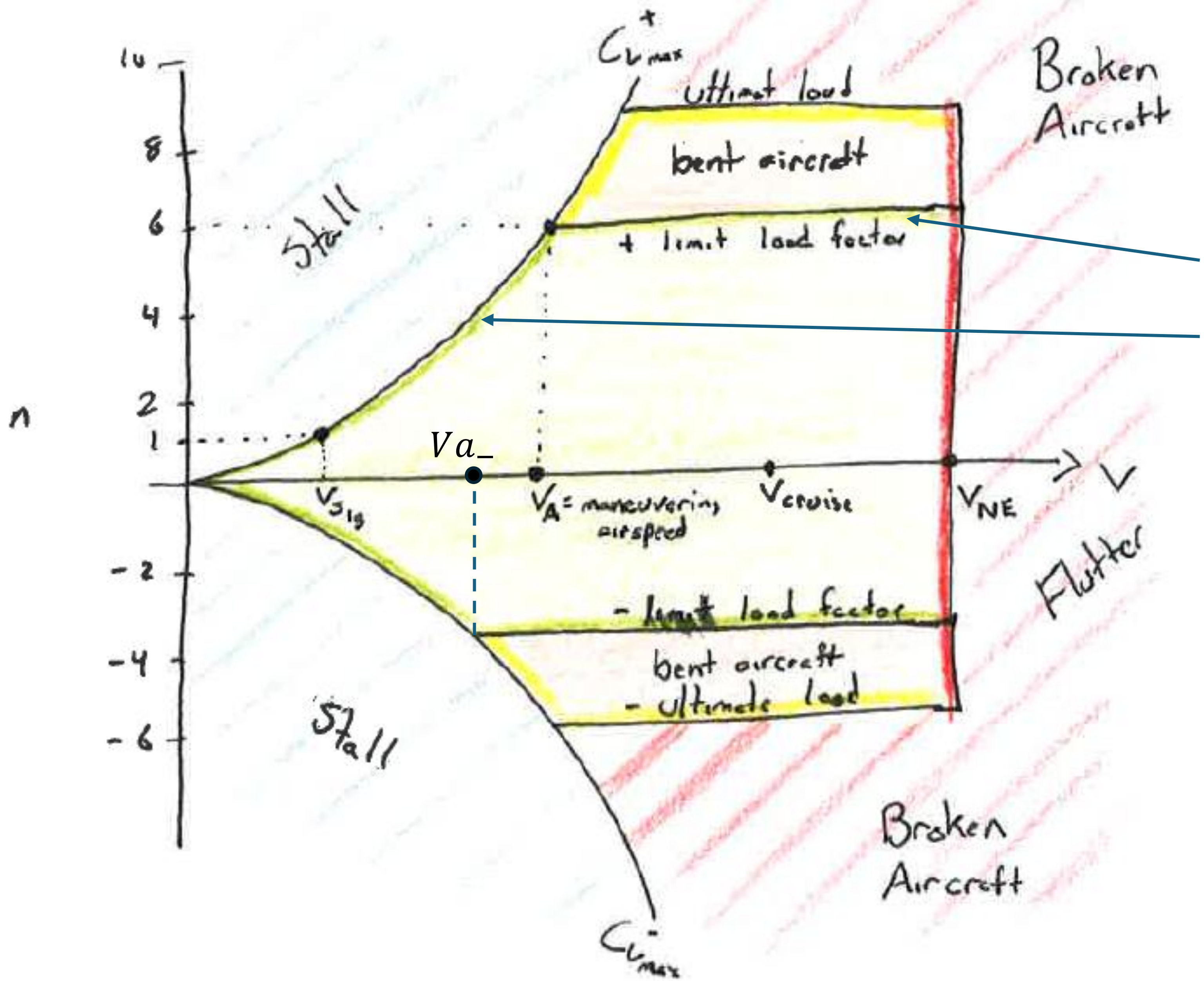
Fact #2: The maneuvering velocity, Va, depends on aircraft weight. Va changes precisely as the square root of the weight to gross weight ratio.

Question 2: *Given a calm atmosphere, no obstructions, and no traffic or wake, can control inputs structurally break an airplane at* ***a weight corrected*** *Va?*

Fact #3: The positive and negative load limits are NOT identical. Usually, negative limits are lower.

Why does this matter?

Flight Envelope Defined by a V-n Diagram

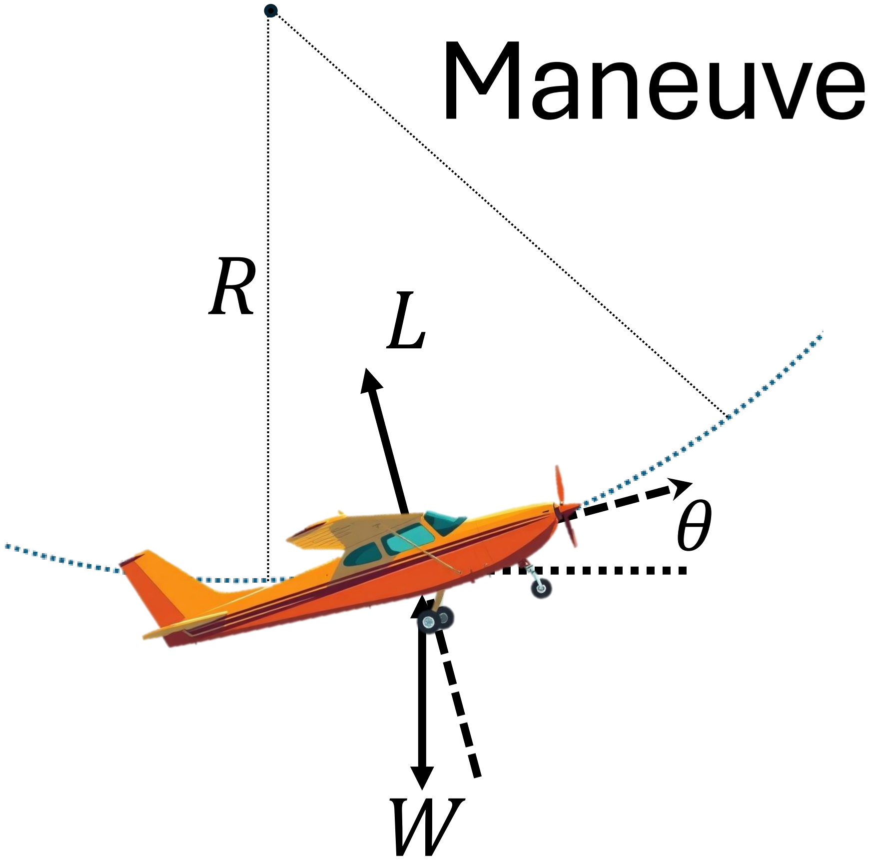


Va is the point where the load limit (horizontal line) meets the AOA stall curve.

Uh oh. The negative limit is less than the positive limit.

Va for negative loads is at a LOWER airspeed!

Maneuvers, Loading and Weight

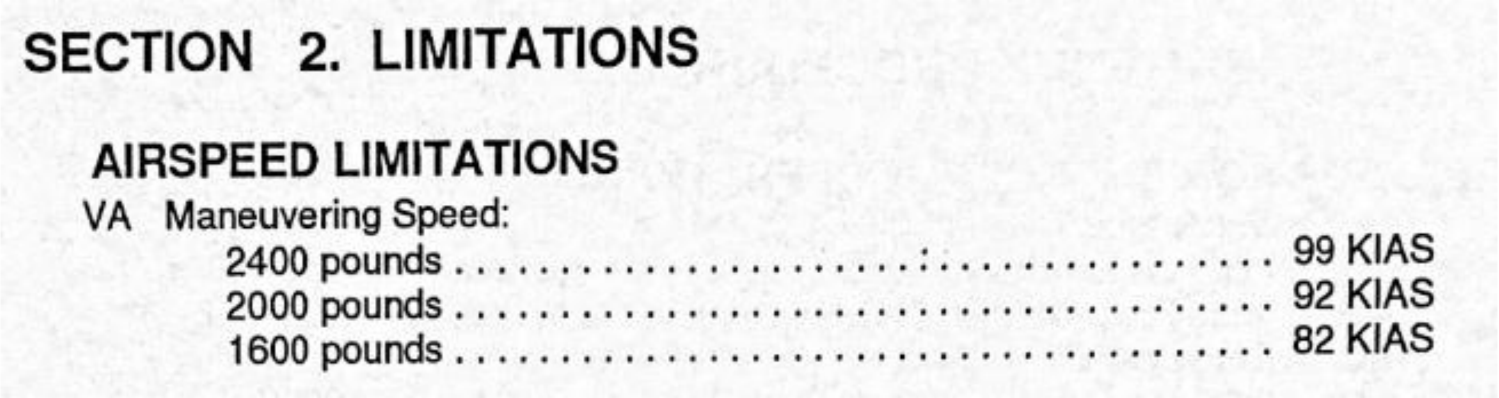


$$\underbrace{\frac{V^2}{R}}_{\text{Flight Path}} = \underbrace{\frac{L}{W}g}_{\text{G load}} - \underbrace{g\cos\theta}_{\text{Gravity}}$$

$$L_{max} = \frac{1}{2}\rho V^2 \cdot S \cdot C_{L_{max}}$$

$$n = \frac{L}{W}$$

Cessna 172 N60HF with 2400# STC



SECTION 2. LIMITATIONS

AIRSPEED LIMITATIONS

VA Maneuvering Speed:

2400 pounds	99 KIAS
2000 pounds	92 KIAS
1600 pounds	82 KIAS

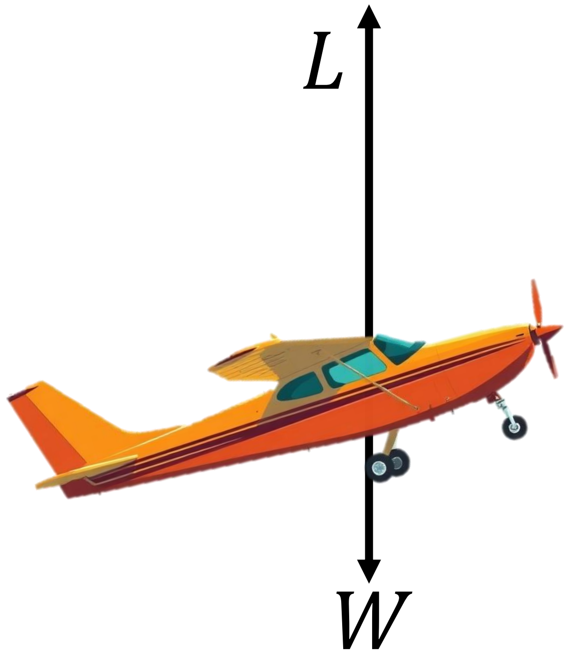
Loads at Va = 99 KIAS

Q: What is the lift that our Cessna 172N wing (174 sq-ft)
with the 2400# STC can safely generate?

Answer: Load limit of 3.8g at 2400# = 9120 pounds

Back calculate the maximum lift coefficient

$$L_{max} = \frac{1}{2}\rho V^2 \cdot S \cdot C_{L_{max}}$$



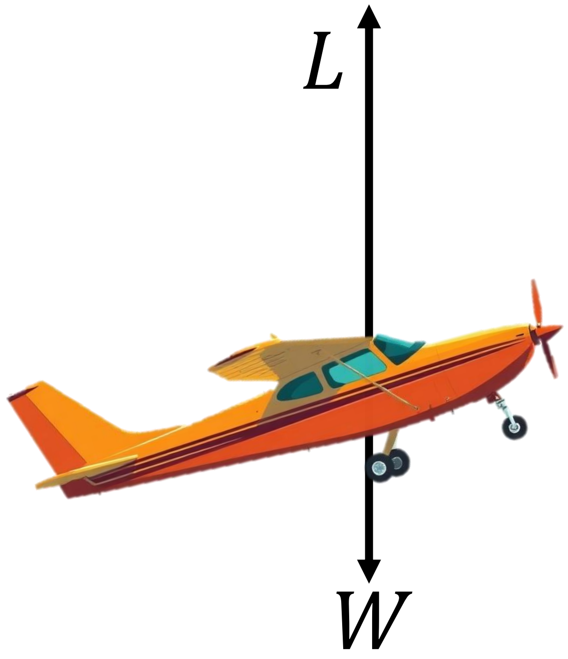
Limits:
$C_{L_{max}} \approx 1.6$
+3.8 g
9120 lbs

Exceeding lift limit breaks the wing.

Exceeding the g-load breaks non-wing components.

Reduced Weight (2000#) at Va=99 KIAS

Q: What are the loads and lift at Va but at 2000#?



Wing stalls at $C_{L_{max}} \approx 1.6$

Back calculate the lift and g-load

$$n = \frac{L}{W} = \frac{1}{2}\frac{\rho V^2 \cdot S \cdot C_{L_{max}}}{W}$$

Same Lift=9120 lbs! But the g-load is 20% higher!

Answer:

+4.6 g

9120 lbs

Maybe the engine, or battery, or avionics, or fuselage fails.

Va is slower at lower weights!

Lower Weights

Q: What is Va at a lower weight: 2000#?

$$Va = Va_{GW}\sqrt{\frac{Weight}{Gross\ Weight}} \qquad Va = 99\sqrt{\frac{2000}{2400}} \approx 90\ KIAS$$

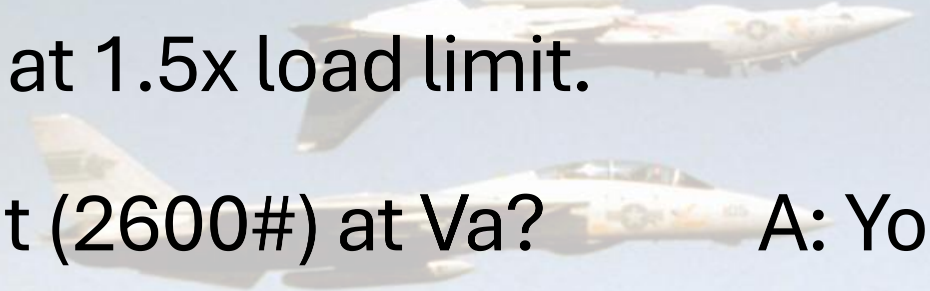
Rule of Thumb:
Reduce by half the ratio of weights.

Q: What is Va for a 3000# airplane at 2400#? Va at gross is 100 kts.

600# difference is 20% gross.
Va will be 10% lower. 90 kts

$$Va = 100\sqrt{\frac{2400}{3000}} \approx 89\ KIAS$$

Various Combinations



Q: Weight 2400# and 120 KTAS?

Lift is 13500# and the g-load is 50% higher (5.6g)
The regulations **allow ultimate failure** at 1.5x load limit.

Answer:
+5.6 g
13,500 lbs

Anything goes!

Q: Overweight (2600#) at Va?

A: You are now a test pilot.

Same Lift! And the g-load is lower.
But the trees will be nearer!

Answer:
+3.5 g
9120 lbs

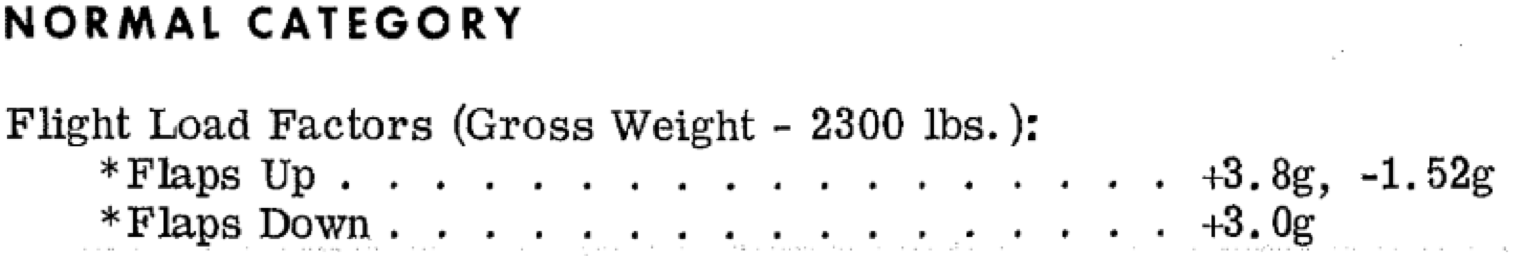
Q: 4g Inverted Dive?

Nope.

Negative g Maneuvers

Q: What is the negative Va at 2400#

The difference is that the Cessna 172 is certified for only -1.52g.



NORMAL CATEGORY

Flight Load Factors (Gross Weight - 2300 lbs.):

*Flaps Up . . . . +3.8g, -1.52g
*Flaps Down . . . . +3.0g

The math gives:

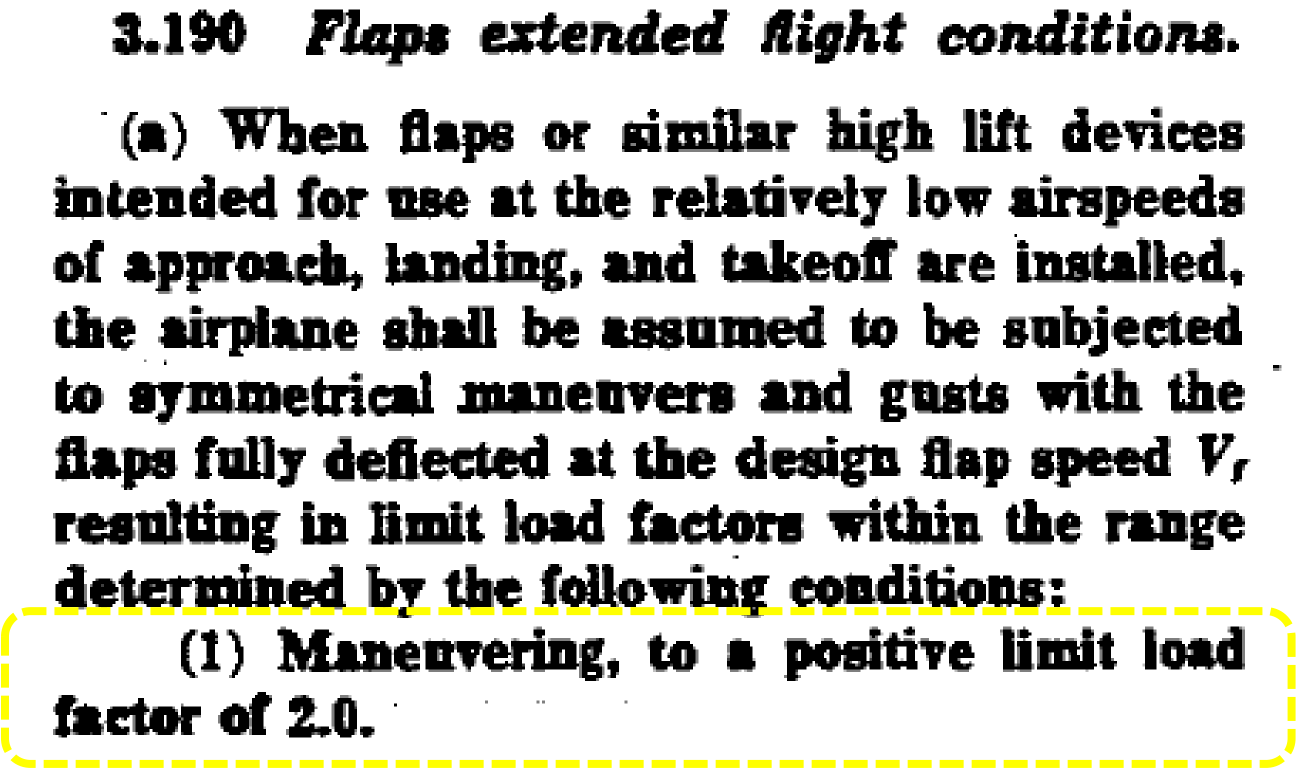
$$Va = Va_{GW}\sqrt{\frac{Weight}{Gross\ Weight}}\sqrt{\frac{n_-}{n_+}} \qquad Va = 99\sqrt{\frac{2400}{2400}}\sqrt{\frac{1.52}{3.8}} \approx 63\ KIAS$$

Surprised? Your follow-up question about **gust loads** is another discussion topic for the future. Regardless, be gentle at negative g loads.

Given a calm atmosphere, no obstructions, and no traffic or wake, can **positive load** control inputs structurally break an airplane at a weight corrected Va?

Yes. The certification standards reduce the positive load limit when flaps are extended. For the C172, the load limit is reduced to n=3.0

See CAR 3.190 with n=2.0 →



3.190 ***Flaps extended flight conditions.***

(a) When flaps or similar high lift devices intended for use at the relatively low airspeeds of approach, landing, and takeoff are installed, the airplane shall be assumed to be subjected to symmetrical maneuvers and gusts with the flaps fully deflected at the design flap speed V_f resulting in limit load factors within the range determined by the following conditions:

(1) Maneuvering, to a positive limit load factor of 2.0.

Question 3: *Given a calm atmosphere, no obstructions, and no traffic or wake, can positive load control inputs structurally break an airplane* ***with flaps retracted*** *at a weight corrected Va?*

Surprisingly, the answer is still **YES**!
How? Why? What is the loophole? Crazy engineers?

This is NOT a theoretical failure, and the regulations are similar for Part 23 and Part 25 aircraft.

The key is one letter. That letter is “**s**”.

Question: *Given a calm atmosphere, no obstructions, and no traffic or wake, can positive load control* ***input<u>s</u>*** *structurally break an airplane with flaps retracted at a weight corrected Va?*

Fact #4: The certification regulations and FAA interpretations (AC 23-19) clearly state that Va only protects single axis control inputs.

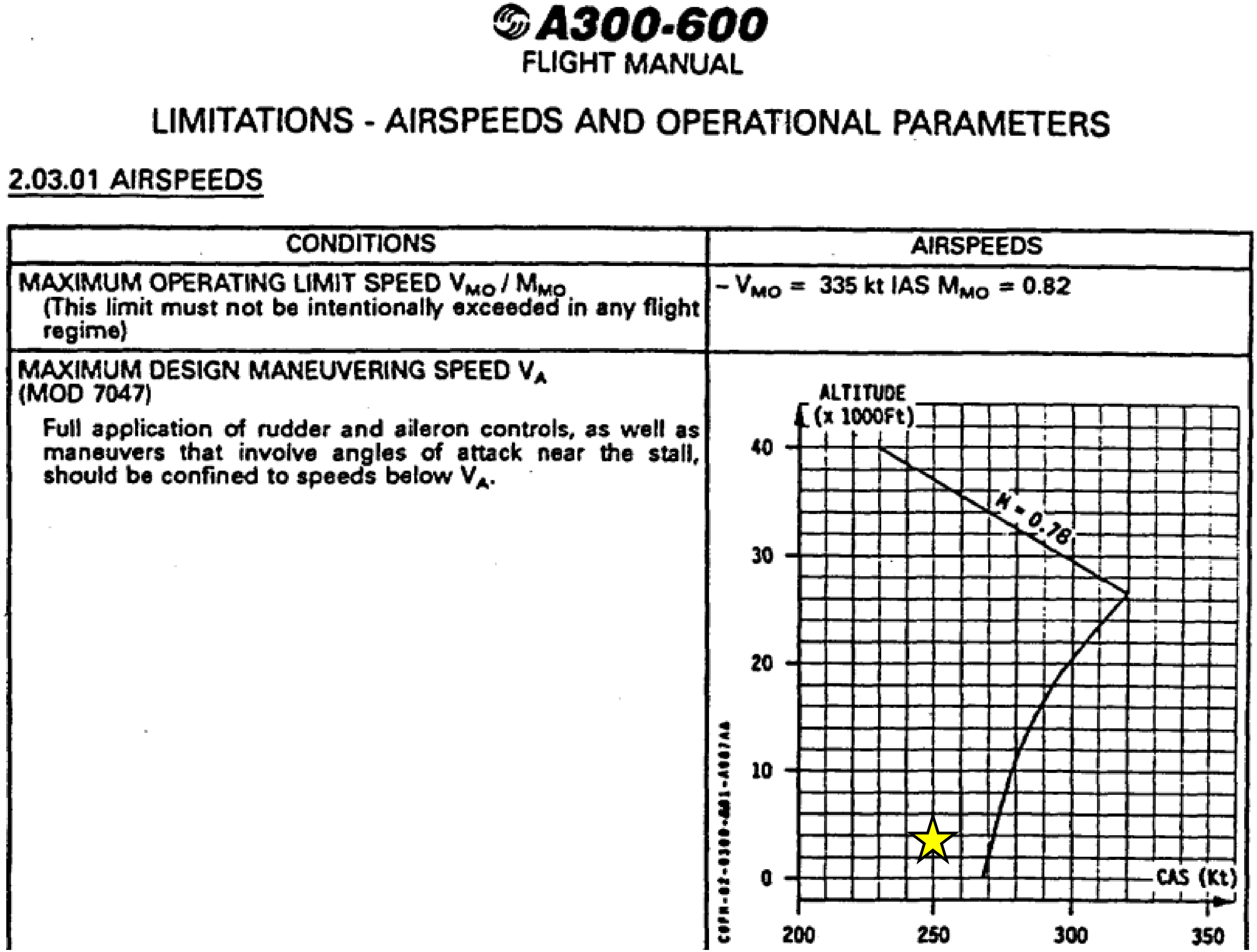
Translation: At Va, full up elevator is ok. But full up elevator and ***any*** aileron or rudder input **may** exceed the aircraft's structural load limits.

Case Study: AA 587, Airbus A300, NYC, 2001

Encountered 747’s wake turbulence. Survivable encounter, but vertical failed. Why?

Data available from the NTSB report. Download and read here:

https://www.ntsb.gov/investigations/AccidentReports/Reports/AAR0404.pdf



A300-600
FLIGHT MANUAL

LIMITATIONS - AIRSPEEDS AND OPERATIONAL PARAMETERS

2.03.01 AIRSPEEDS

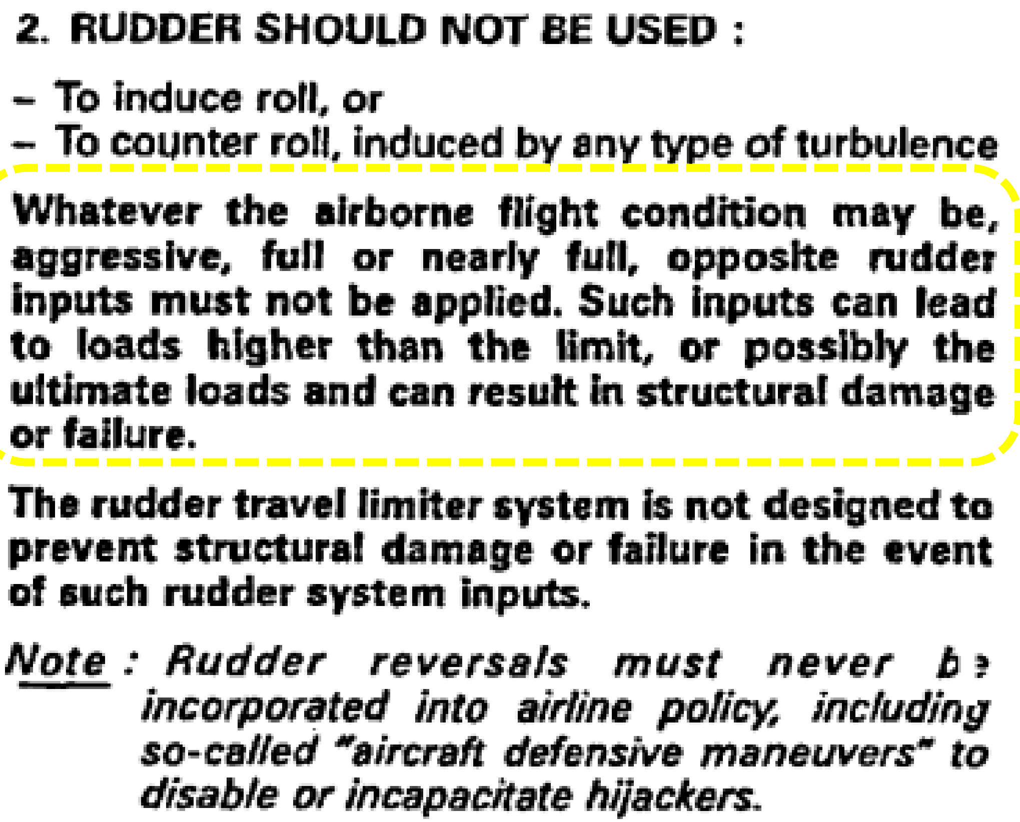
CONDITIONS	AIRSPEEDS
MAXIMUM OPERATING LIMIT SPEED V_{MO} / M_{MO} (This limit must not be intentionally exceeded in any flight regime)	– V_{MO} = 335 kt IAS M_{MO} = 0.82
MAXIMUM DESIGN MANEUVERING SPEED V_A (MOD 7047) Full application of rudder and aileron controls, as well as maneuvers that involve angles of attack near the stall, should be confined to speeds below V_A.	

Failed at:

250 KCAS
3000 MSL

This is **well** inside the 270 KCAS Va envelope.

Case Study: AA 587



2. RUDDER SHOULD NOT BE USED :

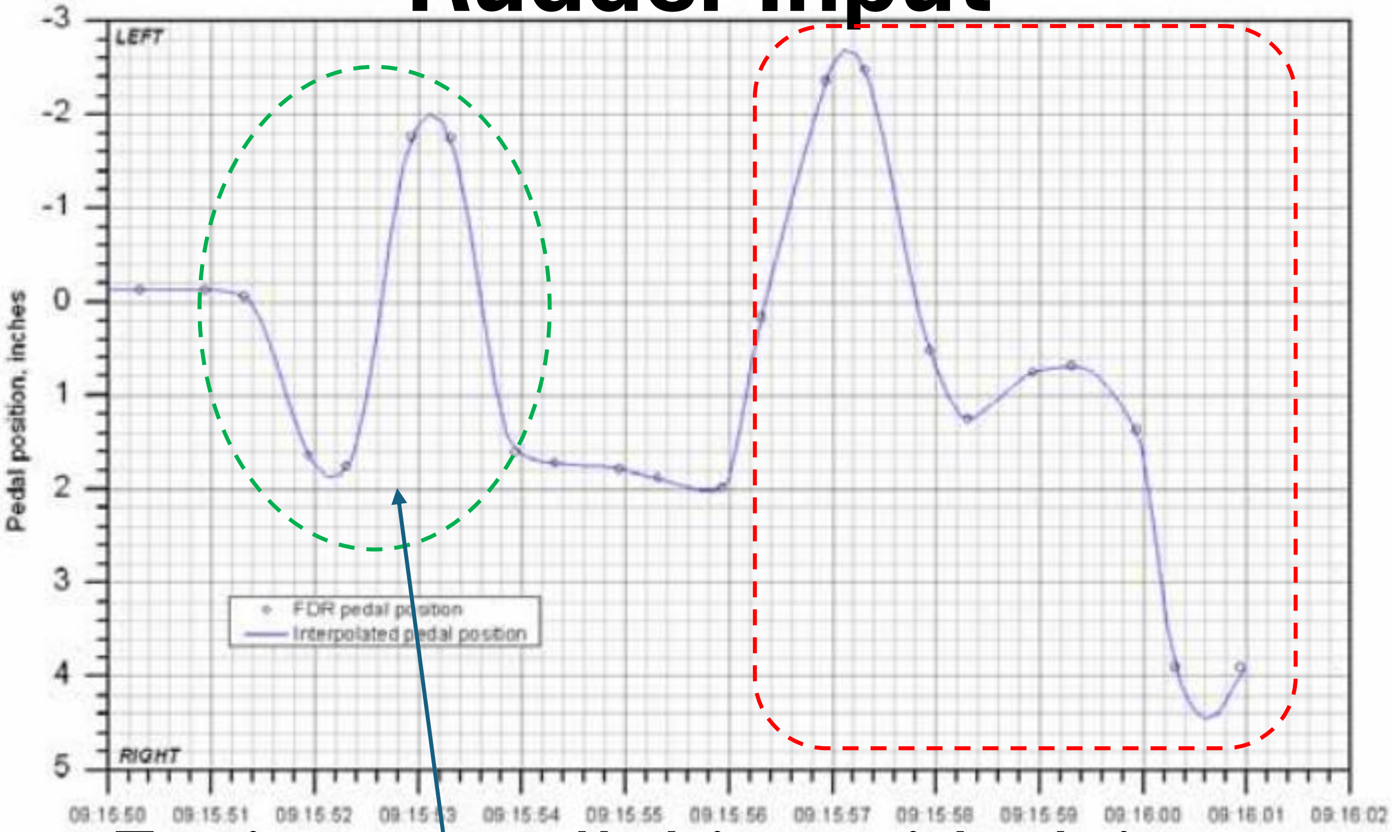
- To induce roll, or
- To counter roll, induced by any type of turbulence

Whatever the airborne flight condition may be, aggressive, full or nearly full, opposite rudder inputs must not be applied. Such inputs can lead to loads higher than the limit, or possibly the ultimate loads and can result in structural damage or failure.

The rudder travel limiter system is not designed to prevent structural damage or failure in the event of such rudder system inputs.

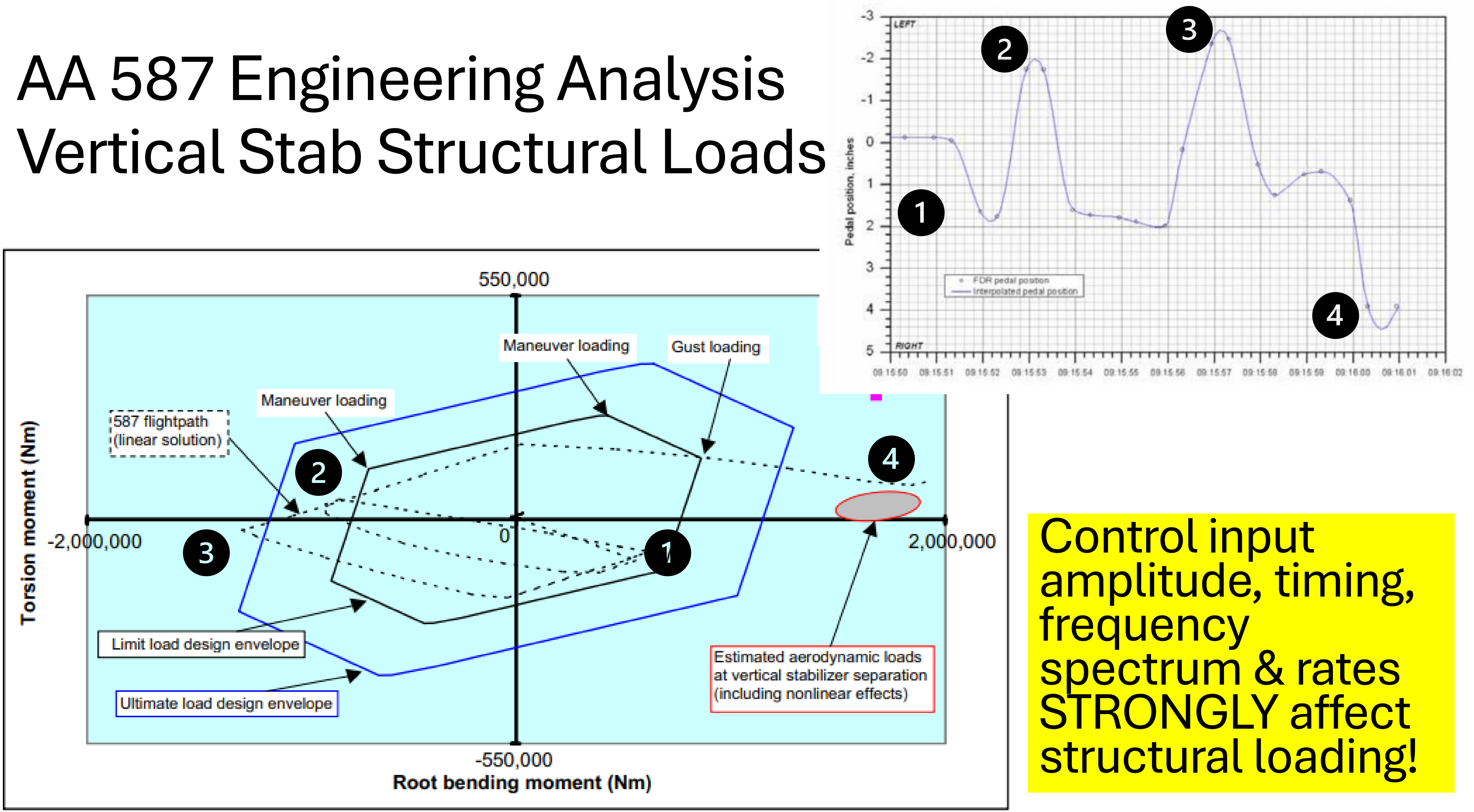
Note : Rudder reversals must never be incorporated into airline policy, including so-called "aircraft defensive maneuvers" to disable or incapacitate hijackers.

Rudder Input



Engineers call this rapid +/- input a *"doublet"*. We use doublets during flight tests to excite specific aircraft & structural dynamics motions! There are 2 doublets here! (Cf. Amplitude & Freq)

AA 587 Engineering Analysis Vertical Stab Structural Loads



Control input amplitude, timing, frequency spectrum & rates STRONGLY affect structural loading!

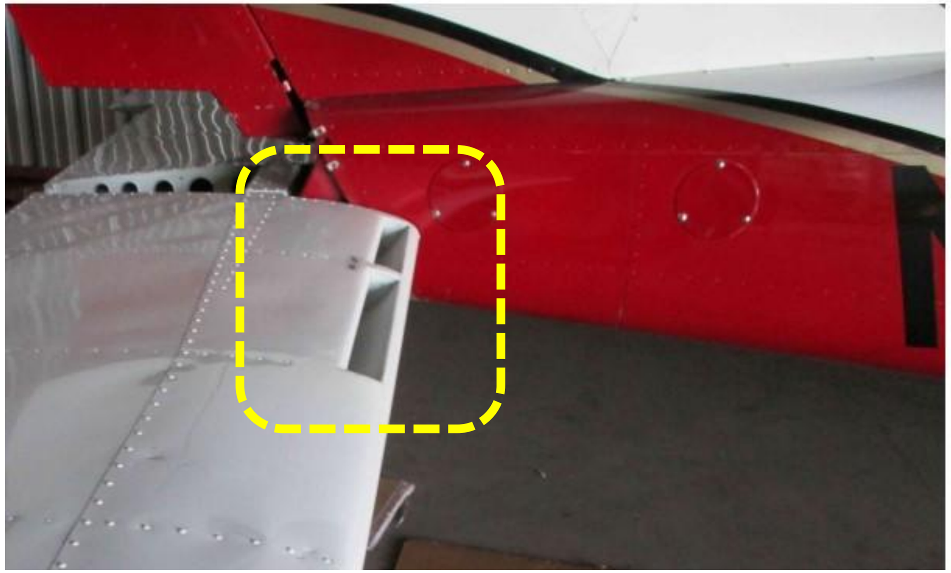
Q: Won't the tail stall to protect the airplane?

This is an interesting question. Short answer, no.

The physics show that a tail stalling at maximum lift coefficient at Va would also stall near the same AOA at lower airspeeds during the approach and landing.

A tail stall is generally regarded as a bad move, especially near the ground.

The Cessna 177 originally had a problem with a (partial) tail stall which was fixed at great company expense with slots in the stabilator.



Any interest in a discussion of longitudinal stability & controls?

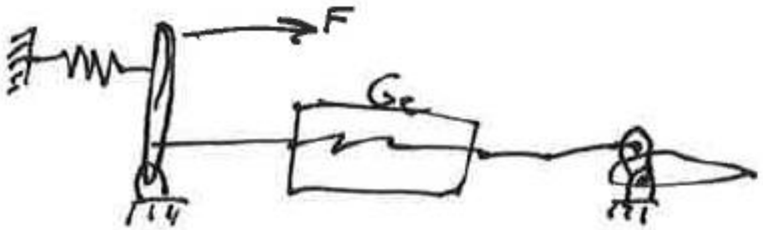
Stick Force per G?

However, as a designer, you could make the stick force per g high enough that a normal pilot couldn't pull too many g. In fact, the FARs **require** the stick force to exceed a specific value at max g load.

$$F \approx \underbrace{\eta}_{\text{propulsion}} \underbrace{G_e S_e \bar{c}_e}_{\text{geometry}} \left(\underbrace{qC}_{\substack{\text{static}\\\text{offsets}}} + \underbrace{\frac{W}{S}}_{\substack{\text{wing}\\\text{loading}}} \underbrace{\frac{C_{h\delta_e}}{C_{m\delta_e}}}_{\substack{\text{elevator}\\\text{aero}}} \cdot \underbrace{SM_{free}}_{\substack{\text{static}\\\text{margin}}} \right)$$

Two strategies are common fixes for high performance reversible controls aircraft:

1) Spring



2) Bob weight

For more, see: https://charles-oneill.com/aemFTE/Lesson13-StickForces.pdf

Harrier Flight Control System

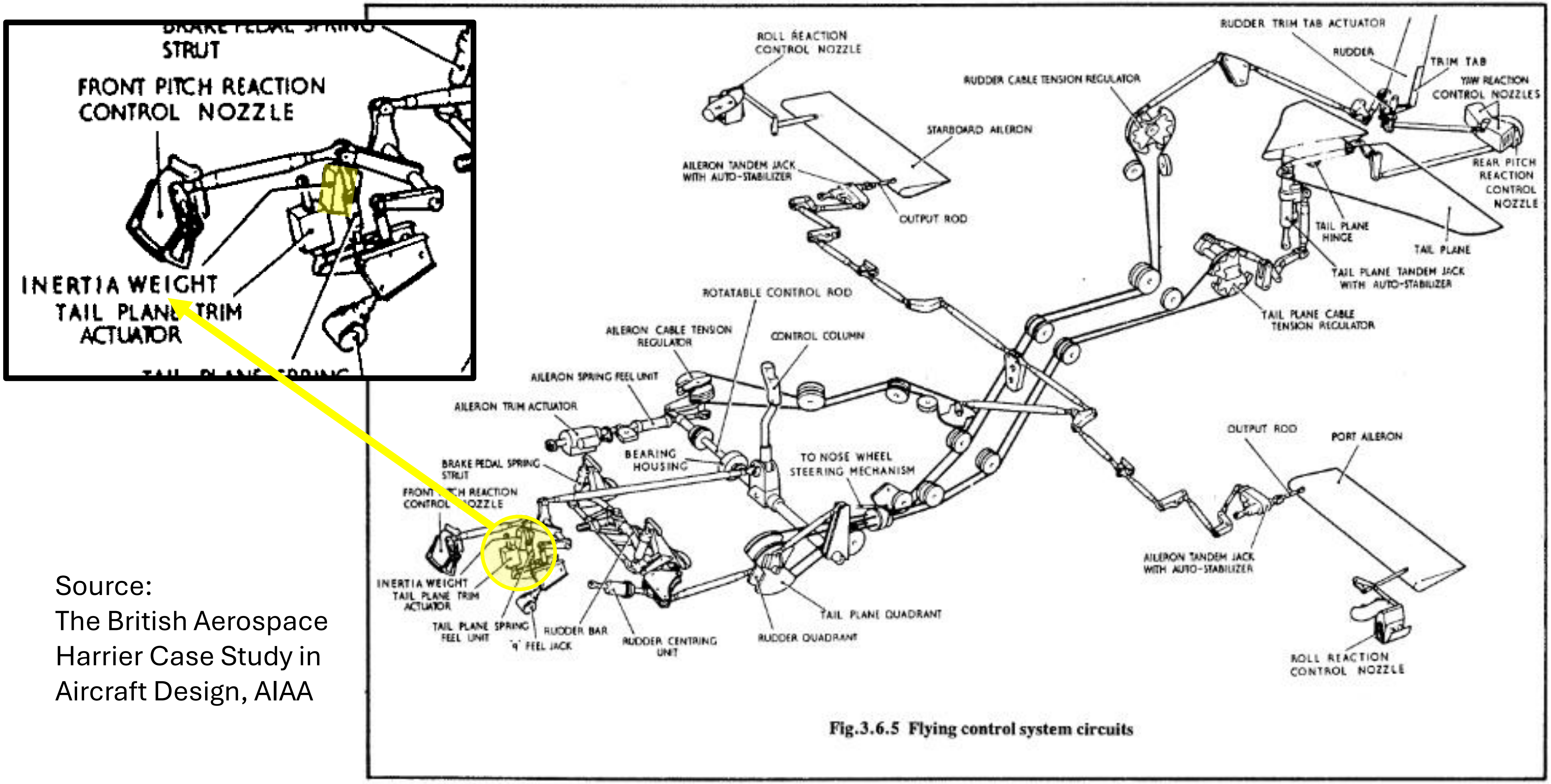
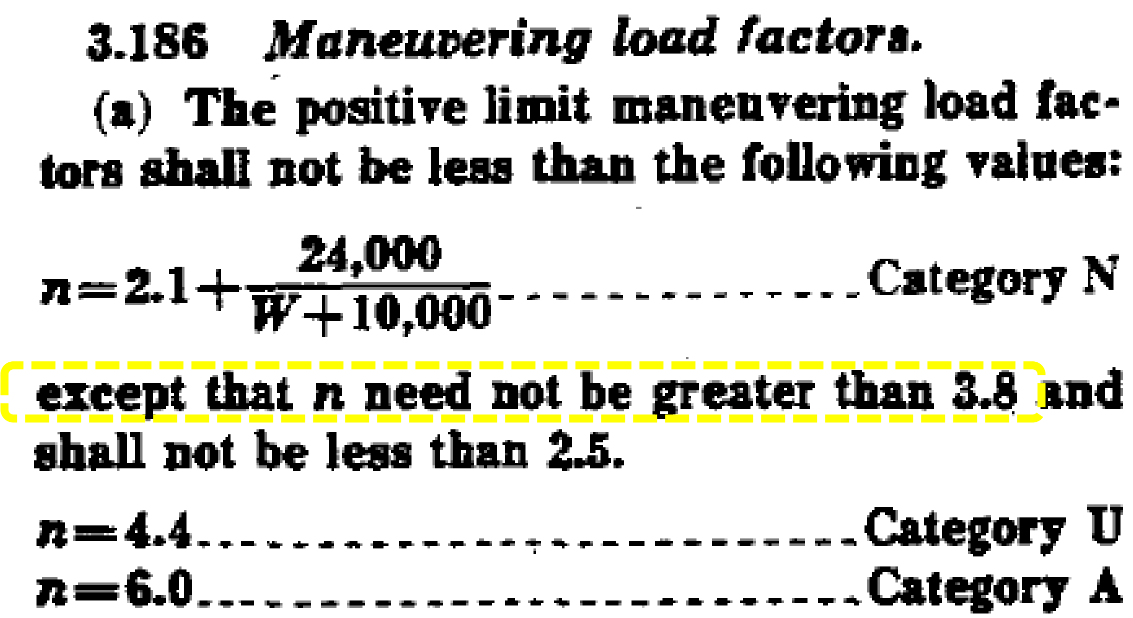


Fig.3.6.5 Flying control system circuits

Source:
The British Aerospace Harrier Case Study in Aircraft Design, AIAA

For design purposes, how is n+ and n- selected?



3.186 ***Maneuvering load factors.***

(a) The positive limit maneuvering load factors shall not be less than the following values:

$$n=2.1+\frac{24{,}000}{W+10{,}000} \text{ .... Category N}$$

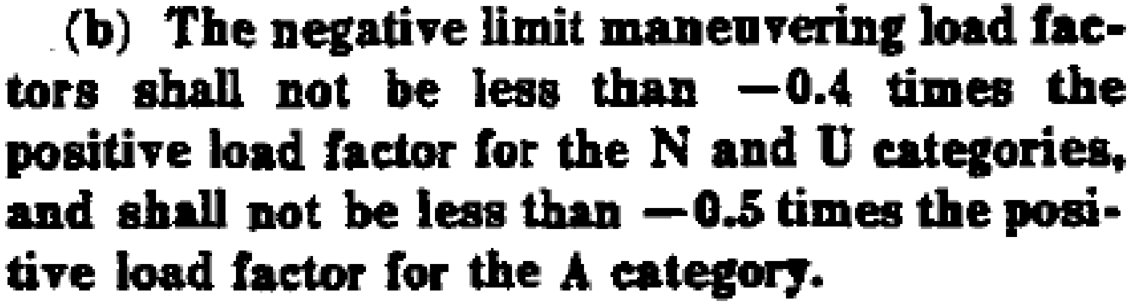
except that n need not be greater than 3.8 and shall not be less than 2.5.

$n=4.4$ .... **Category U**

$n=6.0$ .... **Category A**

For a C172 at 2300#, this formula gives $n = 4.05$ except that n can be a low as 3.8.

Positive limit for the Cessna 172 is n=3.8



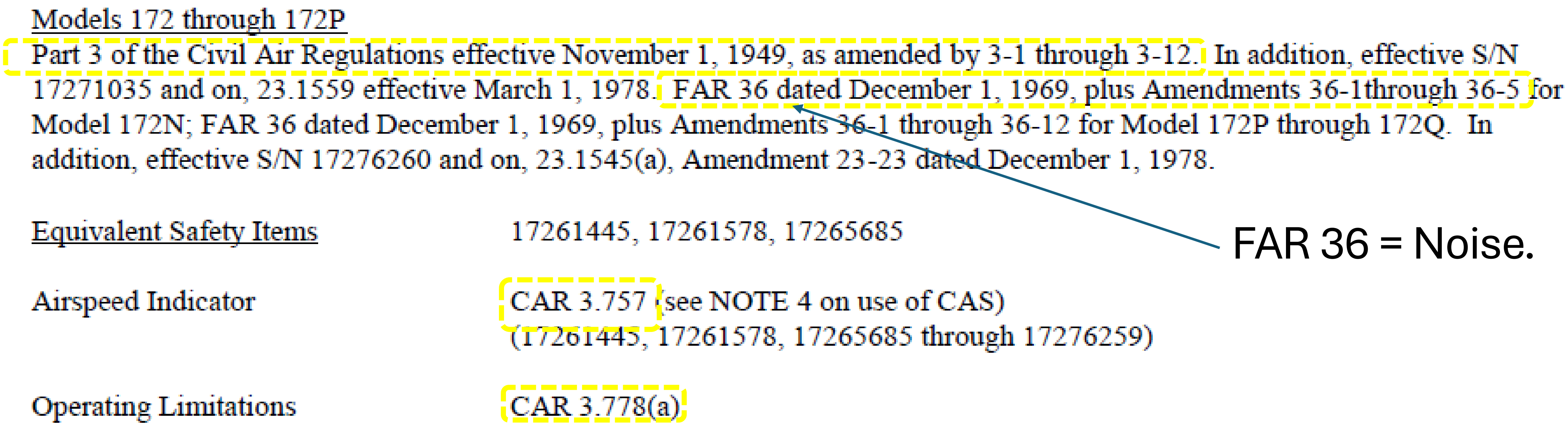
(b) The negative limit maneuvering load factors shall not be less than −0.4 times the positive load factor for the N and U categories, and shall not be less than −0.5 times the positive load factor for the A category.

For a C172 at 2300#, n+ is 3.8 such that n- must be

$$n_{-} = -0.4 \cdot 3.8 = -1.52$$

The negative limit for the Cessna 172 is -1.52

Cessna 172N Certification Basis: TCDS

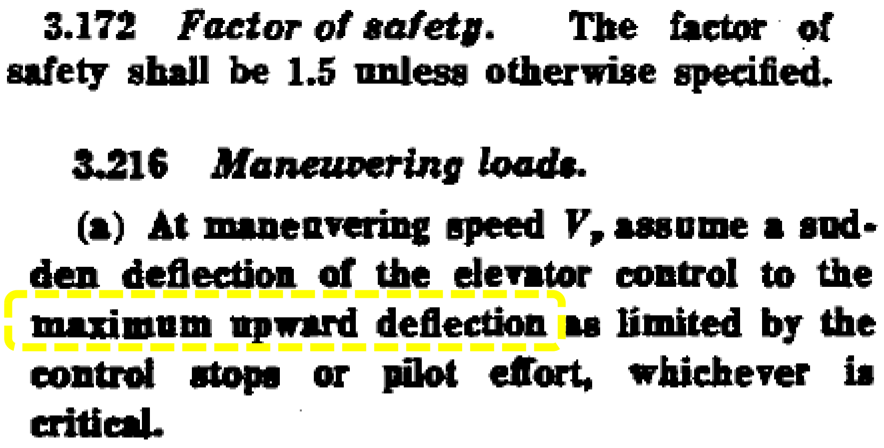


Models 172 through 172P

Part 3 of the Civil Air Regulations effective November 1, 1949, as amended by 3-1 through 3-12. In addition, effective S/N 17271035 and on, 23.1559 effective March 1, 1978. FAR 36 dated December 1, 1969, plus Amendments 36-1through 36-5 for Model 172N; FAR 36 dated December 1, 1969, plus Amendments 36-1 through 36-12 for Model 172P through 172Q. In addition, effective S/N 17276260 and on, 23.1545(a), Amendment 23-23 dated December 1, 1978.

Equivalent Safety Items	17261445, 17261578, 17265685
Airspeed Indicator	CAR 3.757 (see NOTE 4 on use of CAS) (17261445, 17261578, 17265685 through 17276259)
Operating Limitations	CAR 3.778(a)

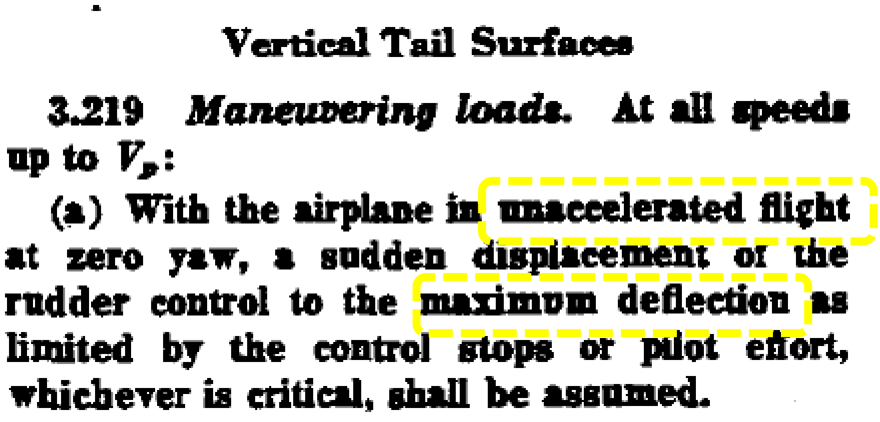
FAR 36 = Noise.



3.172 ***Factor of safety.*** **The factor of safety shall be 1.5 unless otherwise specified.**

3.216 ***Maneuvering loads.***

(a) At maneuvering speed V_p assume a sudden deflection of the elevator control to the maximum upward deflection as limited by the control stops or pilot effort, whichever is critical.

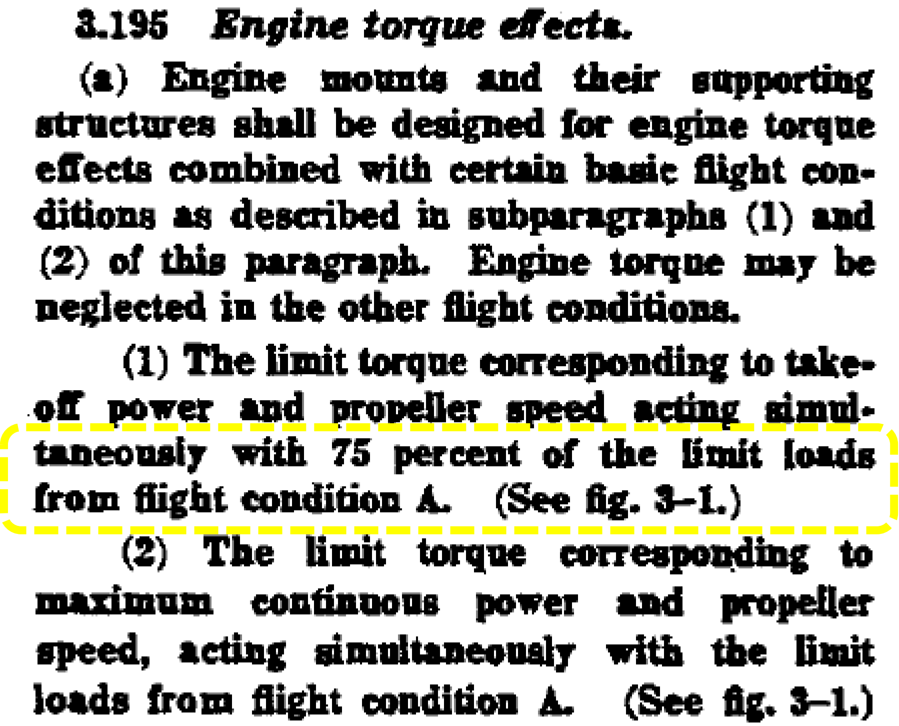


Vertical Tail Surfaces

3.219 ***Maneuvering loads.*** **At all speeds up to V_p:**

(a) With the airplane in unaccelerated flight at zero yaw, a sudden displacement of the rudder control to the maximum deflection as limited by the control stops or pilot effort, whichever is critical, shall be assumed.

Cessna 172N Certification Basis: CAR 3



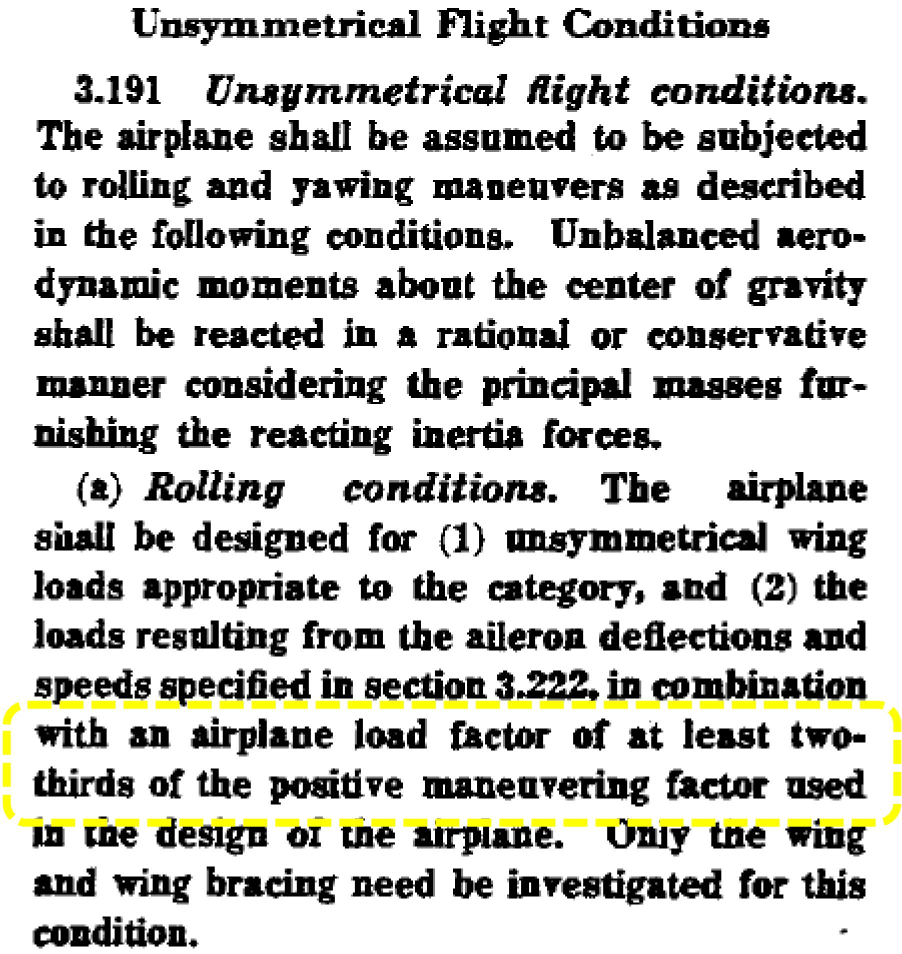
3.195 ***Engine torque effects.***

(a) Engine mounts and their supporting structures shall be designed for engine torque effects combined with certain basic flight conditions as described in subparagraphs (1) and (2) of this paragraph. Engine torque may be neglected in the other flight conditions.

(1) The limit torque corresponding to take-off power and propeller speed acting simultaneously with 75 percent of the limit loads from flight condition A. (See fig. 3–1.)

(2) The limit torque corresponding to maximum continuous power and propeller speed, acting simultaneously with the limit loads from flight condition A. (See fig. 3–1.)

Are these the assumptions that you believed?



Unsymmetrical Flight Conditions

3.191 ***Unsymmetrical flight conditions.*** The airplane shall be assumed to be subjected to rolling and yawing maneuvers as described in the following conditions. Unbalanced aerodynamic moments about the center of gravity shall be reacted in a rational or conservative manner considering the principal masses furnishing the reacting inertia forces.

(a) *Rolling conditions.* The airplane shall be designed for (1) unsymmetrical wing loads appropriate to the category, and (2) the loads resulting from the aileron deflections and speeds specified in section 3.222, in combination with an airplane load factor of at least two-thirds of the positive maneuvering factor used in the design of the airplane. Only the wing and wing bracing need be investigated for this condition.

Read the CAR 3 regulations at: https://charles-oneill.com/docs/CAM476.pdf

Maneuvering Speed Takeaways:

Charles O’Neill
Posted at: https://charles-oneill.com
Email at: oneill@aerofluids.com

① Maneuvering Speed only effectively protects against a SINGLE control input.

② Reduce Va at lower weights.
Reduce by half the weight ratio.

$$Va = Va_{GW}\sqrt{\frac{Weight}{Gross\ Weight}}$$

③ Negative load limits and maneuvering speed is less than the positive load limits and Va.