AIRCRAFT STRUCTURAL DESIGN
SESA3026

3. Aircraft Loads
V-n Diagram

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https://www.youtube.com/watch?v=mQ1ZozXp2tw&feature=emb_logo&ab_channel=BloombergQuicktake

Maximum Load Factor

Load factor

$$L + P = nW$$

$n = 1$: level and straight flight

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

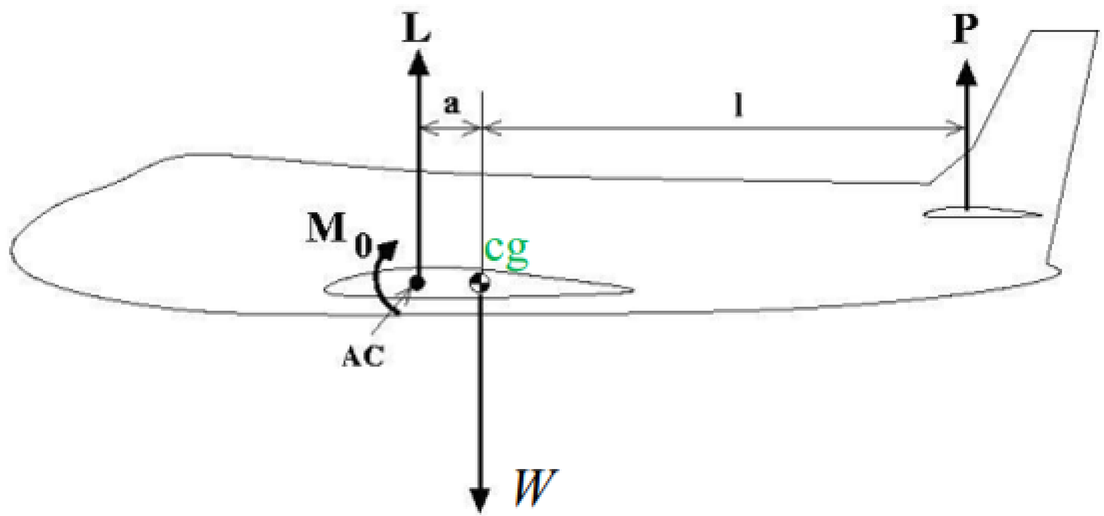
$n = 0$: zero-g (parabolic flight)

Maximum value of n just before stall

$$\boxed{n_{MAX} = \frac{0.5\rho V^2 S C_L^{MAX}}{W}}$$

determined by **total aircraft lift coefficient, C_L^{MAX}**

Total aircraft lift coefficient



Equilibrium rotation around cg:

$$Pl = La + M_0$$

$$P = \frac{L}{l}a + \frac{1}{l}M_0$$

$$P + L = L\left(1 + \frac{a}{l}\right) + \frac{1}{l}M_0$$

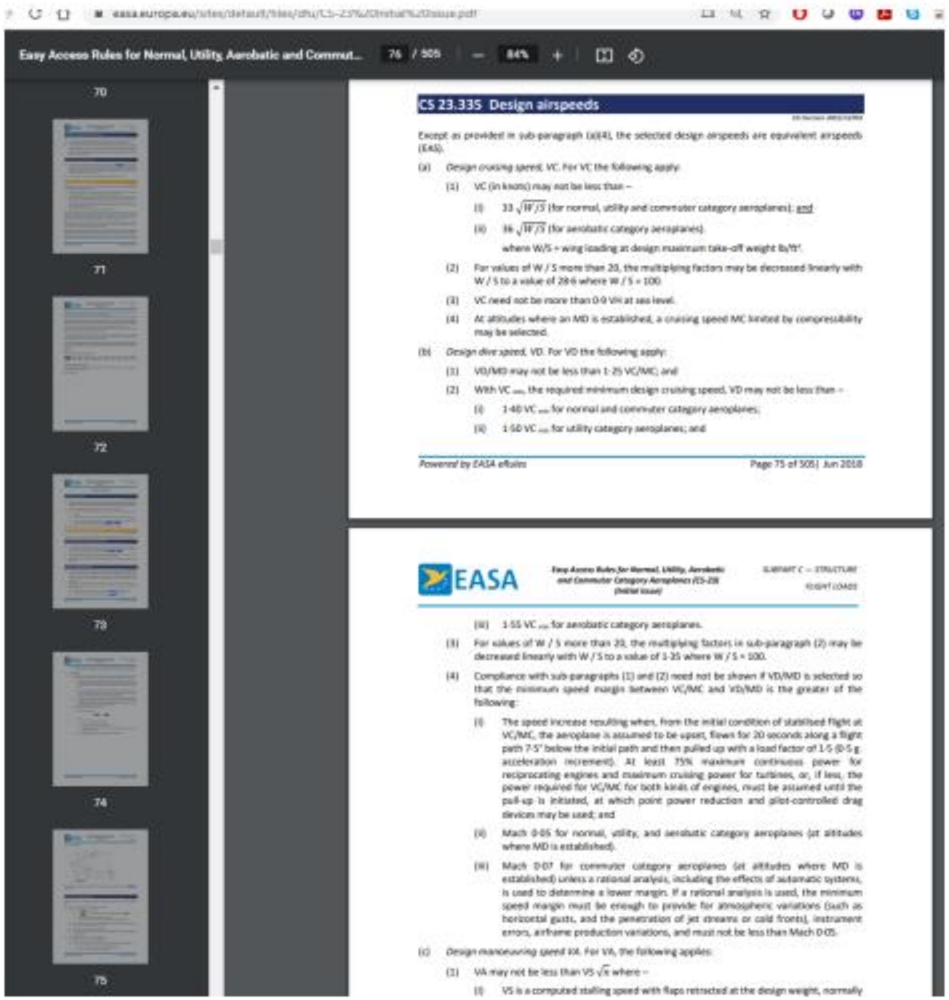
Note that the symbol *a* has been used previously to indicate an acceleration and now a distance. Its meaning, however, should be clear from the expression in which it is used.

Divide by the reference load

$$(C_L^{MAX})_{aircraft} = (C_L^{MAX})_{wing}\left(1 + \frac{a}{l}\right) + \frac{\bar{c}}{l}C_{m0}$$

V-n Diagram: Flight Envelope (EASA)

https://www.easa.europa.eu/sites/default/files/dfu/CS-23%20Initial%20issue.pdf



V-n Diagram: Flight Envelope (EASA)

Annex to ED Decision 2015/018/R

European Aviation Safety Agency

Certification Specifications

and

Acceptable Means of Compliance

for

Normal, Utility, Aerobatic, and Commuter Category Aeroplanes

CS-23

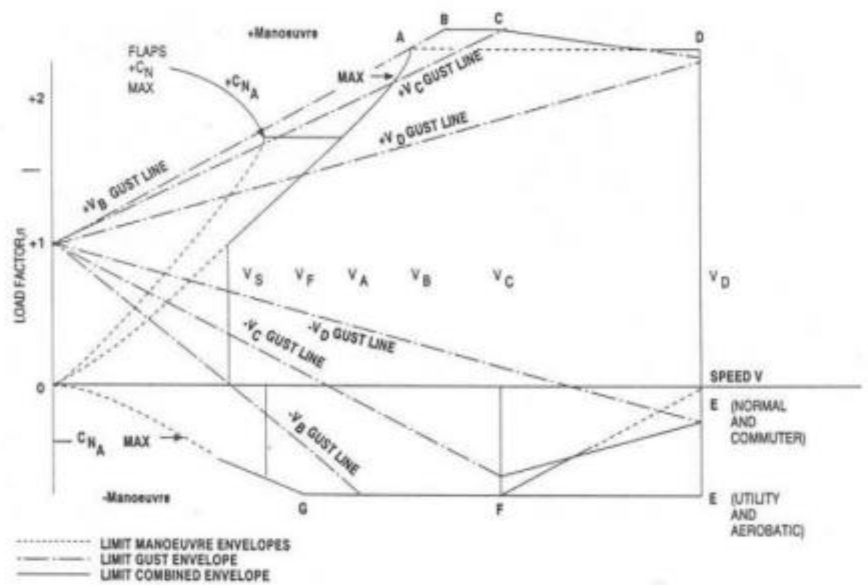
Amendment 4
15 July 2015[1]

[1] For the date of entry into force of this Amendment, kindly refer to Decision 2015/018/R in the Official Publication of the Agency.

Amendment 4

CS-23 BOOK 1

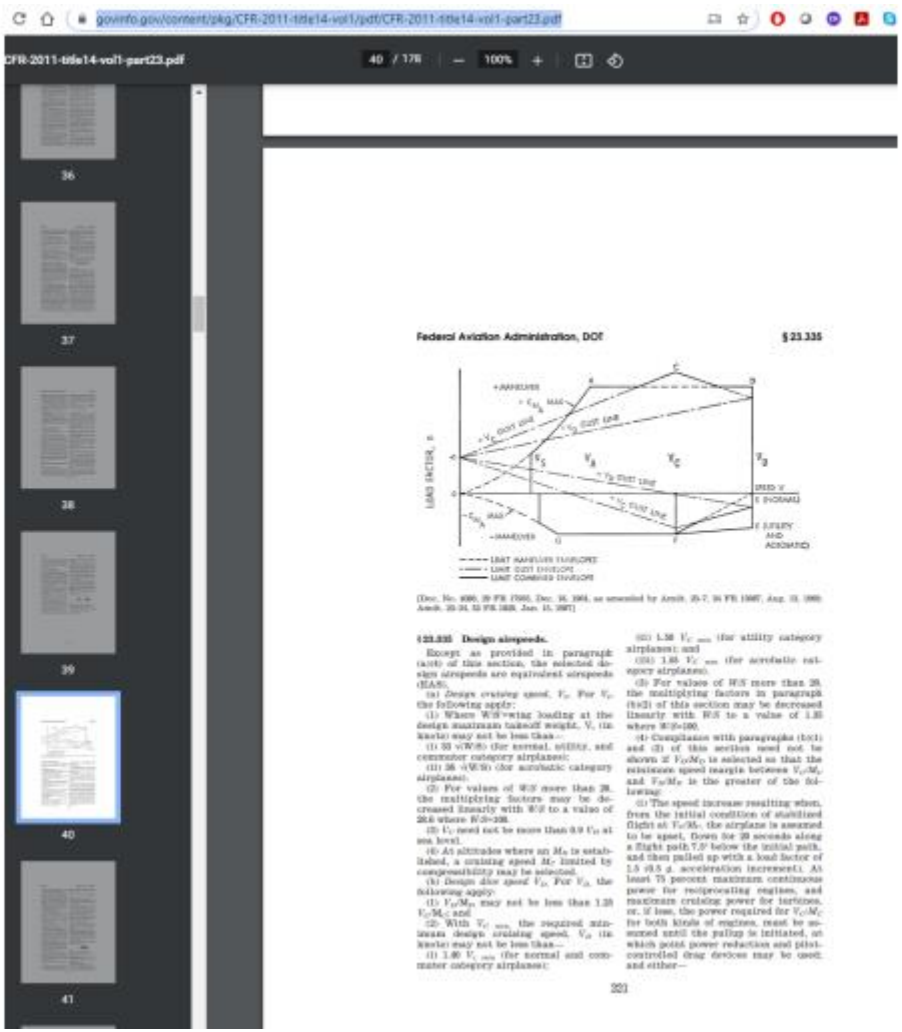
(d) *Flight envelope*



https://www.easa.europa.eu/sites/default/files/dfu/CS-23%20Amendment%204.pdf

V-n Diagram: Flight Envelope (FAA)

https://www.govinfo.gov/content/pkg/CFR-2011-title14-vol1/pdf/CFR-2011-title14-vol1-part23.pdf



V-n Diagram: Flight Envelope

At low speeds

$$\left(C_L^{MAX}\right)_{aircraft} = \boxed{\left(C_L^{MAX}\right)_{wing}} \left(1 + \frac{a}{l}\right) + \frac{\bar{c}}{l} C_{m0}$$

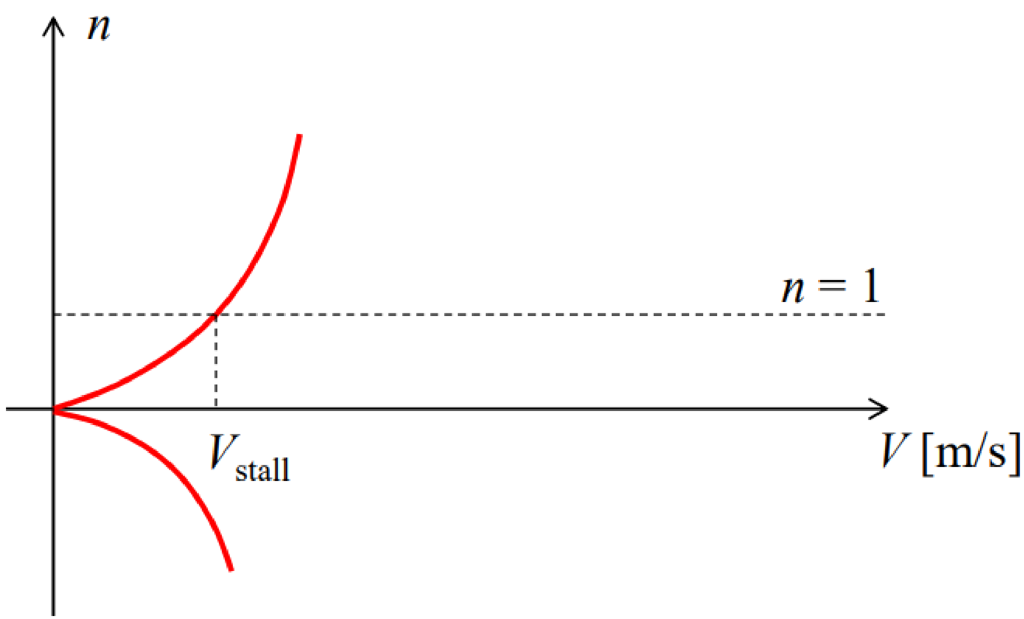
function of velocity, altitude, …

n can be positive or negative

$$n_{MAX} = \frac{0.5 \rho V^2 S C_L^{MAX}}{W}$$

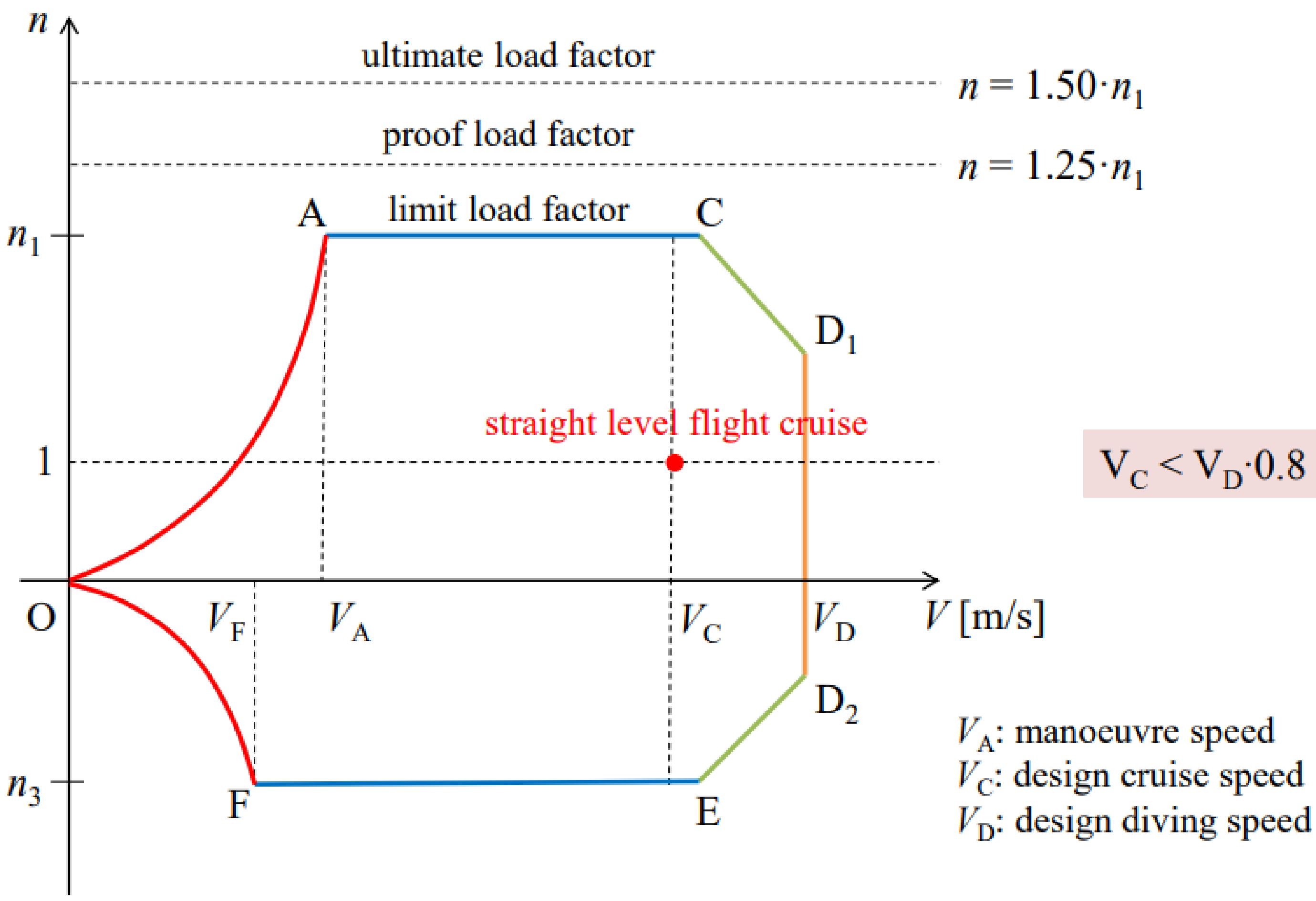
$$n_{MAX} = f(V^2)$$

How do flaps change the red lines?



The Flight Envelope

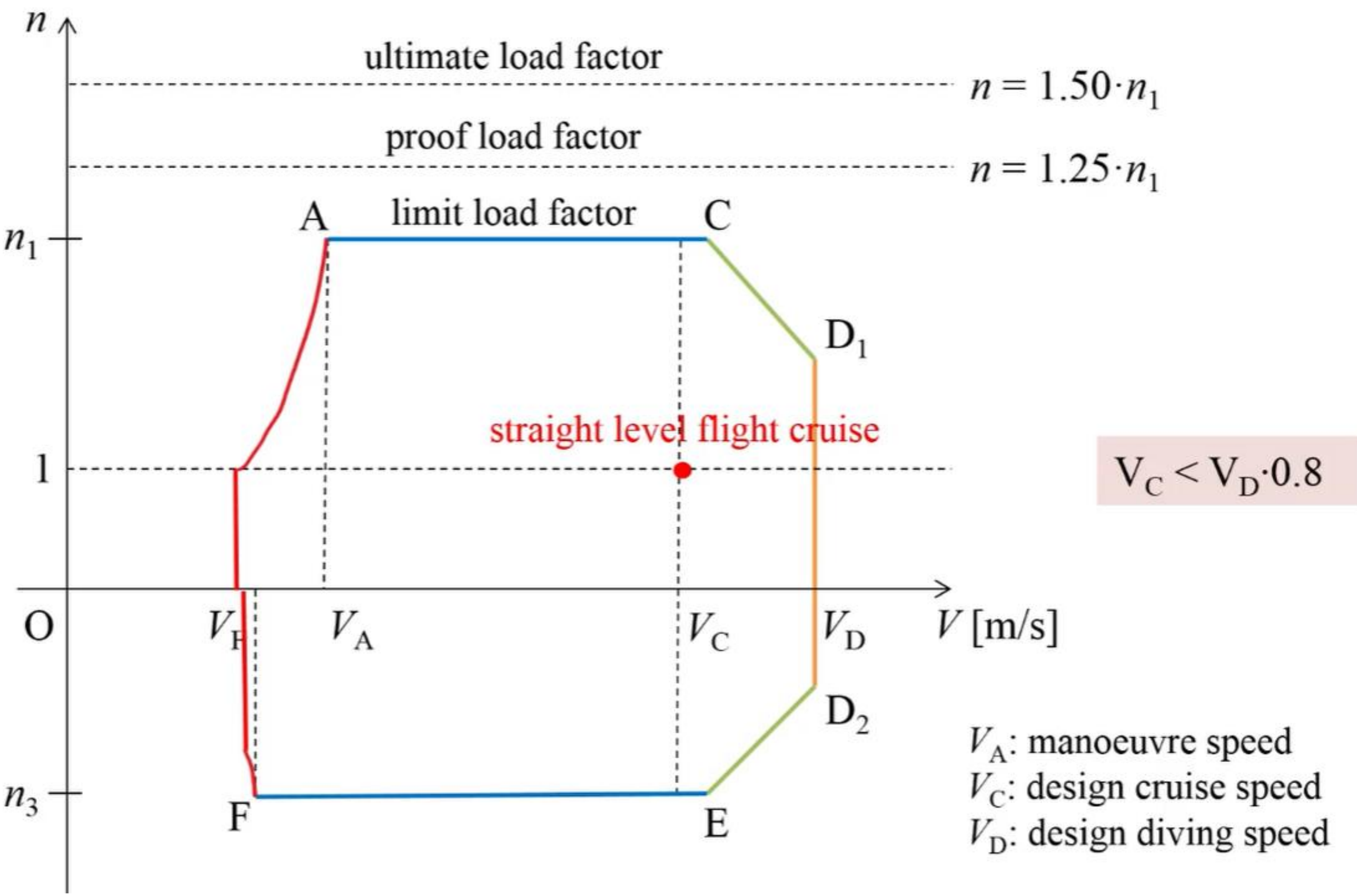
V-n Diagram



$V_C < V_D \cdot 0.8$

The Flight Envelope

V-n Diagram



Symmetric Manoeuvre Loads

V-n Diagram: Limits on Load Factors

Structure must be designed to withstand flight conditions at **any point** in the flight envelope. Load limits are pilot and role dependent, set by Airworthiness Authorities (BCAR, JAR)

Category: normal↑

$$n_1 \leq 2.1 + \frac{24{,}000}{W + 10{,}000}$$
$$n_3 \geq -1.0$$

Category: semi aerobatic↑

$$n_1 \leq 4.5$$
$$n_3 \geq -1.8$$

$$n_1 \leq 6.0$$
$$n_3 \geq -3.0$$

Category: aerobatic ↓

A Light Sport Airplane Flight Envelope

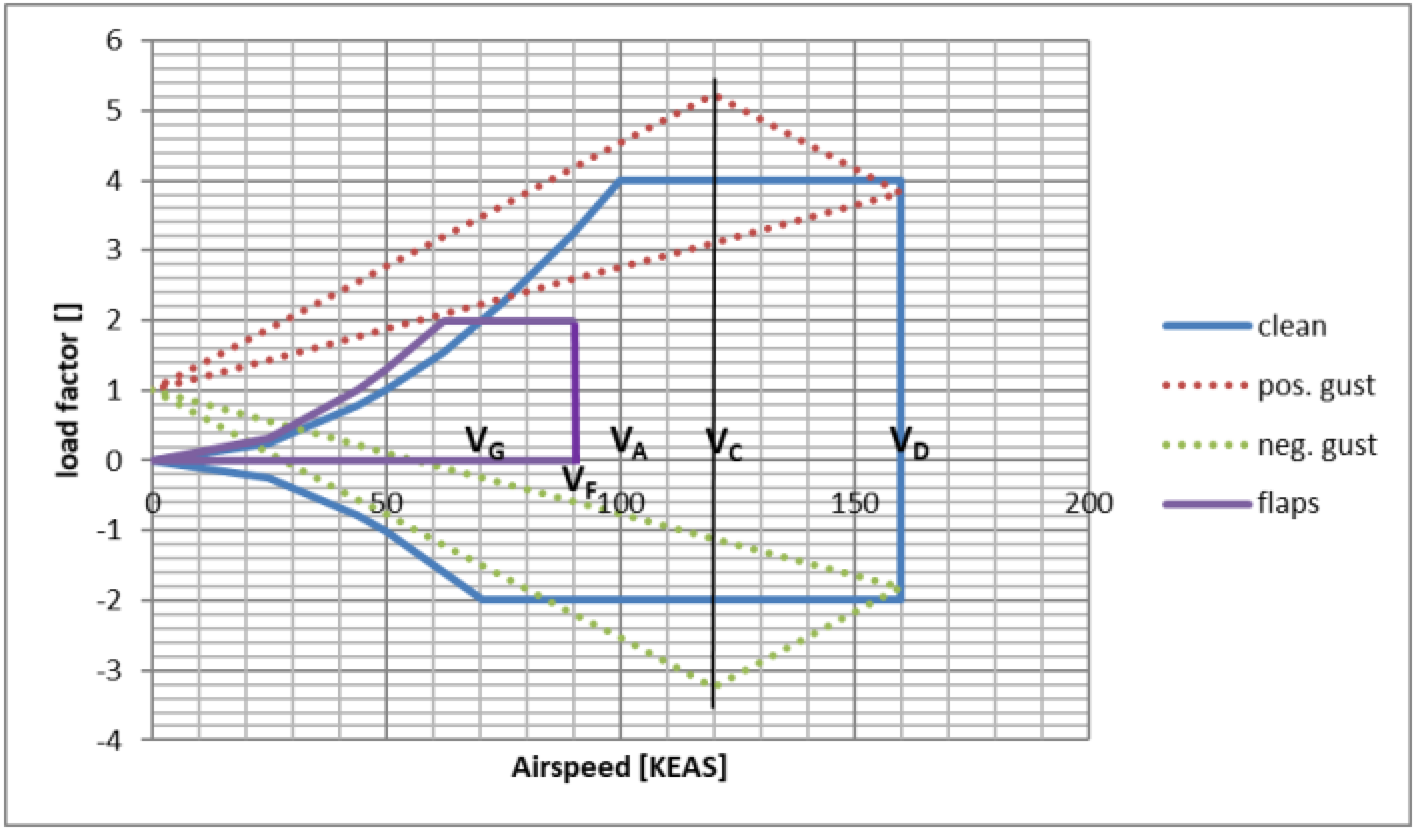


Figure 1 – Reference flight envelope (W_{MTOW}, FL 100)

Taken from EASA document “ABCD-FL-57-00 - Wing Load Calculation - v1 08.03.16.docx” in the Articles Folder, copied from here: https://www.easa.europa.eu/download/general-aviation/documents-guidance-andexamples/ABCD-FE-01-00%20Flight%20Envelope%20-%20v1%2008.03.16.docx

A Light Sport Airplane (LSA) is a simple two-seater with a maximum take-off weight of 600kg. See https://www.easa.europa.eu/faq/19386

Symmetric Manoeuvre Loads

Section 25.337 FAR

§25.337 Limit maneuvering load factors.

(a) Except where limited by maximum (static) lift coefficients, the airplane is assumed to be subjected to symmetrical maneuvers resulting in the limit maneuvering load factors prescribed in this section. Pitching velocities appropriate to the corresponding pull-up and steady turn maneuvers must be taken into account.

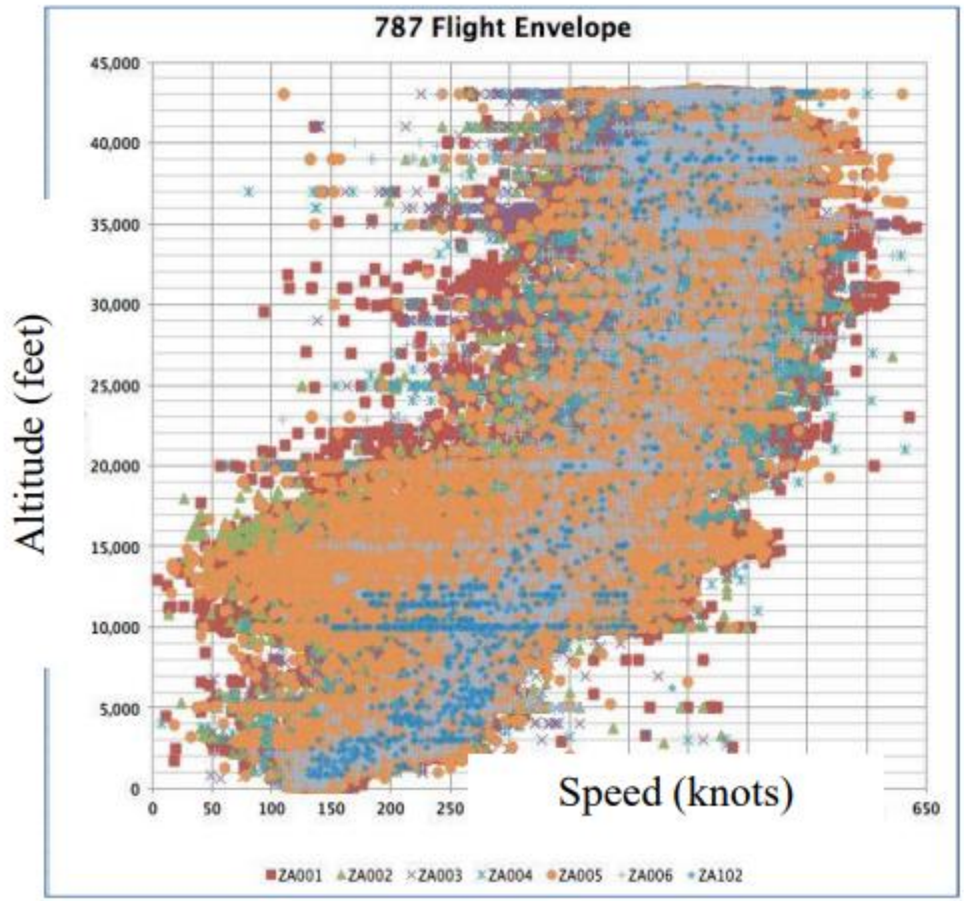
(b) The positive limit maneuvering load factor *n* for any speed up to *Vn* may not be less than 2.1 + 24,000/ (*W*+ 10,000) except that *n* may not be less than 2.5 and need not be greater than 3.8—where *W* is the design maximum takeoff weight.

(c) The negative limit maneuvering load factor—
(1) May not be less than −1.0 at speeds up to V_C; and
(2) Must vary linearly with speed from the value at V_C to zero at V_D.

(d) Maneuvering load factors lower than those specified in this section may be used if the airplane has design features that make it impossible to exceed these values in flight.

787 Dreamliner Flight Envelope

Real performance data



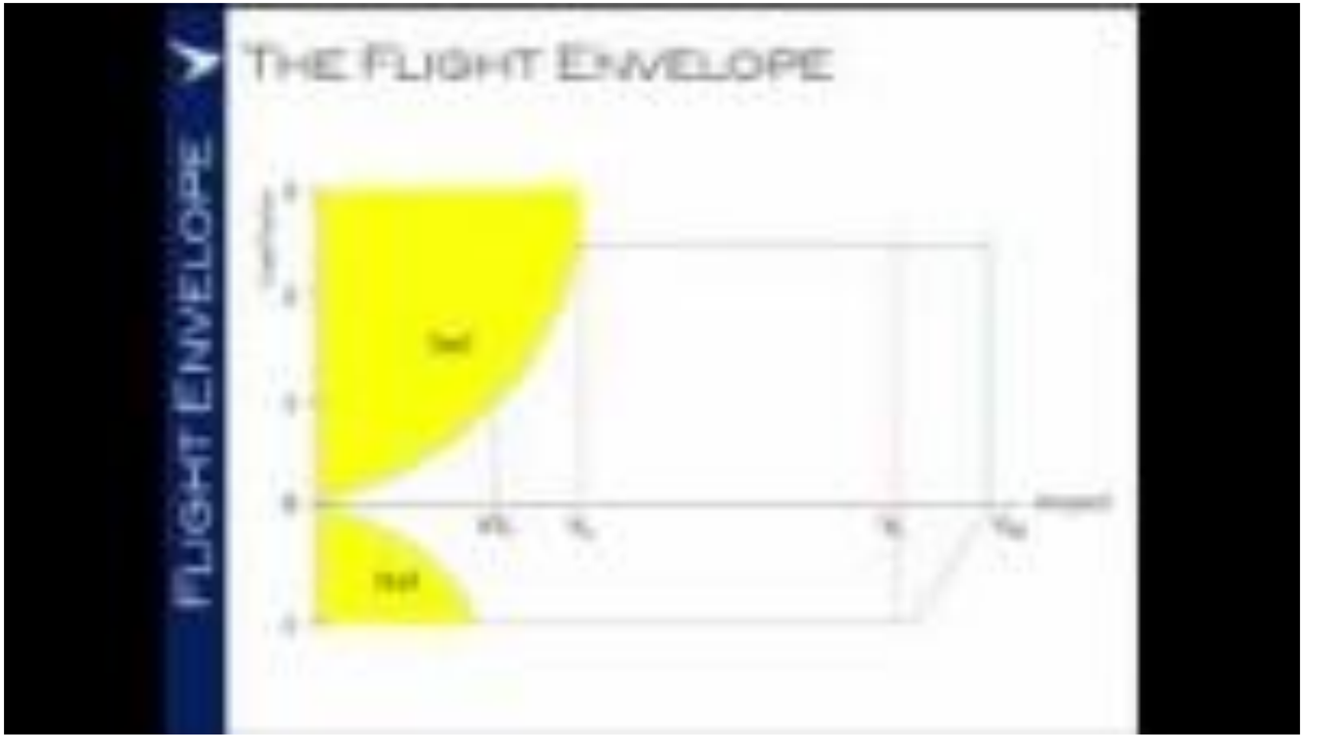
https://aviation.stackexchange.com/questions/7956/what-is-the-maximum-pitch-for-the-boeing-787-dreamliner

Note the flight envelope is **altitude dependent**. The full range of possible altitudes should be investigated in determining the worst case loads.

The Flight Envelope

V-n Diagram: Summary

- The maximum limits in which to operate the aircraft safely and predictably
- Normally larger than the actual flight envelope
- Flight envelopes are multi-layered to account for different altitudes and different lifting configurations
- Different aircraft types have different limits set on the Load Factor, $n = L / W$
- For commercial airliners, normal certification has $n = 2.5$
- Outside of the envelope, stall occurs at relatively low speeds and structural damage is likely above the maximum Load Factor



https://www.youtube.com/watch?v=YqTQCixybSo&feature=emb_logo&ab_channel=WingPro