Loads Analysis and Validation

Herdrice HERESON
Structures Expert CT3.2

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Presentation Guideline

1. Introduction: GA requirements
2. Loads process
3. V-n diagram
4. Fatigue Loads and spectrum
5. Methods for loads calculation
6. Summary and conclusion

1-Introduction: GA one product?

Altitude

20.000 m

A few meters

Product type

Certification requirement

CS23 (pre-amendment 5)
- High performance and jet (+Special condition CRIs)
- Commuter
- Normal, Utility and aerobatic

CS23 (post-amendment 5)
- Level 1* to 4 = f(number of passengers)

*CS VLA is now included in the CS23 Amdt 5 (Level 1)

CS VLA- Very light Aircraft
CS LSA- Light Sport Aeroplanes.

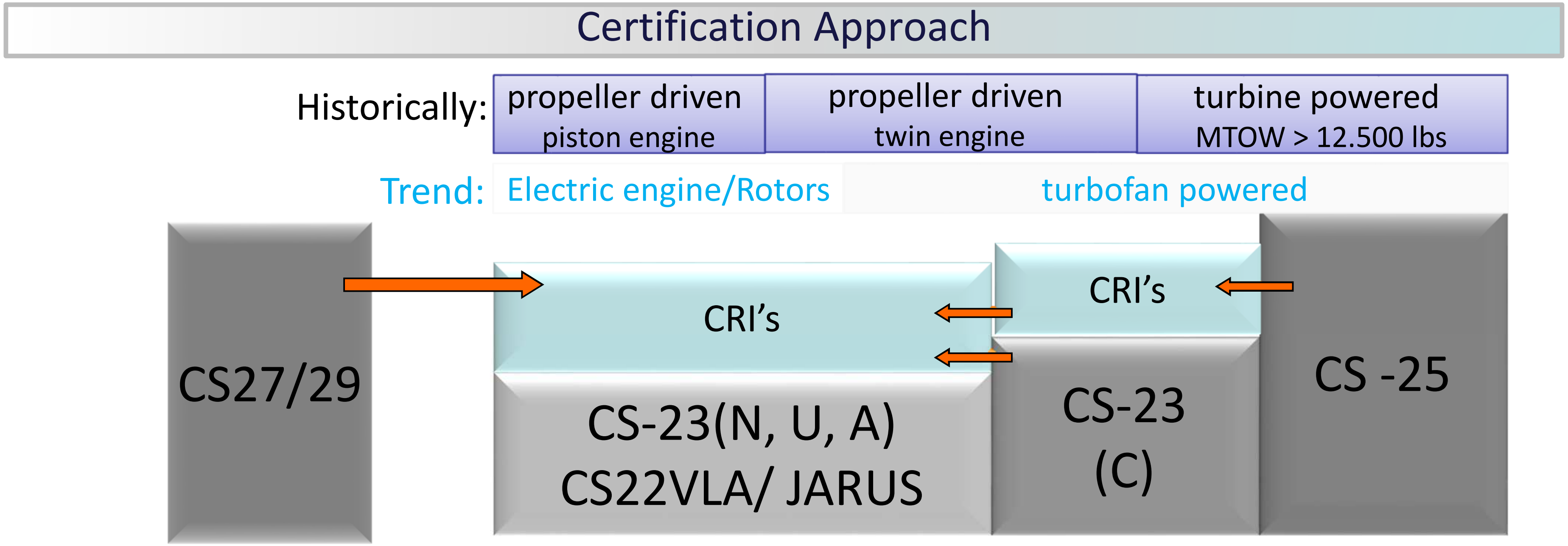
JARUS –drones <750 kg

CS22-Sailplanes and powered sailplanes

CS-31 GB- Gas Balloons
CS-31 HB- Hot Air Balloons
CS-31 TGB- Tethered Gas Balloons

1-Find your certification basis-Not easy

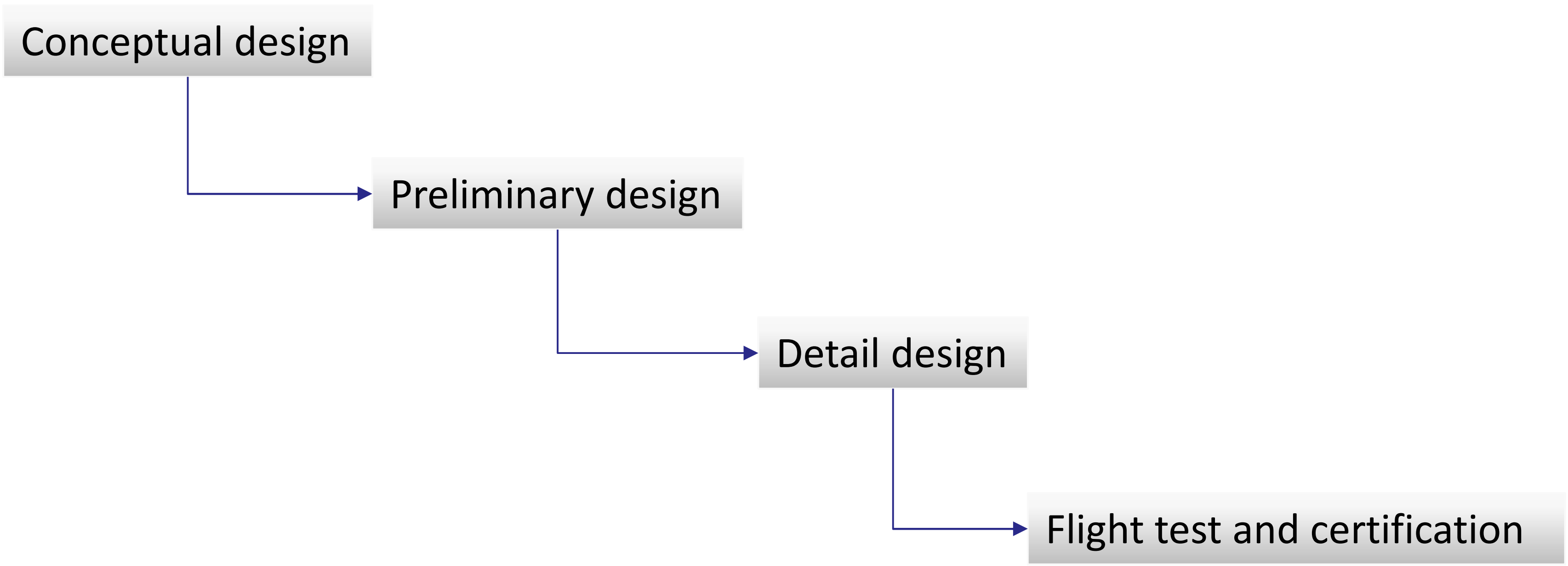
- Loads requirement is provided in subpart C & D of the CS, but in the latest **CS23 amendment 5** , standard specification for loads and design conditions are transferred in the ASTM F3116-15.
- Shall the CS be not adequate, the certification basis will be complemented with special condition CRI's for further guidance.



2-Loads process definition

Loads analysis are performed throughout the aircraft design process.

There are at least 4 phases for which loads analysis are performed:



The level of detail will be different for each phase of the design process and will highly depends on available data. More than one load loop can be necessary.

2-Loads process definition

Loads Criteria in Conceptual/Preliminary Design

- Baseline Design Requirements
  Such as
  - Design Gross Weights and Center of Gravity
  - Design Speeds and Mach Number
  - Maximum Operating Altitude
- Regulatory and Company Policy Requirements
  Such as:
  - Design Load Factors
  - Types of Maneuvers
  - Gust and Turbulence Velocities
  - Landing Conditions
  - Ground Handling & Taxi Requirements

Preliminary Design to Detail Design

- Configuration Geometry
  - wing span, area, taper ratio, airfoil section, location
  - fuselage length, diameter
  - empennage span, area, taper ratio, airfoil section, location
  - landing gear location, length
  - control surface areas, planforms, locations
- Weights and Performance data
  - maximum ramp, takeoff, landing, zero fuel and total structural weights
  - fuel capacity, tank locations
  - payload range curve
  - cruise speed, maximum speed, approach speed
  - thrust
  - preliminary aerodynamic data estimates (theoretical)
- Preliminary component weights break-down and stiffness data
  - wing, fuselage, empennage, propulsion system and landing gear component weights
  - structural, control surface, and systems weights for each component
  - engine, nacelle and mounting weights
- Preliminary structural arrangement
  - wing and empennage spar(s) or torsion box
  - fuselage structure with wing and empennage carry-through structure and location
  - nacelle and landing gear support structure

Detail Design

- At this phase, the aircraft geometry is frozen.
- Mass properties and distributions are further defined to present a production aircraft.
- Aerodynamic wind tunnel data for the final configurations are available.
- Gear reactions obtained from gear drop tests are available.
- Stiffness data are further refined.
- Control surface hinge moment coefficients and control systems characteristics are further refined.
- Loads provided at this phase are the "Design to" loads.

Flight test and certification

NB: Customer requirement can generate new iteration at each step

2-Loads process definition

Flight test

- At this phase, the aircraft is used in flight testing.
- Stall speeds are defined by flight test
- Control surface hinge moments are measured in flight and compared to the ones obtained in wind tunnel
- Ground Vibration test(GVT) on the airplane to validate the structural dynamic and stiffness data of the loads model are complete.

Reduction of loads Vs Design loads

or

Re-design for Weight saving

Conservative loads for future growth (i.e weight increase, cg envelope expansion)

Certification loads

Increase in loads Vs Design loads

Re-design

or

Limitations
(flight envelope…)

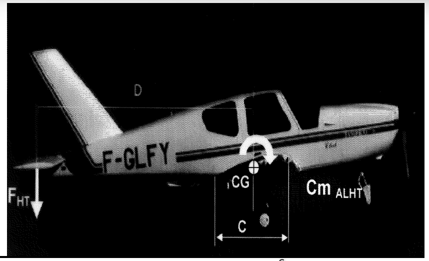
Flight load measurements are not always performed.

Design loads used for certification without flight correlation are often questioned.

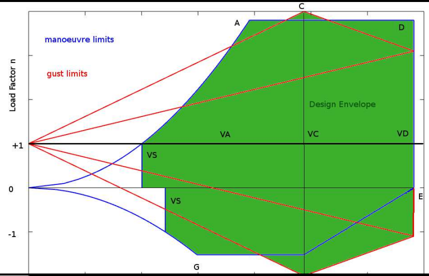
3-Flight loads:V-n Diagram

Detailed guidance in the requirement

- 23.321 : General
- 23.331 : Symmetrical flight conditions



- 23.333 : Flight envelope
- Note: only address symmetrical loads conditions



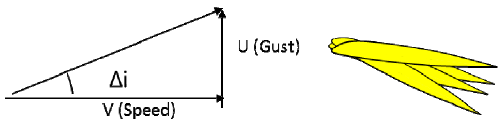
- 23.335 : Design Airspeed

Aircraft	Cessna 172	Cirrus SR22	Mudry CAP10B	Extra300	Skylander	Pilatus PC12
Category	Normal	Normal	Aerobatic	Aerobatic	Commuter	Normal
W [Lbs]	2449	3400	1168	1914	19069	9039
S [ft²]	174	135	116.7	112	461	280
W/S Lbs/ft²]]	14	25.2	10.	17	41.3	32.3

- 23.337 : Limit manoeuvring load factors

Category	Normal	Utility	Aerobatic	Commuter
Positive Load factor	3.8	4.4	6	3.8
Negative load factor	-1.5	-1.8	-3	-1.5

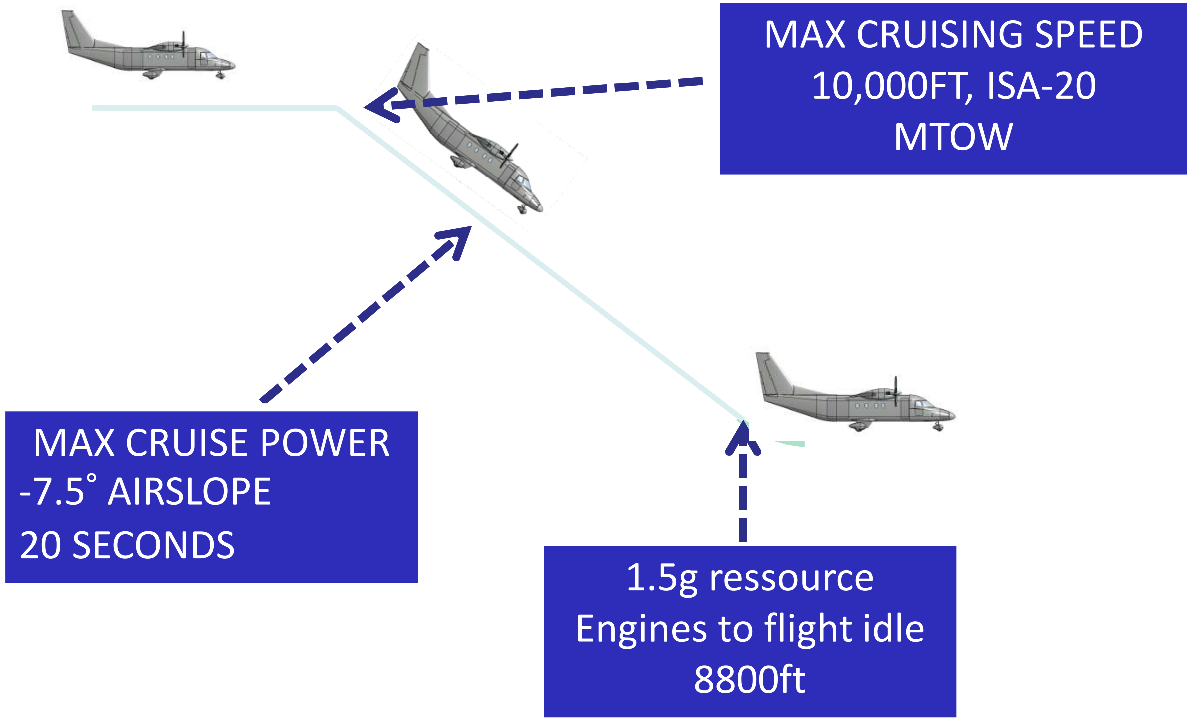
- 23.341 : Gust load factor



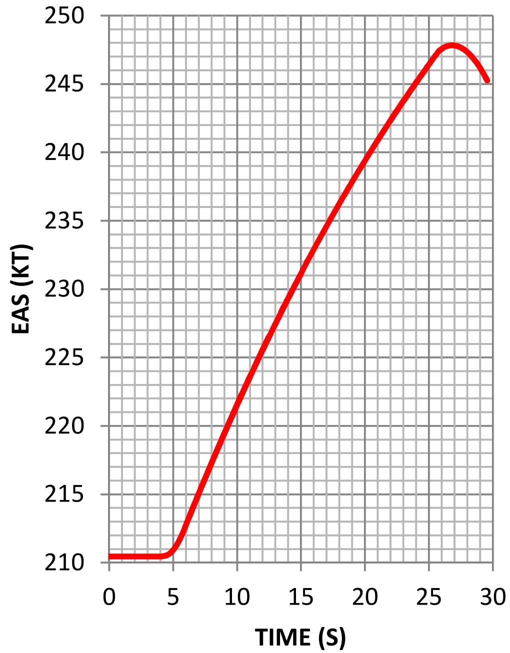
	VC	VC	VD	VD	VB	VB
Gust velocity	50ftps	25ftps	25 fps	12.5 fps	66fps	38 fps
Altitude	sea level and 6096 m (20000 ft).	at 15240 m (50 000 ft);	sea level and 6096 m (20 000 ft).	at 6096 m (20 000 ft)	sea level and 6096 m (20 000 ft).	at 15240 m (50 000 ft).
Linear Gust velocity reduction btw 20000 and 5000 ft						

3-Flight loads: V-n Diagram

VC and VD (1,25VC §335 b(1)) are often defined by analysis but margin between VC and VD can be derived by flight test or simulation* to increase VC.



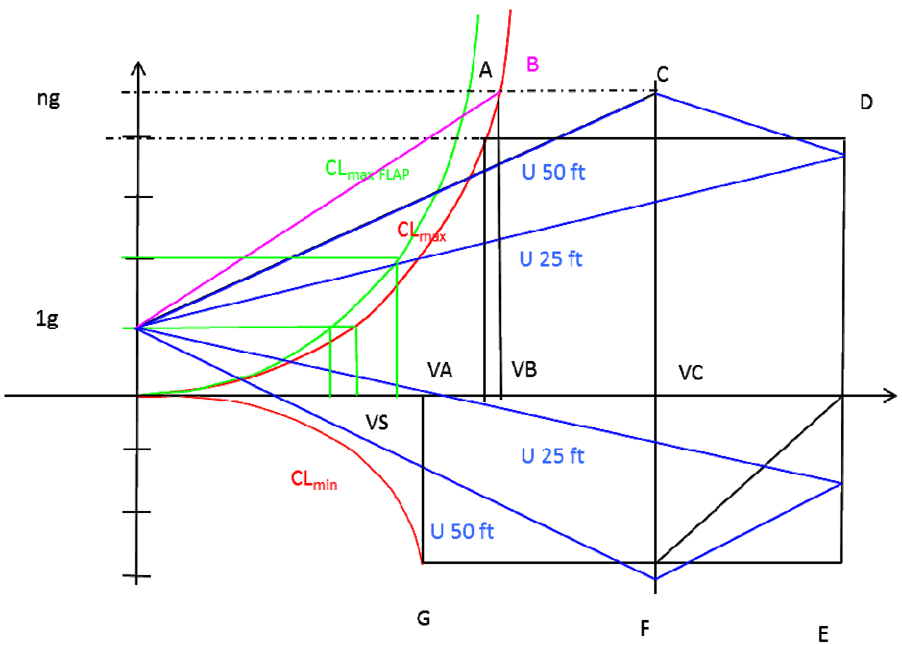
Evolution of EAS – VD calculation

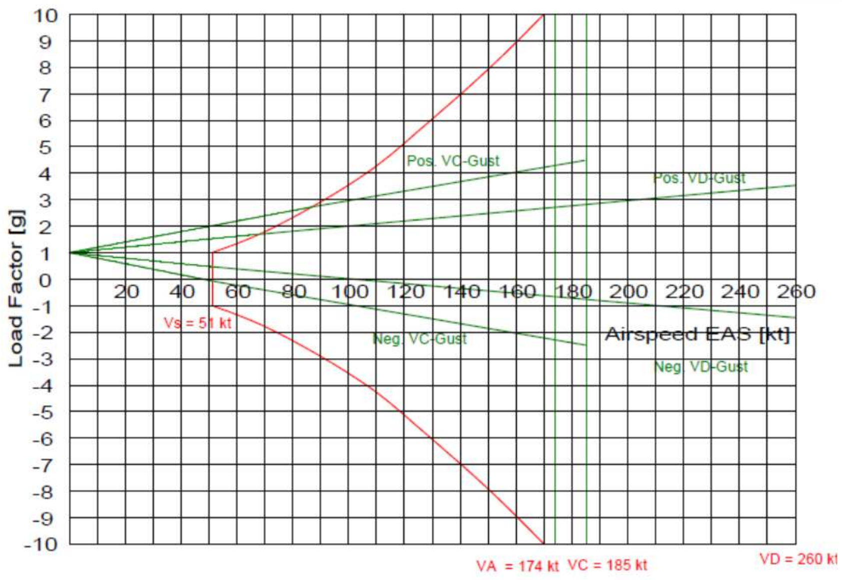


*to be discussed

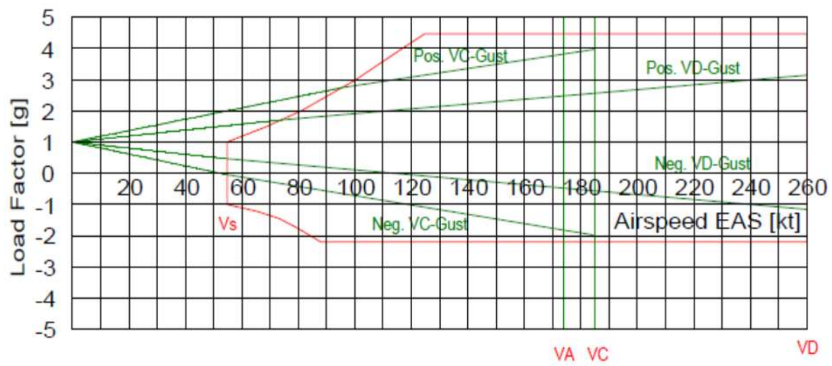
3-Flight loads:V-n Diagram

Symmetrical gust and manoeuver





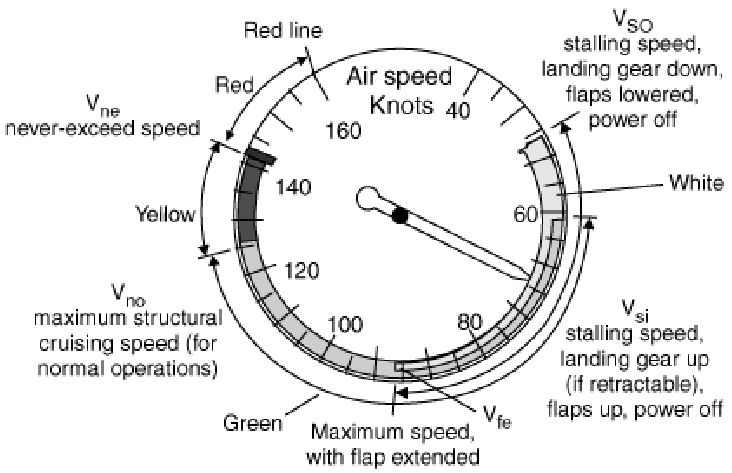
v-n-Diagramm
Category Aerobatic (MTOW = 850 kg)



v-n-Diagramm
Category Utility (MTOW = 999 kg)

3-Flight loads:V-n Diagram– Airspeed

Airspeed indicator (CS 23.1545) provide a direct reading of V-n diagram **.....**



Except VB and VA. This latest is reported in the flight manual:

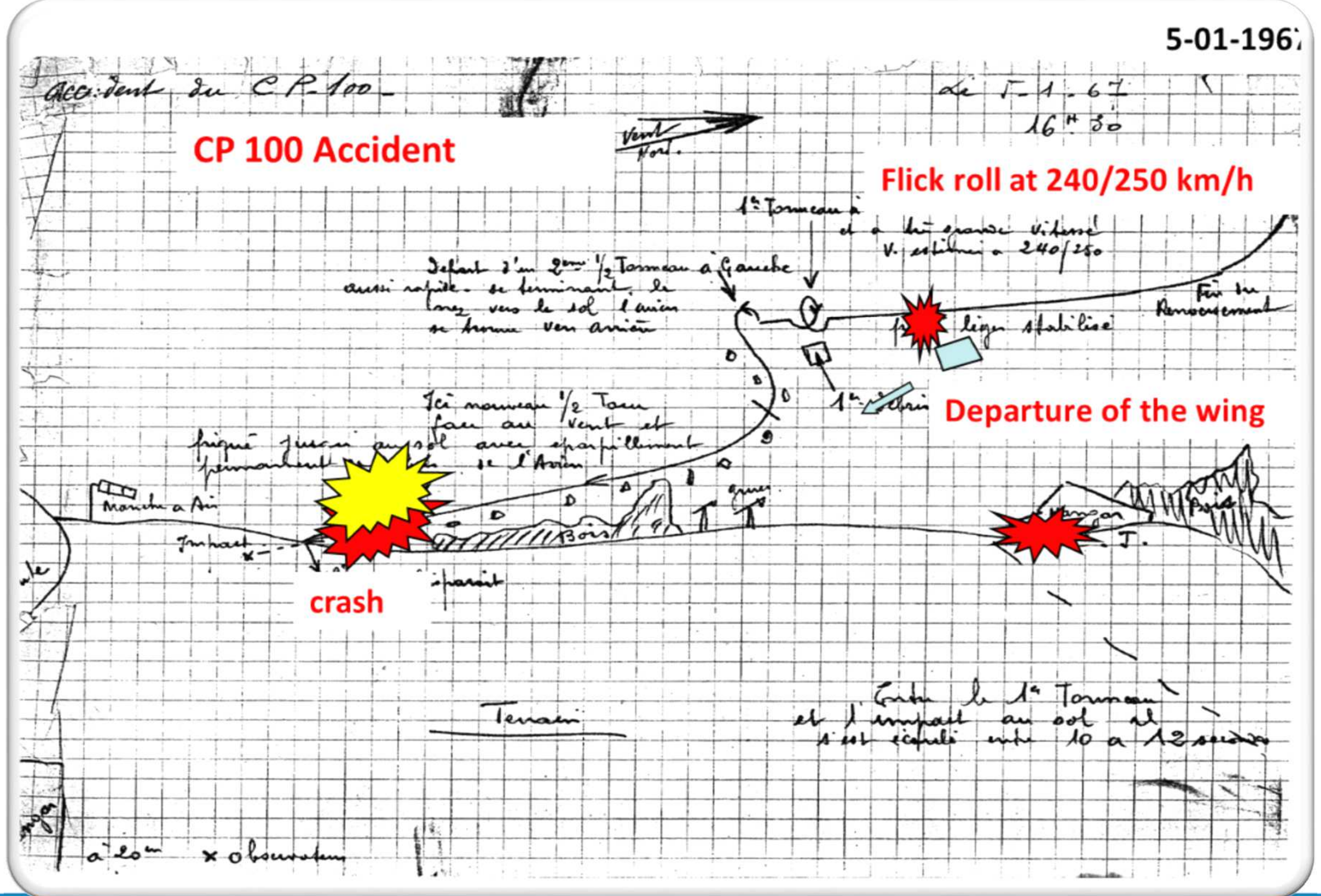
	SPEED	KIAS	REMARKS
V_{MO}	Maximum Operating Speed	175	Do not exceed this speed in any operation.
V_A	Maneuvering Speed 8360 Pounds 8000 Pounds 6300 Pounds 4600 Pounds	 153 150 134 115	Do note make full or abrupt control movements above this speed.
V_{FE}	Maximum Flap Extended Speed: 0° - 10° 10° - 20° 20° - 30°	 170 145 120	Do not exceed these speeds with the given flap settings
	Maximum Window Open Speed	175	Do not exceed this speed with window open.

Figure 2-1. Airspeed Limitations

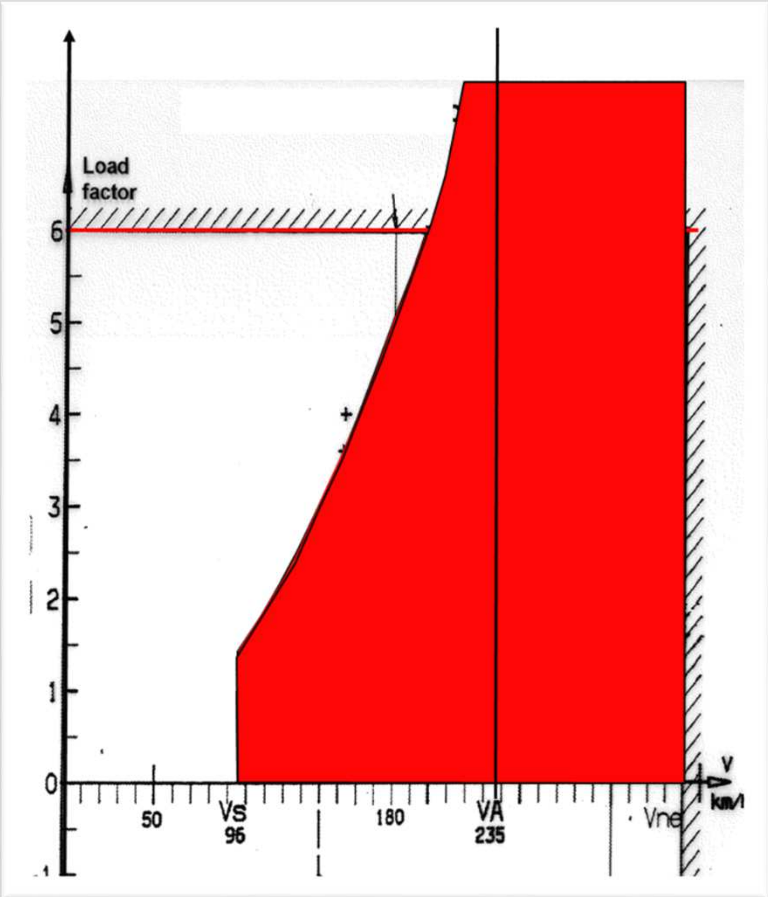
….. but in some cases it did not prevent accident….

3-Flight loads:V-n Diagram
Accident due to V-n Diagram exceedance

- CP100 Accident 05/01/1967

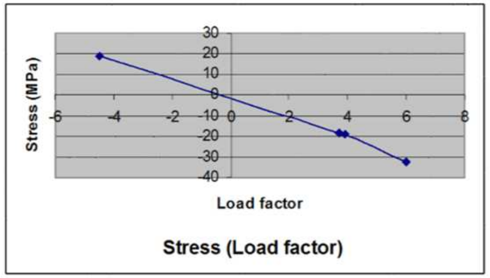


3-Flight loads: V-n Diagram
Accident due to V-n Diagram exceedance



strength/stress in wing structure increase directly with the load factor

Manoeuvre	loop	loop	Pull-up	Pull-down
Load factor	3.7	3.9	6	-4.5
Stress σ (MPa)	-18.6	-18.9	-32.5	19

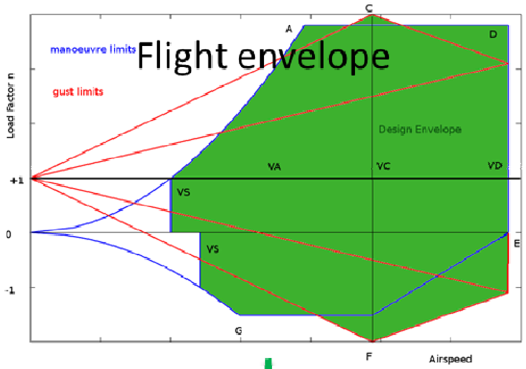


Speed (km/h)	235	240	250
Load factor	6	6.2	6.8
Load factor factor $CL_{DYNAMIC} = 1.25\ CL_{MAX}$	7.5	7.75	8.5

CS 23.301 Loads

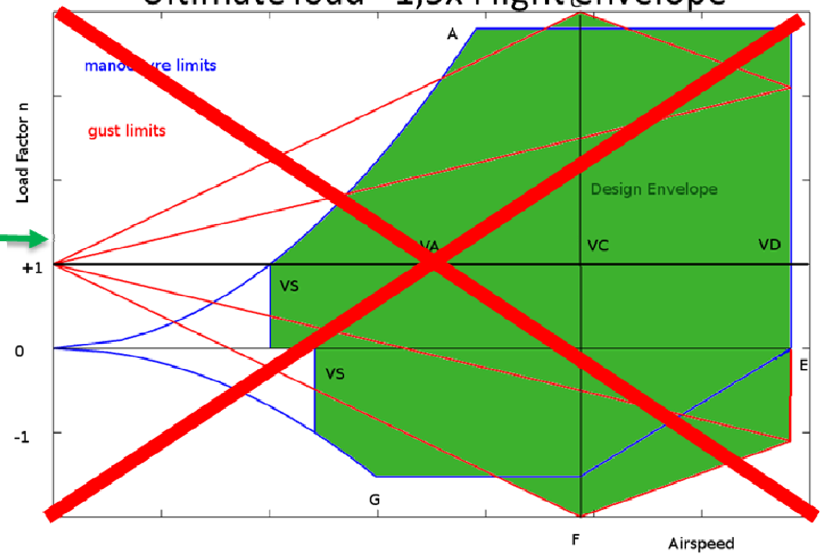
(a) Strength requirements are specified in terms of limit loads (the maximum loads to be expected in service) and ultimate loads.

Loads envelop are derived from flight envelop for any altitude and weight distribution (including fuel).



X1,5

~~Ultimate load= 1,5x Flight envelope~~



Limit Loads

Ultimate loads=1,5xLimit Loads

3-Flight loads:V-n Diagram-Conclusion and lesson learnt

- Margin between VC and VD should prevents VNE exceedance.

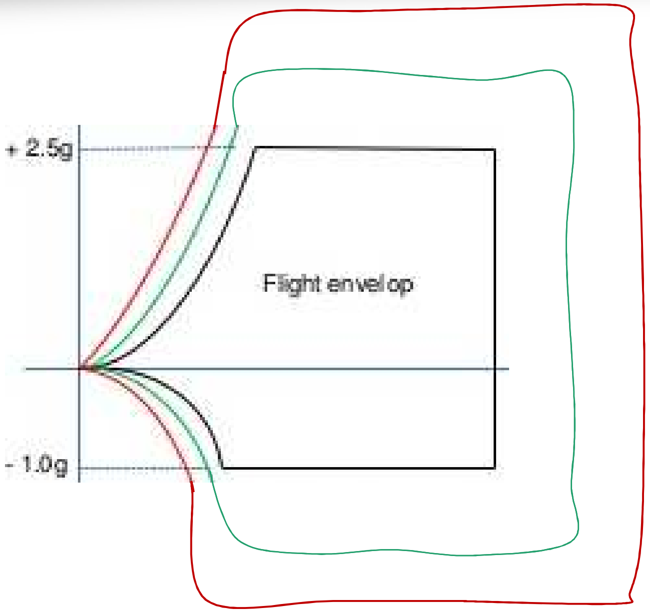
- The stall curve is a «natural » protection against g exceedance however this ”1-g static” derived limit can be exceeded in dynamic manœuvres.

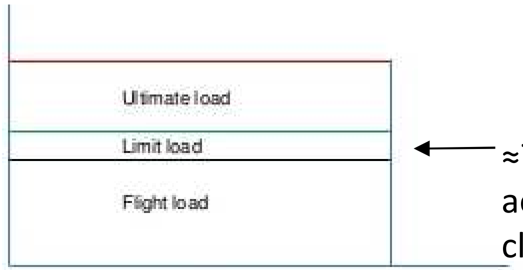
- The load factor can be exceeded in case of full displacement of the control surface (above VA).

- Load factor and weight are a key parameter for the determination of the loads and stresses.

- For Aerobatic aircraft, flight measurements **must** be performed to investigate dynamic manoeuvres such as flick rolls.

4-Fatigue Loads and spectrum





≈70%LL: Fatigue loads but aerobatic aircrafts operate close to LL

Main challenge for aircrafts certified for more than one category (e.g Normal, Utility and aerobatic):

- Limit loads determination,
- A conservative fatigue spectrum definition:
  - A. 1 Envelop spectrum covering all the usage (penalizing) or
  - B. 1 combined usage spectrum X% Normal, Y% Utility, Z% Aerobatic*

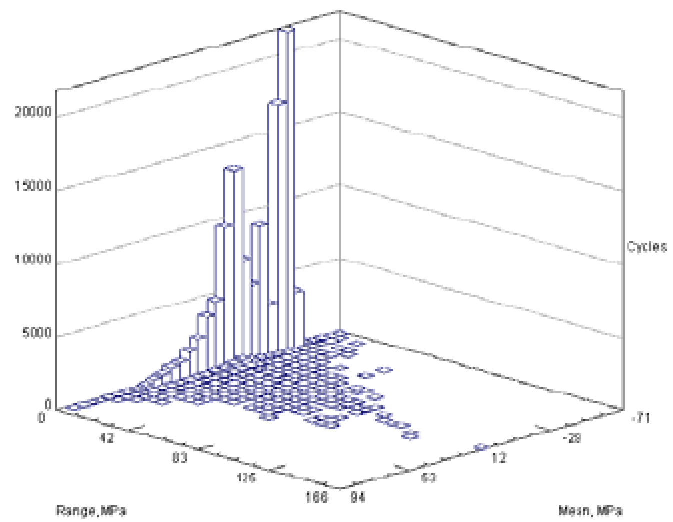
*Request close usage monitoring.

4-Fatigue Loads and spectrum Conclusion and summary

Definition of limit loads and fatigue spectrum can be a challenge particularly for aircraft operating in several categories.

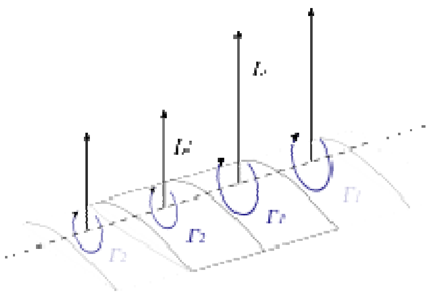
Closer usage monitoring will be requested to ensure no exceedance of fatigue limits.

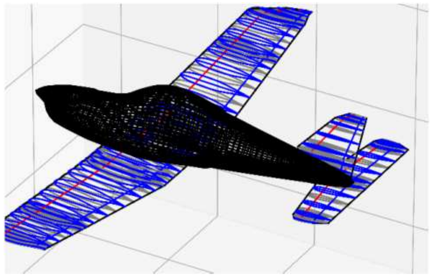
Minimum margin between fatigue loads and limit loads will have to be ensure , also for aerobatic aircrafts.



5-Methods for loads calculation

1. Simplistic methods (Lifting line theory)
2. Appendix A
3. Commercial software 3D

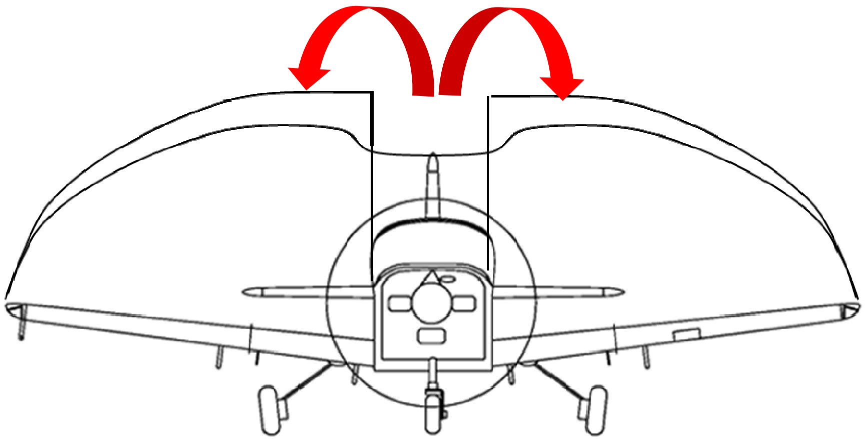




5-Air loads-Simplistic methods- lifting line theory

Load distribution at the wing to fuselage intersection….

In the absence of other method, the loads on the fuselage can conservatively redistributed to the wing when using the lifting line theory for wing



In addition simplistic methods request equilibrium with inertia masses and the complete aircraft (iterative process);

5-Simplified methods- Appendix A

CS 23.301 Loads

(d) Simplified structural design criteria may be used if they result in design loads not less than those prescribed in CS 23.331 to 23.521. For aeroplanes described in appendix A, paragraph A23.1.

Deleted in CS23 amdt 5 and moved to AMC.

- For aeroplanes described in appendix A,§ A23.1, the design criteria of Appendix A of CS-23
- are an approved equivalent of CS 23.321 to 23.459.

Simplified Design Load Criteria for Conventional, Single Engine Airplanes of 2722 kg (6000 Pounds) or Less Maximum Weight.

(1) A single engine excluding turbine powerplants;

(2) A main wing located closer to the aeroplane's centre of gravity than to the aft, fuselage-mounted, empennage;

(3) A main wing that contains a quarterchord sweep angle of not more than 15 degrees fore or aft;

(4) A main wing that is equipped with trailing-edge controls (ailerons or flaps, or both);

(5) A main wing aspect ratio not greater than 7; (b^2/S)

(6) A horizontal tail aspect ratio not greater than 4;

(7) A horizontal tail volume coefficient not less than 0.34;

(8) A vertical tail aspect ratio not greater than 2;

(9) A vertical tail platform area not greater than 10 percent of the wing platform area; and

(10) Symmetrical airfoils must be used in both the horizontal and vertical tail designs.

(b) Appendix A criteria may not be used on any aeroplane configuration that contains any of the following design features:-

(1) Canard, tandem-wing, close coupled, or tailless arrangements of the lifting surfaces;

(2) Biplane or multiplane wing arrangements;

(3) T-tail, V-tail, or cruciform-tail (+) arrangements;

(4) Highly-swept wing platform (more than 15-degrees of sweep at the quarter-chord), delta planforms, or slatted lifting surfaces; or

(5) Winglets or other wing tip devices, or outboard fins.

Low aspect ratio wing (AR=5.6) of a

Piper PA-28 Cherokee

Very restrictive!!

5-Simplified methods- Appendix A

Reminder !!!

CS23.301-Loads (d): If Appendix A is used, **the entire Appendix** must be substituted for the corresponding paragraphs of this CS-23.
Use of Appendix A to define aerodynamic loads distribution only on control surfaces is in principle not accepted.

Accepted deviation to Appendix A:

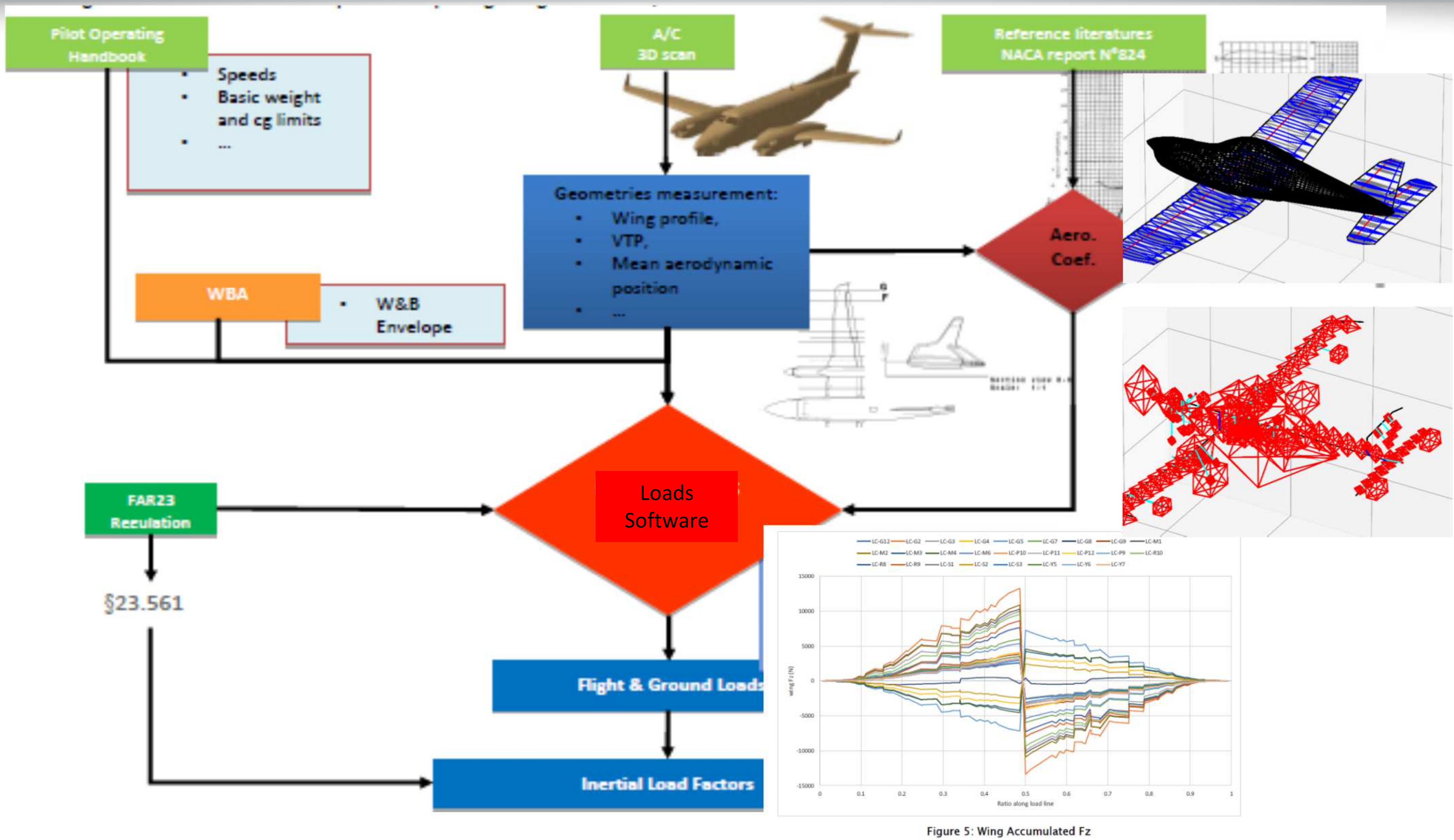
1. The model A has a wing aspect ratio of 9.14. The model B has a wing aspect ratio of 10., exceeding the JAR23 Appendix A23.1(a) maximum limitation of 7.
2. The model A and B have a horizontal tail aspect ratio of 6.64, exceeding the JAR 23 Appendix A23.1(a) maximum limitation of 4.

5-Simplified methods- Appendix A

Rational for deviations acceptance:

The primary purpose of the Appendix A simplified loads was to provide configuration limitations to certain aspect ratios for the wing and stabilizer to ensure that the gust load factor does not exceed the 3.8g normal category limit manoeuvre load. The aspect ratios for the model B do not result in unconservative gust load factors by using Appendix A methods. The selected cruise and dive speeds ensure that the gust load factor as calculated per FAR 23.341 (b) is less than the selected manoeuvre load of 3.8g as defined in Appendix A. Therefore use of Appendix A is conservative.

5-Commercial software 3D



5-Sofware with extended loads computation

- Flight envelope data (V-n diagrams), taking into account for wing loads, balancing horizontal tail loads, load factors, drag loads, angle of attack, speeds, Mach numbers, pitching moment of wing + fuselage, lift coefficient for exact load case defined.
- Selection of critical flight load cases for wings, vertical tail horizontal tail and fuselage.
- Landing loads and landing load factors taking into account for nose and main gear drag, side loads, airplane linear inertia factors and unbalanced angular moments.
- Engine mounts and failure loads

5-Software verification & validation vs correlation

Software are usually used to support certification process…

BUT

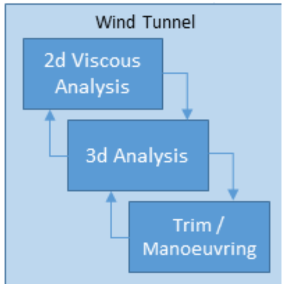
….the certification process do not "certify" the software.

Software verification and validation (V&V) process allow to support sales.

To support certification process, loads analysis outcome have to be…

…. Verified (speed, angle of attack, attitude of the aircraft…) and/or

…. Correlated



Flight test

- At this phase, the aircraft is used in flight testing.
- Stall speeds are defined by flight test
- Control surface hinge moments are measured in flight and compared to the ones obtained in wind tunnel
- Ground Vibration test(GVT) on the airplane to validate the structural dynamic and stiffness data of the loads model are complete.

6-Example of software issue

An applicant in house loads program has been used successfully for decades to predict the loads of previous turboprop models.
The same program was used to predict the Design Loads of the latest twin-engine business jet and did not work as expected.
AN independent aircraft load analysis was outsourced and have confirmed the issue and software limits.

A new loads program was purchased with
–More sophisticated aerodynamic solver
–Provides capability for transonic analysis
–Can be used for Loads and Flutter
–Can be used for loads on elastic structures

Identified increased positive wing bending moment due to suction of the Belly fairing (increased fuselage effect) and decreased negative wing bending moment.
As a consequence, the wing has been completely redesigned. Additional test correlation has been considered necessary.

6-Loads calculation methods- Conclusion & lesson learnt

All proposed methods from the simplest to the more complex are proposed by Industry and reviewed by EASA.
The CS23 offer the alternative to use appendix A (also in amendment 5). Deviation will be justified in a CRI.

While some applicants develop their own loads tool, independent software companies offering computer aided engineering approach for loads calculation are growing.

EASA expect to have loads correlation/validation of the aircraft.
Any configuration change before TC will request revision of the loads set.
For STC holders loads set are not available and reverse engineering is often the only alternative (for small changes). Not valid for more complex changes.

7-High performance Aircrafts

- Additional conditions for high performance aircrafts will be addressed in SC derived from CS25 requirement.

Key issues for loads:
turbine engines, high altitude, high speed, ground loads, interaction system and structure

	Eclipse EA500 (CS-23 N)	Cessna CJ4 (CS-23 C)	Cessna 560 Citation (Encore) (CS-25)
MTOW (lbs)	5.995	16.910	16.630
MOA (ft)	41.000	45.000	45.000
Vc/Mc	275 KEAS / 0.64	305 KCAS / 0.77	290 KCAS / 0.75

8-Summary and conclusion

- There are generally no major issues with loads determination but some lessons can be learnt from past and more recent service experience to improve compliance demonstration.
- The CS23 amendment 5 will not drastically change loads requirement but guidance for loads and design will be moved into the ASTM F3116-15.
- Computer aided engineering approach for loads calculation is more widely used and EASA will request further validation (not limited to aerobatic aircrafts).
- Change of configuration during the development and certification process is a major issue which request to reassess loads.
- Challenge for loads determination remain a major concern when dealing with STC holders.

- More challenge for loads determination in the near future on new products with unusual operations (Vertical Take-Off and Landing).