



**EASA**  
European Aviation Safety Agency

# VTOL Special Condition

Laurent PINSARD  
EASA Senior Structures Expert

**Rotorcraft Structures Workshop**  
19-20 February 2019





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VTOL Special Condition

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### Rotorcraft

a heavier-than-air aircraft that depends principally for its support in flight on the lift generated by one or more rotors.

### Helicopter

A rotorcraft that, for its horizontal motion, depends principally on its engine-driven rotors.

➤ Autorotation



### VTOL Definition.

- Person-carrying Vertical Take-Off and Landing (VTOL) aircraft in the small category, with lift/thrust units used to generate powered lift and control
  - Distributed lift/thrust units are used (multiple lift units >2 for VTO&L)

Note. these aircraft may not be able to perform an autorotation or a controlled glide in the event of a loss of lift/thrust.





# Applicable Requirement

## Rotorcraft

- CS VLR Very light
- CS 27 Small rotorcraft
- CS29 Large rotorcraft

## Aircraft

- CS VLA Very Light Aircraft
- CS 23 Small aircraft pre Amdt 5
- CS 23 Small aircraft Post Amdt 5
- CS 25 Large Aircraft






# CS 23 Amdt 5 Reorganisation History



Experimental  
and  
light sport  
aircraft.

2011 charter for the Part 23 Reorganisation :

- Reorganize part 23 based on performance and complexity (objectives)



PART 23  
Certified  
airplane

- Revised Criteria for PART/CS 23
  - Complexity & Performance



## CS 23 Amdt 5 Reorganisation History

FAR /CS 23 have been reorganised to provide requirements that:

1. Bring safe designs for aeroplanes
2. Support innovation
3. are “sized” with risks
4. can follow technical developments
5. lower administrative burden





## How ?

CS-VLA Amdt 1

CS-23 Amdt 4



CS-23 Amdt 5  
Objective rules &  
Safety level definitions



**AMC**

Ref to CS-23 Amdt 4

Ref to CS-VLA Amdt 1

Ref to **ASTM F44 Standards**

### Aeroplane certification levels

- Level 1 — for aeroplanes with a maximum seating configuration of 0 to 1 passengers.
- Level 2 — for aeroplanes with a maximum seating configuration of 2 to 6 passengers.
- Level 3 — for aeroplanes with a maximum seating configuration of 7 to 9 passengers.
- Level 4 — for aeroplanes with a maximum seating configuration of 10 to 19 passengers.



## Examples

**Pre Amdt 5 CS23.307 Proof of structure**



**CS 23 Post Amdt 5**

**CS 23 Amdt 5**

**None**



**ASTM 3114-15**

**4.4 Proof of Structure:**



## Examples

### **CS 23 Pre Amdt 5**

23.373 Speed control devices

23.391 Control surface loads

23.395 Control system Loads

23.399 Limit control forces and torques

23.405 Secondary control system

23.407 Trim tab effects

23.409 Tabs

23.415 Ground gust conditions

**CS 23 post Amdt 5**  
**CS23.2225 Component**  
**loading conditions**



# Examples

**Pre Amdt 5 CS23.333, 335, 341**

**CS 23.2215** Critical flight loads are established for symmetrical and symmetrical loading from all combinations of airspeeds and load factors at and within the boundaries of the manoeuvre and gust envelope...

+

## **ASTM 3116-15**

4.4	Flight Envelope:
4.4.3	Gust Envelope:
4.6	Gust Load Factors:



## Examples

**Pre Amdt 5 CS 23. 561, 562, 787...**

### **Post Amdt 5**

#### **CS 23.2270 Emergency conditions**

(a) The aeroplane, even when damaged in an emergency landing, must protect each occupant against injury that would preclude egress when

(a) .....



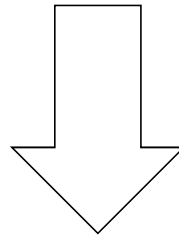
#### **ASTM 3116-15**

Standard Specification for  
Emergency Conditions,  
Occupant Safety and  
Accommodations



## VTOL Conditions?

- Design novelties
- Performances based requirement



CS 23 Post Amdt 5 Format



## Special Condition - VTOL

- Organisation of recent CS-23 Amdt. 5
- Safety Objectives well segregated from the Acceptable Means of Compliance
- Performance/objective based

Safety Objectives



Acceptable  
Means of  
Compliance



# Special Condition - VTOL

## PREAMBLE

### SUBPART A — GENERAL

- CS **23.2000** Applicability and definitions
- CS**23.2005** Certification of **normal-category** aeroplane
- CS**23.2010** Accepted means of compliance

### SUBPART B — FLIGHT

- CS **23.2100** Mass and centre of gravity
- CS **23.2105** Performance data



## PREAMBLE

### SUBPART A — GENERAL

- **VTOL.2000** Applicability and definitions
- **VTOL.2005** Certification of **small-category VTOL** aircraft
- **VTOL.2010** Accepted means of compliance

### SUBPART B — FLIGHT

- **VTOL.2100** Mass and centre of gravity
- **VTOL.2105** Performance data





# Special Condition - VTOL

## VTOL.2000 Applicability and definitions

### **Applicability.**

- Person-carrying VTOL aircraft in the small category, with lift/thrust units used to generate powered lift and control (VTOL definition)
- Not pressurized.
- Pilot on-board, remotely piloted or with various degrees of autonomy

### **Definition**

- 'Continued safe flight and landing' capable of continued controlled flight and landing at a "vertiport", possibly using emergency procedures.
- 'Congested area' area for residential, commercial or recreational purposes;
- 'Commercial air transport' means an aircraft operation to transport passengers, cargo or mail for remuneration



## Special Condition - VTOL

# VTOL.2005 Certification of small-category VTOL aircraft

### Small category

- passenger of 9 or less
- Maximum Take-Off Mass of 7000 Lbs or less.

### Category Enhanced:

Capable of continued safe flight and landing after “*critical malfunction*” of thrust/lift. Requested for operations over congested areas or for Commercial Air Transport operations of passengers

**Category Basic:** the aircraft is capable of a controlled emergency landing after critical malfunction of thrust/lift.



## Special Condition - VTOL

### VTOL.2010 Accepted Means of Compliance

**Acceptable Means of Compliance (AMC)** issued by EASA, or another means of compliance which may include consensus standards, when specifically accepted by EASA at project level.

An applicant requesting EASA to accept a Means of Compliance must provide the means of compliance to EASA in an acceptable form and manner.

**ASTM**



## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2200 Structural design envelope

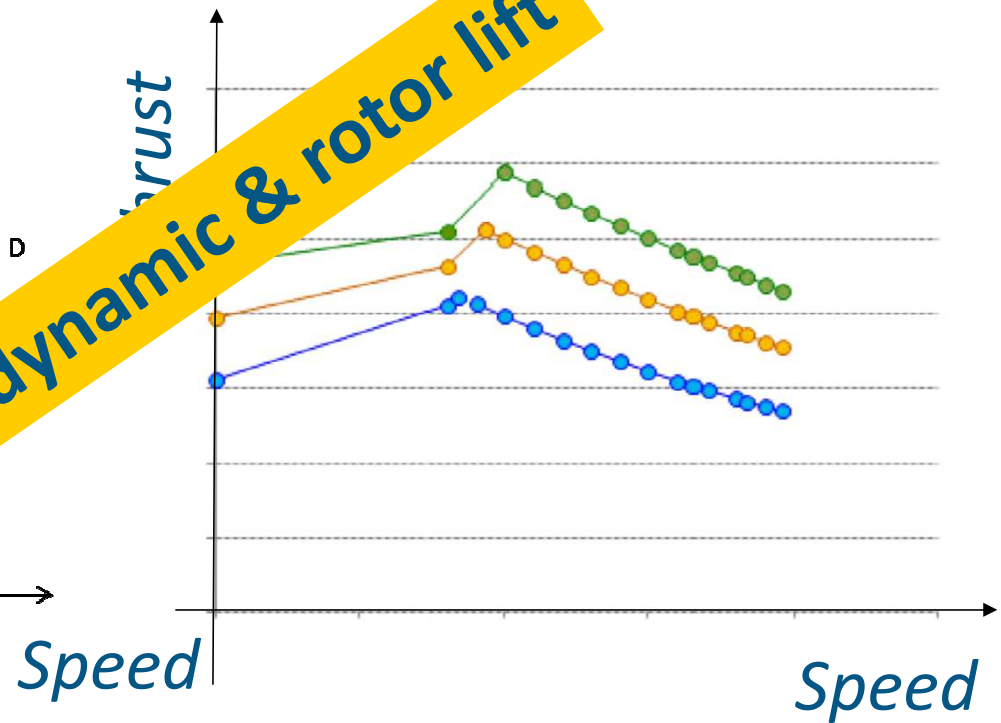
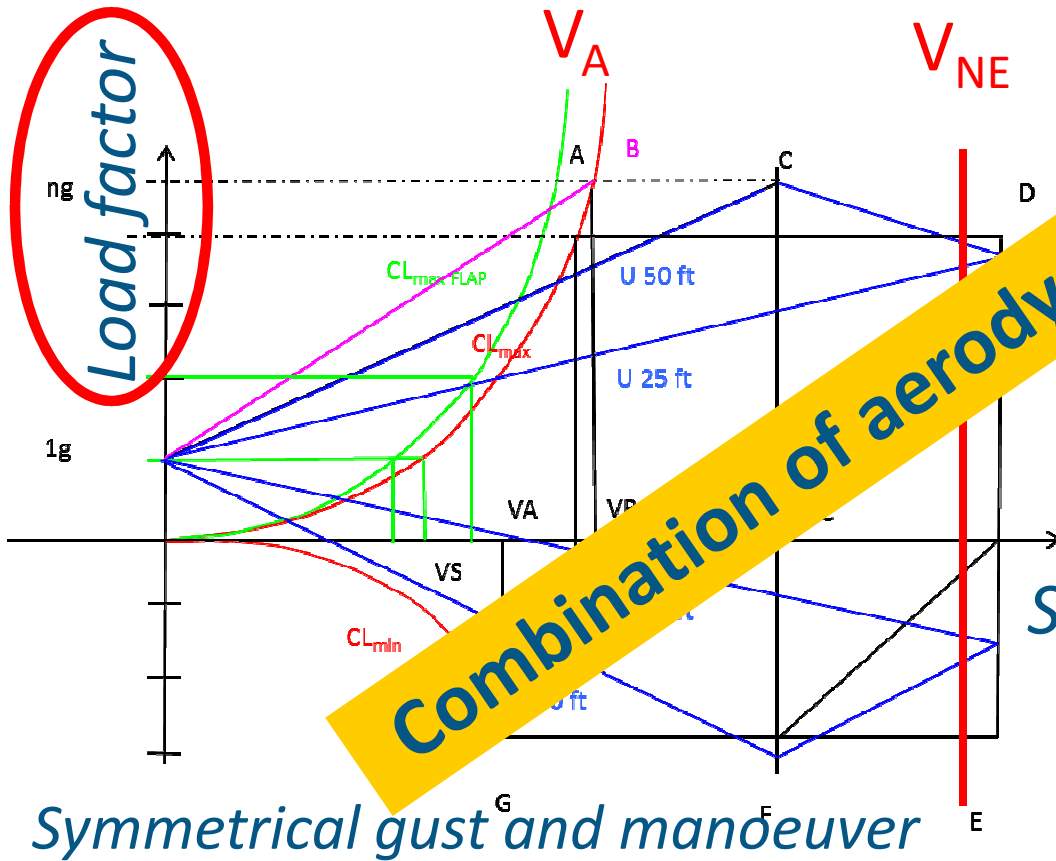
- Compliance within the range & limits of aircraft design and operational parameters.
- structural loads, strength, durability, and aeroelasticity,
- For manoeuvring flight:
  - Lift generated by the aircraft to safeguard against loss of control in turbulent air, and stalling speed of the aircraft;
  - provide sufficient margin for the establishment of practical flight envelopes.
- flight load conditions, mass variations and distributions, loads in response to all designed control inputs; and
- redistribution of loads if deflections

**No load factor defined**



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2200 Structural design envelope





## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2200 Structural design envelope

#### CS 29.337 Limit manoeuvring load factor

The rotorcraft must be designed for

- (a) A limit manoeuvring load factor ranging from a **positive limit of 3.5 to a negative limit of -1.0**; or
- (b) Any positive limit manoeuvring load factor **not less than 2.0** and any negative limit manoeuvring load factor of not less than  $-0.5$  for which:
  - (1) The probability of being exceeded is shown by analysis and flight tests to be extremely remote...



## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2200 Structural design envelope

#### CS 23.337 Limit manoeuvring load factors

(a) The positive limit manoeuvring load factor  $n$  may not be less than

(1)  $2 \cdot 1 + \frac{24000}{W + 10000}$  for normal and commuter category aeroplanes except that  $n$  need not be more than 3.8;

(2) 4.4 for utility category aeroplanes; or

(3) 6.0 for aerobatic category aeroplanes.



## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2205 Interaction of systems and structures

Systems that affect structural performance, either directly or as a result of failure or malfunction, the applicant must account for the influence and failure conditions of these systems when showing compliance with the requirements of this Subpart.

- Initially developed for loads alleviation function/system
- addressed already for yawing condition CS29.351





## Special Condition – VTOL SUBPART C -STRUCTURES VTOL.22XX loads

- **VTOL.2210 structural design loads (general)**
- **VTOL.2215 Flight loads conditions**
- **VTOL.2220 Ground loads conditions**
- **VTOL.2225 Components loading conditions**



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2210 Structural design loads

### Structural design loads (general)


(a)(1) flight, ground and water operations, ground- and water-handling, and while the aircraft is parked or moored

(a)(2). determine the loads at all critical combinations of parameters, on and within the boundaries of the structural design envelope



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2210 Structural design loads

**Loads requirement not detailed in the SC-VTOL**  
 **transferred to AMC**

**CS 29.341 Gust loads**

**CS 29.351 Yawing conditions**

**CS 29.361 Engine torque**

**CS 29.397 Limit pilot forces and torques**

**CS 29.427 Unsymmetrical loads**

**CS 29.473 Ground loading conditions and assumptions**



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2215 Flight load conditions

**Critical loads** from all combinations of flight parameters and load factors at and within the boundaries of the manoeuvre and gust envelope:

- symmetrical and asymmetrical loading
- altitude
- Max mass

### **Vibration and buffeting**

- up to dive speed
- within the limit flight envelope



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2235 Structural strength

The structure must support

- limit loads without:
  - interference with the safe operation of the aircraft and
  - detrimental permanent deformation.
- ultimate loads.

### **CS 29.305 Strength and deformation**

(a) The structure must be able to support limit loads without detrimental or permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure. This must be shown by:

(1) Applying ultimate loads to the structure in a static test for at least 3 seconds; or



## Special Condition – VTOL SUBPART C -STRUCTURES VTOL.2225 Component loading conditions

### Loads requirement not detailed in the SC-VTOL

The applicant must determine the loads acting upon all relevant structural components, in response to:

- interaction of systems and structures.
- structural design loads.
- flight load conditions; and
- ground and water load conditions



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2235 Structural strength

The structure must support

- limit loads without:
  - interference with the safe operation of the aircraft and
  - detrimental permanent deformation.
- ultimate loads.

### **CS 29.305 Strength and deformation**

(a) The structure must be able to support limit loads without detrimental or permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure. This must be shown by:

(1) Applying ultimate loads to the structure in a static test for at least 3 seconds; or



## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2230 Limit and ultimate loads

#### CS 29.303 Factor of safety

Unless otherwise provided, a factor of safety of 1.5 must be used. This factor applies to external and inertia loads unless its application to the resulting internal stresses is more conservative

Unless special or other factors of safety are necessary to meet the requirements of this Subpart, the applicant must determine:

- the limit loads, which are equal to the structural design loads;
- the ultimate loads, which are equal to the limit loads multiplied by a **1.5 factor of safety**, unless otherwise provided.





# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2240 Structural Durability

### Fatigue vs Durability

implement inspections or other procedures to prevent structural failures due to foreseeable causes of strength degradation, which could result in serious or fatal injuries, or extended periods of operation with reduced safety margins

For **Enhanced Category**, the procedures developed for compliance with SC VTOL.2240(a) must be capable of detecting structural damage before the damage could result in structural failure.

**Enhanced Category : Damage Tolerance (threat assessment...)**



## Special Condition – VTOL SUBPART C -STRUCTURES CS 27/29.571 Fatigue tolerance evaluation

**CS 29.571(a)** A fatigue tolerance evaluation of each Principal Structural Element (PSE) must be performed, and appropriate inspections and retirement time or approved equivalent means must be established to avoid Catastrophic Failure

**catastrophic vs serious and fatal injuries and  
PSE not addressed in the SC VTOL**

### **CS 27.571**

- *Replacement time evaluation.*
- *Fail-safe evaluation*
- *Combination of replacement time and fail-safe evaluations*



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2240 Structural Durability

How to comply for basic VTOL?

- Fail-safe
- Damage tolerance
- Safe life
- Flaw tolerance safe life

### Applicability

- Metallic
- Composite



## Special Condition – VTOL VTOL.2625 Instructions for Continued Airworthiness

The applicant must prepare Instructions for Continued Airworthiness that are appropriate for the certification level and performance level of the aircraft.

### **CS 23-27-29.1529 Instructions for Continued Airworthiness**

Instructions for continued airworthiness in accordance with Appendix A to CS must be prepared



## Special Condition – VTOL SUBPART C -STRUCTURES VTOL.2240 Structural Durability

(e) For Category Enhanced, provisions for in-service monitoring of parts having an important bearing on safety in operations must be established.

CIVP (CM S-007) “Post Certification Actions to Verify the Continued Integrity of Safety Critical Parts”



## Special Condition – VTOL SUBPART C -STRUCTURES

### VTOL.2240 Structural Durability

(d) The aircraft must be designed to minimise hazards to the aircraft due to structural damage caused by high-energy fragments from an uncontained thrust/lift unit or rotating-machinery failure

VTOL.2250 (f) For Category Enhanced, the aircraft must be designed to assure capability of continued safe flight and landing after a likely bird impact.

*Damage-tolerance (**discrete source**) evaluation.*

CS The aeroplane must be capable of successfully completing a flight during which likely structural damage occurs as a result of  
(1) Bird impact...



## Special Condition – VTOL SUBPART C -STRUCTURES VTOL.2435 Thrust/lift installation support systems

Likely foreign object damage that would be hazardous to the thrust/lift unit must be prevented.

Threat assessment to be performed with structural consequence



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2250 Design and construction principles

For Category Enhanced, a single failure must not have a catastrophic effect upon the aircraft.

Criteria in addition to Durability

NO SINGLE STRUCTURE FAILURE CATASTROPHIC

HOW?

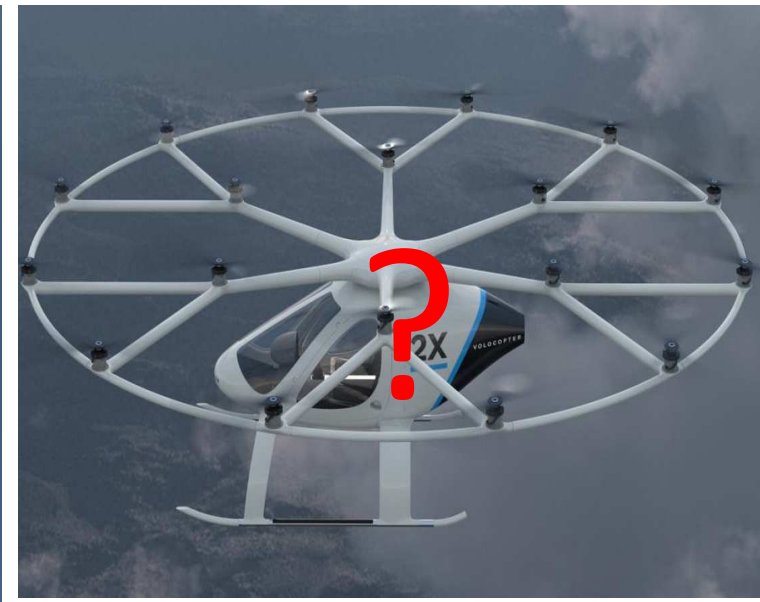
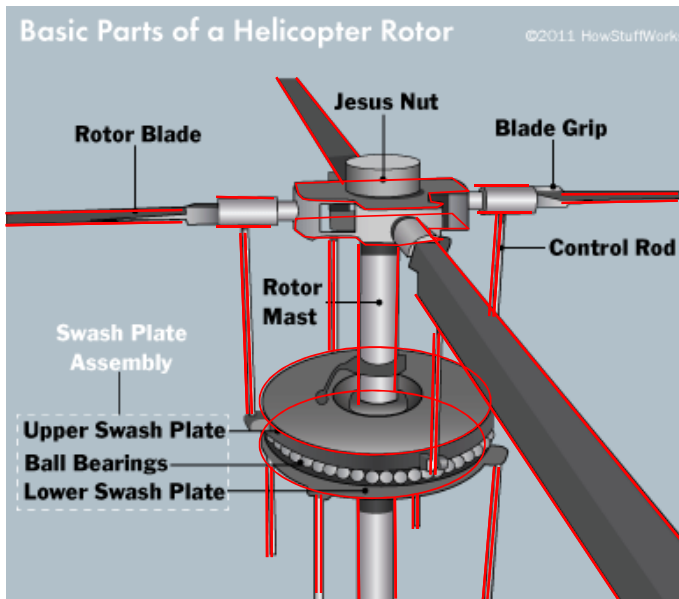
STRUCTURAL SLP Definition?





# Special Condition – VTOL SUBPART C -STRUCTURES VTOL.2250 Design and construction principles

NO SINGLE FAILURE CATASTROPHIC



HOW?

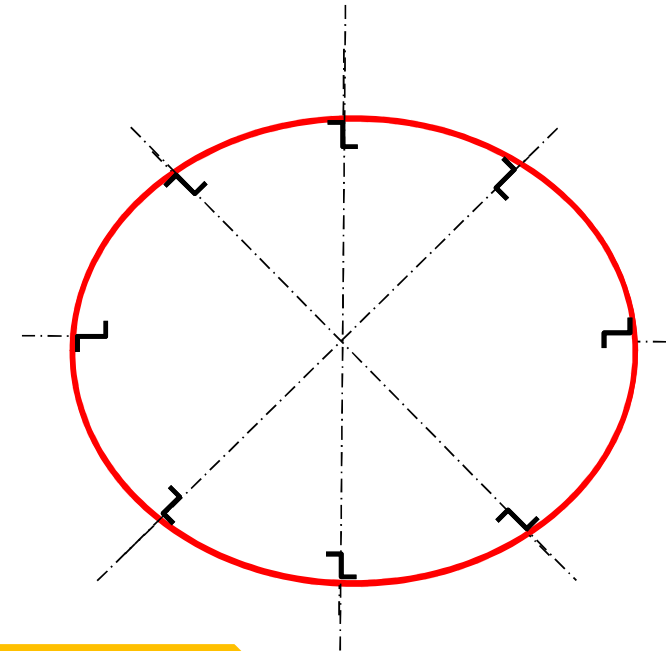
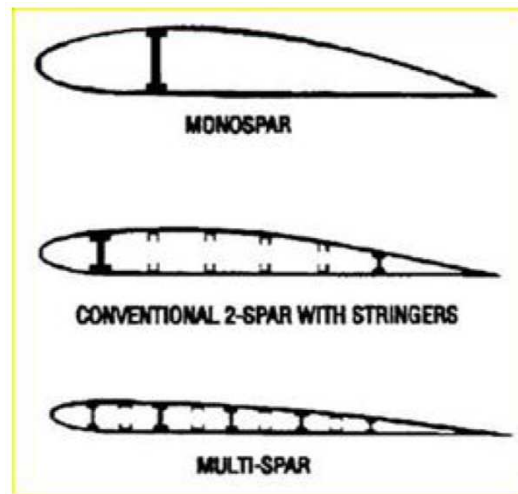
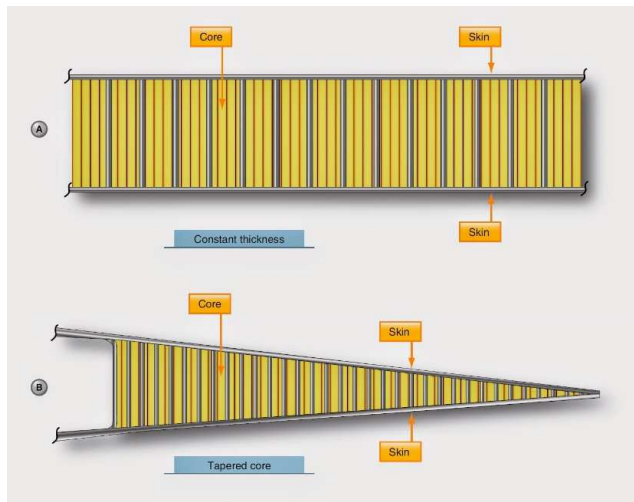
STRUCTURAL SLP FAILURE Definition?



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2250 Design and construction principles

NO SINGLE FAILURE CATASTROPHIC



SLP

MLP



# Special Condition – VTOL SUBPART C -STRUCTURES

## VTOL.2250 Design and construction principles

Composite intrinsically MLP ?

Sandwich structure MLP ?

Does MLP design prevent single structure failure catastrophic?

Failure Modes/ Scenario TBD



## Special Condition – VTOL VTOL.2245 Aeroelasticity

The aircraft must be free from flutter, control reversal, and divergence:

- 1) at all speeds within and sufficiently beyond the structural design envelope;
- 2) for any configuration and condition of operation;
- 3) accounting for critical degrees of freedom; and
- 4) accounting for any critical malfunctions or malfunctions.

The applicants' design must account for tolerances for all quantities that affect flutter.



## Special Condition – VTOL VTOL.2270 Emergency conditions

The emergency landing conditions specified in SC VTOL.2270(a) must:

- include dynamic conditions that are likely to occur in an emergency landing; and
- not generate loads experienced by the occupants, which exceed established human-injury criteria for human tolerance due to restraint or contact with objects in the aircraft.
- The aircraft must provide protection for all occupants, accounting for likely flight, ground, and emergency landing conditions.

CS 23/27/29.561-562 & 785 Emergency landing condition



## Special Condition – VTOL VTOL.2270 Emergency conditions

### CS XX.562 Emergency dynamic landing condition

Acceleration	Vertical	Horizontal
CS23	19/15g	26/21g
CS25	14g	16g
CS27	30 g.	18.4 g
CS29	30 g.	18.4 g



## Special Condition – VTOL Conclusion

CS 23 Amdt 5 organisation applicable to SC VTOL

- adapted to complex, new technology
- Means of Compliance to be developed

AMC to be developed



## Special Condition – VTOL Conclusion - Challenges

- Combined Flight envelopes (aero lift & lift units)
- Manoeuver (symmetrical/unsymmetrical) condition directly derived from flight control system & lift/thrust units law (instationnary conditions, flight / simulation multidisciplinary activities?)
- Interaction system and structure





## SC VTOL Conclusions-Challenges

- Durability
  - DT (fatigue tolerance evaluation) for Enhanced VTOL
  - Inspectability / Detectability
  - could result in serious or fatal injuries, or extended periods of operation with reduced safety margins (no PSE catastrophic Classification).
  - CIVP intent / reporting / monitoring.
  - Discrete source damage
- Design: No catastrophic single failure
- Crashworthiness Occupant Protection.



**EASA**  
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**Thank you for your attention!**

Any questions....?

**Your safety is our mission.**

An agency of the European Union 