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# VTOL Crashworthiness
based on
# EASA Special Condition

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# Content

- → EASA way to address VTOL (VTOL-Special Condition)
- → Crashworthiness requirements in EASA SC-VTOL
- → History of rotorcraft crashworthiness
- → Load factors in emergency landing conditions
- → Battery crashworthiness
- → Battery safety in overwater operation

# VTOL Special Condition

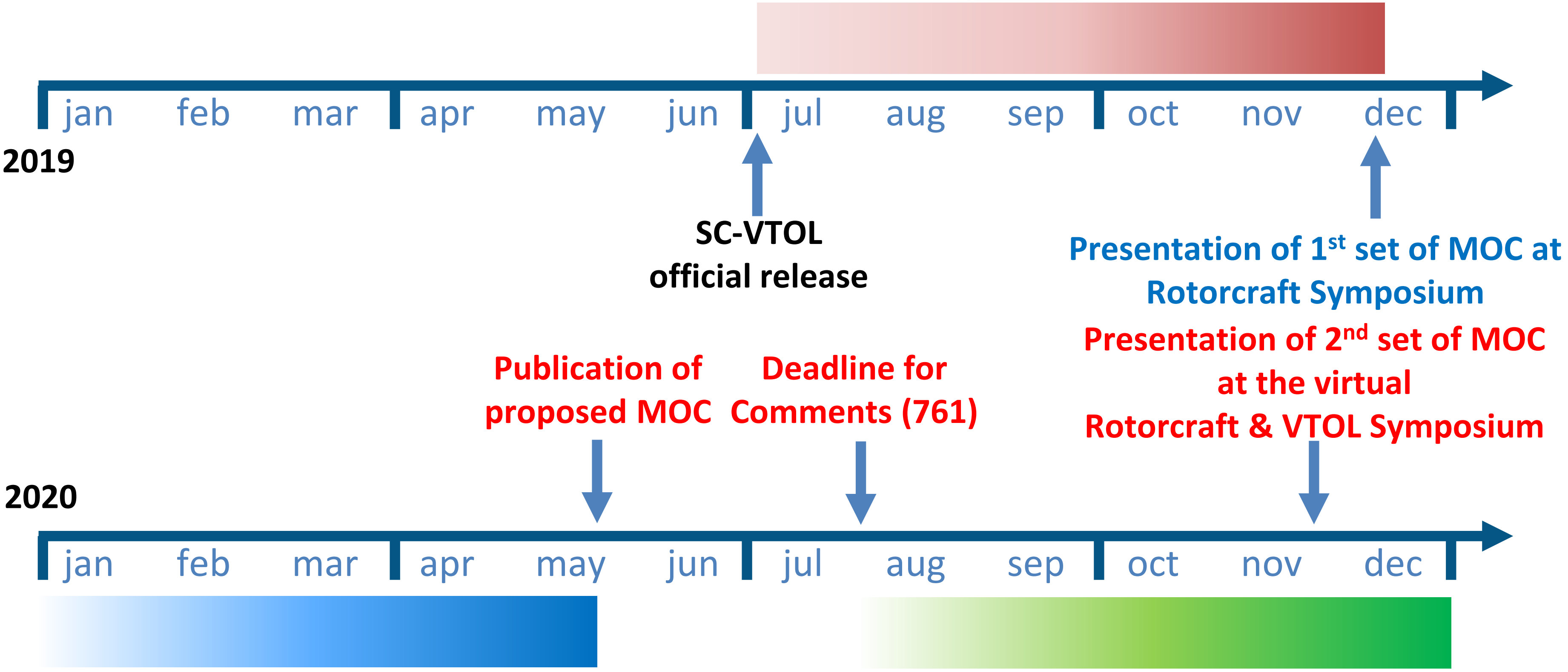
## Objective:

- → Level playing field with adequate safety objectives for Pax and 3rd parties
- → Using advantage of possible higher redundancy due to multiple lift thrust units

## Decision:

- → standalone, incorporating elements of CS-27 and CS-23
- → composed of high-level objectives, similar to CS-23 Amdt 5 and complemented by Means of Compliance (MOC),
- → will be supplemented in future to address aspects such as remote piloting or autonomy
- → Up to 9 Pax, max. 3175 kg, Special Class Aircraft

# SC-VTOL MOC (Means of Compliance)

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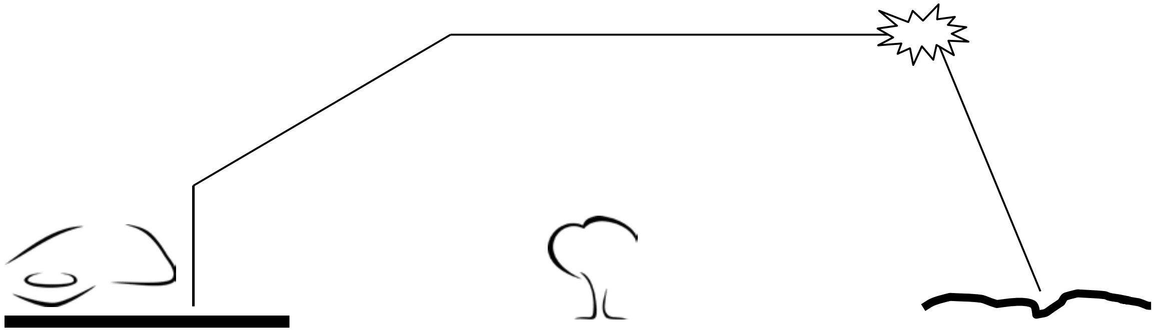
**Note: European Rotors is postponed to November 2021**

# VTOL Categories

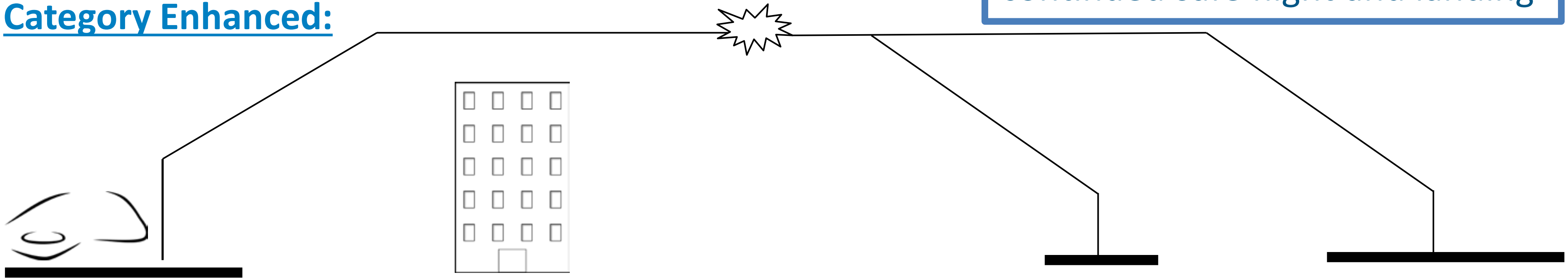
controlled emergency landing

**Category Basic:**



continued safe flight and landing

**Category Enhanced:**



# Safety Levels

- Category Basic
  - Analogue to CS-23 level 1-3, but slightly higher due to Fly by Wire technology
  - Controlled Emergency Landing

- Category Enhanced
  - Analogue to CS-27 Category A helicopters and CS-23 Level 4 aircraft
  - Continued safe flight and landing

# Safety Objectives

| | CS-23 | | CS-27 | | JARUS (Fly-by-Wire) | | SC-VTOL | | JARUS (Autonomy) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Assessment Level | pax | Cat | pax | Cat | pax | Cat | pax | Cat | pax | Cat |
| IV | 10 to 19 | **$10^{-9}$** | | | | **$10^{-9}$** | Enhanced 0 to 9 | **$10^{-9}$** | | **$10^{-9}$** |
| III | 7 to 9 | **$10^{-8}$** | 0 to 9 | **$10^{-9}$** | 0 | **$10^{-9}$** | 7 to 9 | **$10^{-9}$** | 0 | **$10^{-9}$** |
| II | 2 to 6 | **$10^{-7}$** | | | | **$10^{-8}$** | Basic 2 to 6 | **$10^{-8}$** | | **$10^{-9}$** |
| I | 0 to 1 | **$10^{-6}$** | | | | **$10^{-7}$** | 0 to 1 | **$10^{-7}$** | | **$10^{-8}$** |

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# Crashworthiness Requirements Special condition VTOL

SC VTOL.2325, SC VTOL.2270, SC-VTOL.2430

# Overview

- → Crashworthiness of SC-VTOL is covered in 3 paragraphs
- → SC-VTOL.2270 “Emergency Conditions”
  - → **occupant protection in case of an emergency landing**
- → SC-VTOL.2325 “Fire Protection”
  - → Fire initiation
  - → Fire propagation
  - → **Post crash fire/hazard protection**
- → SC-VTOL.2430 (a)(6) “Energy Storage”
  - → Retention of energy during any **survivable** emergency landing

# SC-VTOL.2270 Emergency Landing

- Protect each occupant against injury that would preclude egress when
  - Using safety features (seat belts…)
  - Experiences ultimate static inertia loads likely to occur
  - Items of mass experience ultimate static inertia loads
- Must include dynamic conditions
- Baggage compartment
  - Prevent items of mass to shift or become a hazard
  - Protect flight controls, wires… which damage could become a hazard

# SC-VTOL.2325 Fire Protection

- Minimize the risk of fire initiation due to
  - Systems failures, overheat, energy dissipation
  - Ignition of flammable fluids, gases or vapours
  - Oxygen system
  - **Survivable emergency landing**
- Minimize the risk of fire propagation by
  - Providing adequate smoke and fire awareness
  - Use of self-extinguishing, flame-resistant or fireproof material
  - Specifying designated fire zones

# Basis for Crashworthiness MOC: CS-27

- VTOL can be operated similar to a rotorcraft
- BUT it can be more diverse:
  - Speed range could be wider than for rotorcraft
  - VTOLs might have CTOL (conventional take-off and landing) capability
- MOC will be based on
  - CS-27.561 General Emergency landing conditions
  - CS-27.562 Emergency landing dynamic conditions
  - CS-27.952 Fuel System Crash resistance
  - Complemented by CS-23.561/.562 requirements for CTOL

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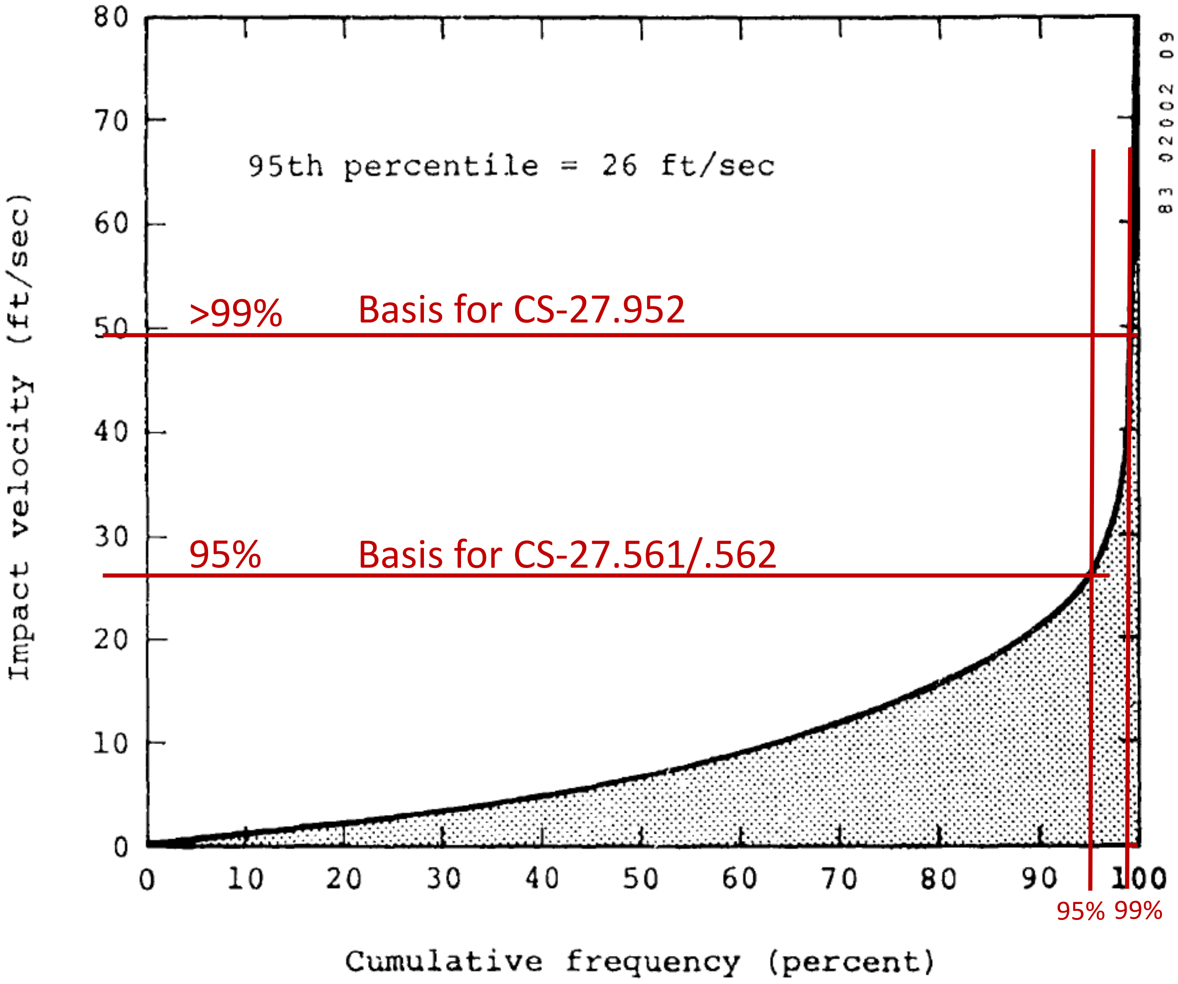
# History of rotorcraft crashworthiness

# History of CS-27 Crashworthiness

- Crashworthiness requirements originated from the FAA study DOT/FAA/CT-85/11 by Coltman/Balukbasi/Laananen "Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria"
- Review of 1351 rotorcraft accidents between 1974 and 1978
- Main outcome:
  - Vertical impact velocity and Survivability
  - Impact scenarios




DOT/FAA/CT-85/11
"Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria"

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# CS 27 Crash Scenarios – 2 Layers of protection

- CS-27.561/.562
  - **Minor** emergency (crash) landing
  - 9.1 m/s (30 ft/s) impact velocity, covering 95% of crashes
  - Loads should not exceed 30 g on seat attachment level
  - Occupants must be able to evacuate themselves after the impact
- CS-27.952
  - **Survivable** emergency (crash) landing
  - 15.2m (50ft) drop test height
  - Exceeds (deliberately) the 99% survivable impact velocity envelope
  - Occupants should be protected from post crash fire / post crash hazard

# Load factors in Emergency Landing and Crashworthiness for VTOL

SC VTOL.2270

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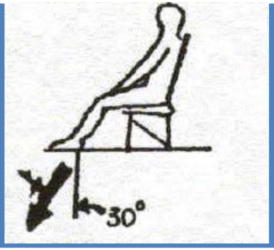
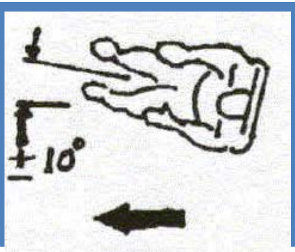
# MOC for VTOL.2270 based on CS-23/27.561

→ Give each occupant every reasonable chance of escaping serious injury under static ultimate inertial load factors

| Direction | Occupants<br>Items in cabin | Items adjacent<br>Cabin | Structure in area near<br>energy storage system |
|---|---|---|---|
| Upward | 4 g | 1.5 g | 1.5 g |
| Forward | 16 g (**CTOL: 18 g**) | 12 g | 4 g |
| Sideward | 8 g | 6 g | 2 g |
| Downward | 20 g | 12 g | 4 g |
| Rearward | 1.5 g | 1.5 g | - |

Load factors are only valid if the structure underneath the seat has equal or better dampening characteristic than a conventional rotorcraft.

# MOC for VTOL.2270 based on CS-23/27.562

| 77 kg Test Dummy | Test 1 (downward) 60° canted upwards  | | Test 2 (Forward) 10° yaw  | |
|---|---|---|---|---|
| | VTOL | CTOL | VTOL | CTOL |
| Min. Velocity | 9.1 m/s<br>30 ft/s | | 12.8 m/s<br>42 ft/s | |
| Min. G Force | 30 g * | | 18.4 g | **1st row: 26 g**<br>**Other: 21 g** |
| Max peak floor deceleration after | 0.031 s | | 0.071 s | **0.05 s** |
| Floor deformation | Degrees Roll: 10° / Degrees Pitch: 10° | | | |

*Load factor is only valid if the structure underneath the seat has equal or better dampening characteristic than a conventional rotorcraft.

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# Energy storage drop test

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# MOC VTOL.2325 Energy Storage Drop Test(1/3)

- → Based on CS-27.952 „Fuel system crash resistance "
- → **Minimize** hazards to occupants caused by the energy storage system in an otherwise **survivable crash landing**
- → Written to address liquid, gaseous and solid (battery) energy storage systems
- → Self-insulations means have to be provided
- → For electrical systems, an automatic insulation means is requested

# MOC VTOL.2325 Energy Storage Drop Test(2/3)

- Test conditions:
  - Energy storage system should be tested in a representative surrounding structure → Full scale drop test is an option
  - The entire energy storage system, or the most critical one, needs to be dropped
  - Must be filled or charged to the most critical condition
  - 15.2 m drop height on non-deformable surface
  - Must be dropped freely
  - Impact in a horizontal position ±10°

# MOC VTOL.2325 Energy Storage Drop Test(3/3)

- Pass/fail criteria
  - For liquid or gaseous fuels:
    - no leakage of flammable fluids or gases.
  - For Batteries
    - structural damage should not lead to a fire, leakage of harmful fluids, fumes or gases;
      or
    - Fire or leakage of harmful fluids, fumes or gases should be contained for at least 15 minutes in non-occupied areas and outside the evacuation path.
  - Any projectile release should not lead to serious injury to occupants or persons on ground

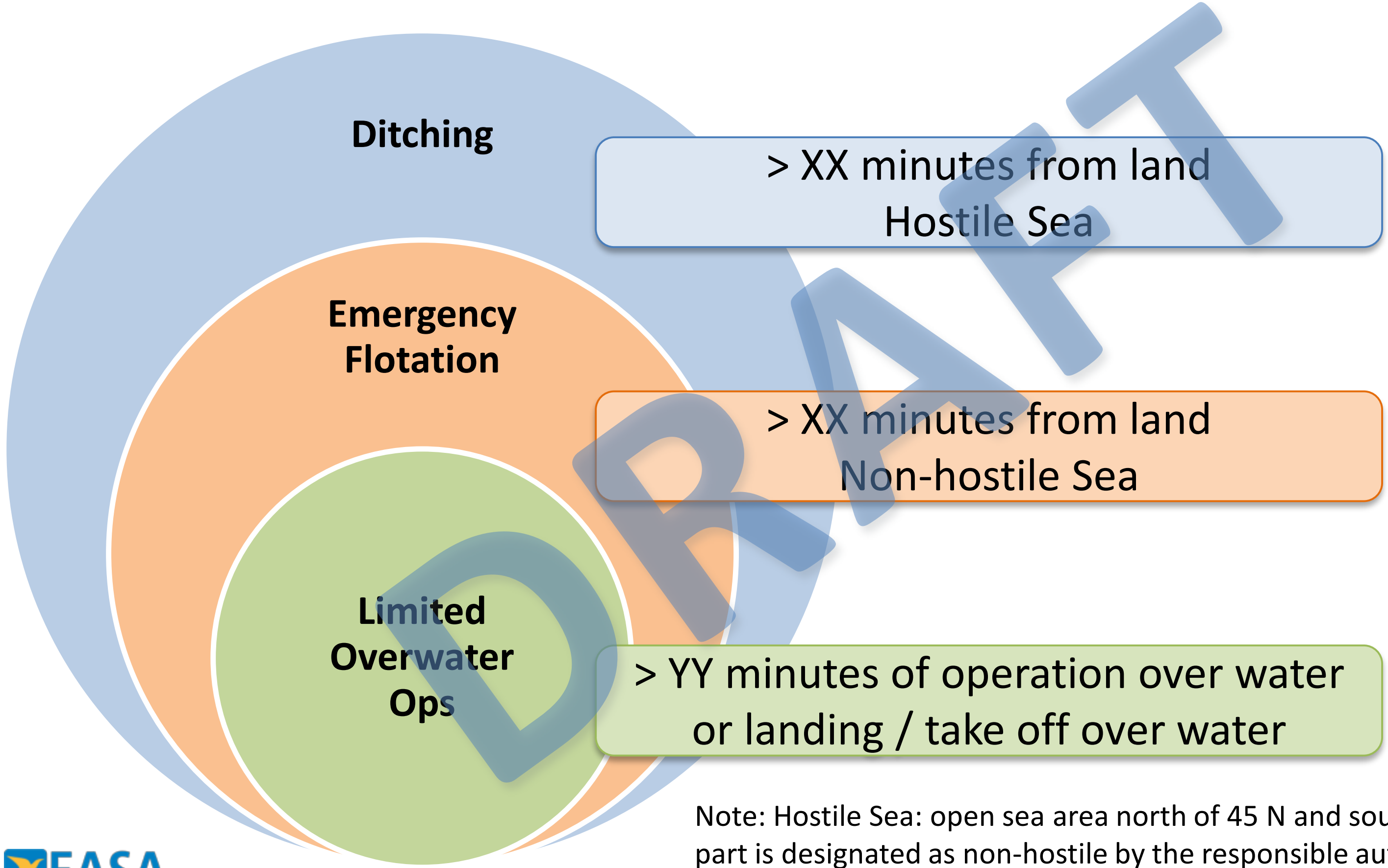
# Battery Drop Test Overwater Operations - eVTOL

Currently under EASA internal discussion

# Emergency landing on water

→ Requirement:
VTOL 2430 (a)(6) Energy Storage
Each system must be designed to **retain the energy** under all likely operating conditions and minimise hazards to the occupants and people on the ground during **any survivable emergency landing.**

# Proposed Airworthiness Categories




**Equivalent to rotorcraft**
CAT.IDE.H.320

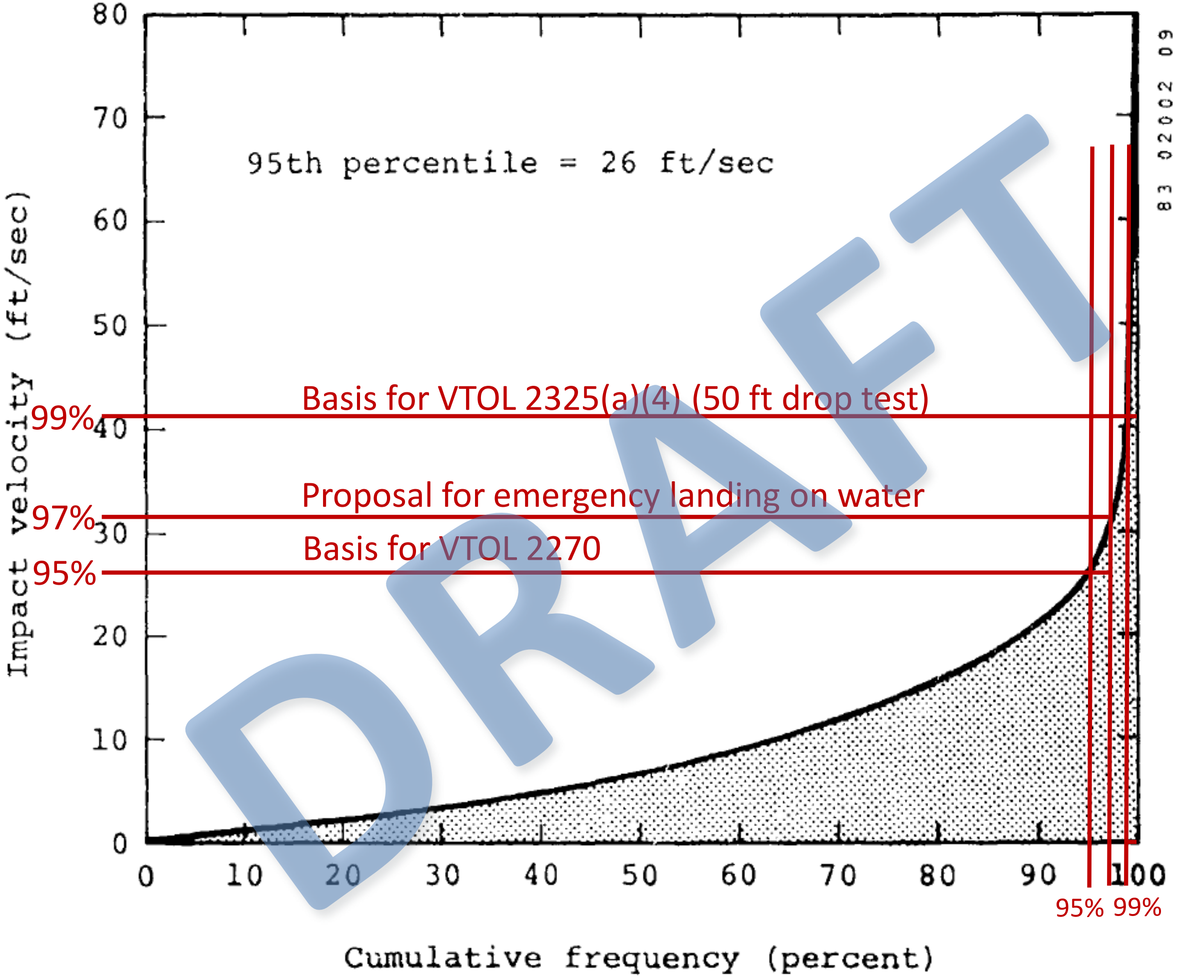
**Equivalent to rotorcraft**
CAT.IDE.H.320

**NEW CATEGORY**

Note: Hostile Sea: open sea area north of 45 N and south of 45 S, unless any part is designated as non-hostile by the responsible authority of the State in which the operations take place, ref: ANNEX I – Definitions (69)(b)(i)

# Currently established crash scenarios

- CS-27.561/.562
  - **Minor** emergency (crash) landing
  - 9.1 m/s (30 ft/s) impact velocity, covering 95% of crashes
  - Loads should not exceed 30 g on seat attachment level
  - Occupants must be able to evacuate themselves after the impact
- CS-27.952
  - **Survivable** emergency (crash) landing
  - 15.2m (50ft) drop test height
  - Exceeds (deliberately) the 99% survivable impact velocity envelope
  - Occupants should be protected from post crash fire / post crash hazard




DOT/FAA/CT-85/11 Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria

# Proposed Battery System drop test on water

| Airworthiness Category | Possible Operational Use | Battery system (drop test) | Crashes covered |
|---|---|---|---|
| Operations on water | Equivalent to seaplane | 15.2 m drop test height (approx. 15 m/s impact speed) | >99 % |
| Ditching | > XX minutes from land Hostile seas | | |
| Emergency Flotation | > XX minutes from land Non-hostile seas | | |
| Limited Overwater Operations | > YY mins of operation of water | 6 m drop test height (approx. 10 m/s impact speed) | 97 % |



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*Currently under EASA internal review*

# Ballistic Recovery System (BRS)

- BRS are certified on CS 23 aircraft (e.g. Cirrus)
  - Only to be used if no suitable landing site is available
  - CS 23 aircraft are assumed to operate mainly outside cities
- Have been treated on „no credit no harm“ basis
  - No credit can be taken for emergency landing conditions
  - The system should not cause any additional harm to the VTOL
- If used in a untimely manner, it could cause harm if used over congested areas

# Thank you
# Any further question?