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)

2019
- Publication of proposed MOC
- Deadline for Comments (761)
- SC-VTOL official release
- Presentation of 1st set of MOC at Rotorcraft Symposium

2020
- Note: European Rotors is postponed to November 2021
- Presentation of 2nd set of MOC at the virtual Rotorcraft & VTOL Symposium
VTOL Categories

Category Basic:

Category Enhanced:

controlled emergency landing

continued safe flight and landing
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

<table>
<thead>
<tr>
<th>Assessment Level</th>
<th>CS-23</th>
<th>CS-27</th>
<th>JARUS (Fly-by-Wire)</th>
<th>SC-VTOL</th>
<th>JARUS (Autonomy)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pax</td>
<td>Cat</td>
<td>pax</td>
<td>Cat</td>
<td>pax</td>
</tr>
<tr>
<td>IV</td>
<td>10 to 19</td>
<td>$10^{-9}$</td>
<td>0 to 9</td>
<td>$10^{-9}$</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>III</td>
<td>7 to 9</td>
<td>$10^{-8}$</td>
<td>0 to 9</td>
<td>$10^{-9}$</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>2 to 6</td>
<td>$10^{-7}$</td>
<td>0 to 9</td>
<td>$10^{-8}$</td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>0 to 1</td>
<td>$10^{-6}$</td>
<td>0 to 1</td>
<td>$10^{-7}$</td>
<td>0</td>
</tr>
</tbody>
</table>

**Enhanced**

0 to 9

**Basic**

$10^{-8}$

$10^{-7}$

$10^{-9}$

$10^{-6}$

$10^{-7}$

$10^{-8}$

$10^{-9}$

$10^{-6}$

$10^{-7}$

$10^{-8}$

$10^{-9}$
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
History of rotorcraft crashworthiness
History of CS-27 Crashworthiness

→ Crashworthiness requirements originated from the FAA study DOT/FAA/CT-85/11 by Coltman/Balukbasi/Laanananen “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
95th percentile = 26 ft/sec

>99% Basis for CS-27.952

95% Basis for CS-27.561/.562

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

<table>
<thead>
<tr>
<th>Direction</th>
<th>Occupants Items in cabin</th>
<th>Items adjacent Cabin</th>
<th>Structure in area near energy storage system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upward</td>
<td>4 g</td>
<td>1.5 g</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Forward</td>
<td>16 g (CTOL: 18 g)</td>
<td>12 g</td>
<td>4 g</td>
</tr>
<tr>
<td>Sideward</td>
<td>8 g</td>
<td>6 g</td>
<td>2 g</td>
</tr>
<tr>
<td>Downward</td>
<td>20 g</td>
<td>12 g</td>
<td>4 g</td>
</tr>
<tr>
<td>Rearward</td>
<td>1.5 g</td>
<td>1.5 g</td>
<td>-</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>77 kg Test Dummy</th>
<th>Test 1 (downward) 60° canted upwards</th>
<th>Test 2 (Forward) 10° yaw</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>VTOL</th>
<th>CTOL</th>
<th>VTOL</th>
<th>CTOL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Min. Velocity</strong></td>
<td>9.1 m/s</td>
<td>12.8 m/s</td>
<td>30 ft/s</td>
<td>42 ft/s</td>
</tr>
<tr>
<td></td>
<td>30 ft/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Min. G Force</strong></td>
<td>30 g *</td>
<td>18.4 g</td>
<td>1st row: 26 g</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Other: 21 g</td>
<td></td>
</tr>
<tr>
<td><strong>Max peak floor deceleration after</strong></td>
<td>0.031 s</td>
<td>0.071 s</td>
<td>0.05 s</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Floor deformation</strong></td>
<td>Degrees Roll: 10° / Degrees Pitch: 10°</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

SC VTOL.2325
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

- Ditching
  - > XX minutes from land Hostile Sea
  - Equivalent to rotorcraft CAT.IDE.H.320

- Emergency Flotation
  - > XX minutes from land Non-hostile Sea
  - Equivalent to rotorcraft CAT.IDE.H.320

- Limited Overwater Ops
  - > YY minutes of operation over water or landing / take off over water
  - 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
Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria

95th percentile = 26 ft/sec

Basis for VTOL 2270

Basis for VTOL 2325(a)(4) (50 ft drop test)

Proposal for emergency landing on water
# Proposed Battery System drop test on water

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

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?