

Airworthiness and Crashworthiness

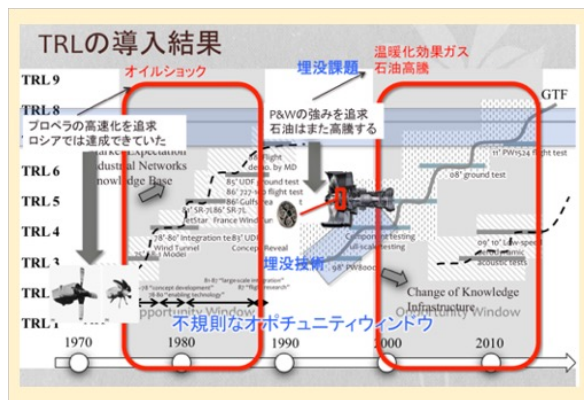
Hiroko Nakamura, UIC2-
Japan (Cities Community
for AAM)



Agenda

- Introduction of the presenter; Social Acceptance and Safety
- eVTOL and Airworthiness: what is the problem on eVTOL and certification path at FAA/EASA
- eVTOL and Crashworthiness : what is Crashworthiness, and what is the problem on eVTOL
- Crashworthiness standardization activities
- Academic activities on eVTOL Crashworthiness
- Summary

Passion for Innovation from Air



- Long career at University of Tokyo & research Innovation Transition Management in the Aviation Industry
- Running various industrial initiatives in Japan for enabling innovation from Air
 - Japan RPAS Committee
 - Aviation AI Committee
 - Japan UTM Consortium
 - Advance Air Mobility Cities Community
- Work with European UAM Cities Community on Social Acceptance
 - Safety is one of biggest concerns from habitants



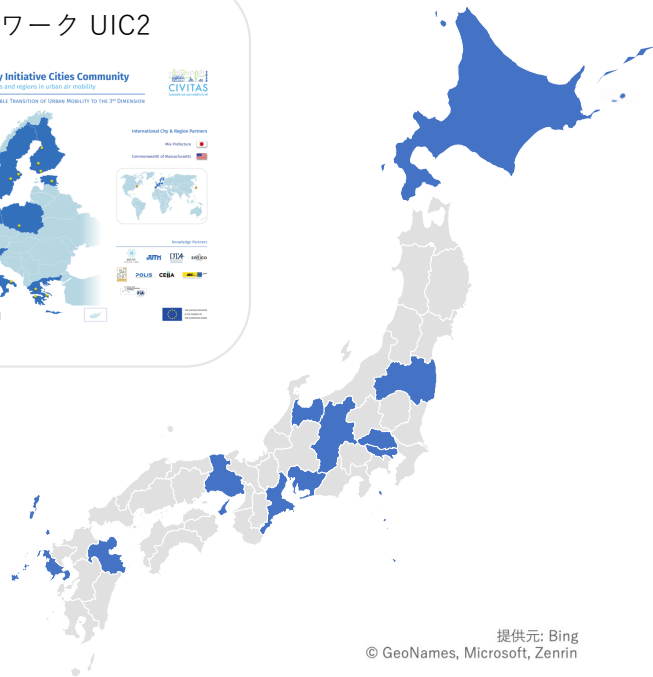
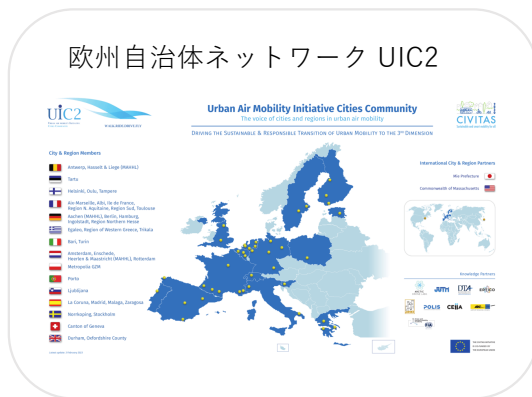
UIC2-Japan

Toward Social Embracement

住民目線で空づくり

UIC2-Japan

We work on the air-mobility in a way habitants are centered



- UIC2 Japan was found in 2021.
- 11 prefectures (total. 49.5 million ppt) and METI are members.
- Recent activities at UIC2 Japan is to promote the industry in the members' region;
 - Business model study focusing on drone delivery function;
 - Legal side studies on relationship with land owner;
 - Social Acceptance and city planning;
 - Drone Summit Support
- We are also working on how to use drones for disaster relief safely and efficiently <- JUTM and Fukushima RTF develop a guideline.

近日公開URL: uic2-japan.org

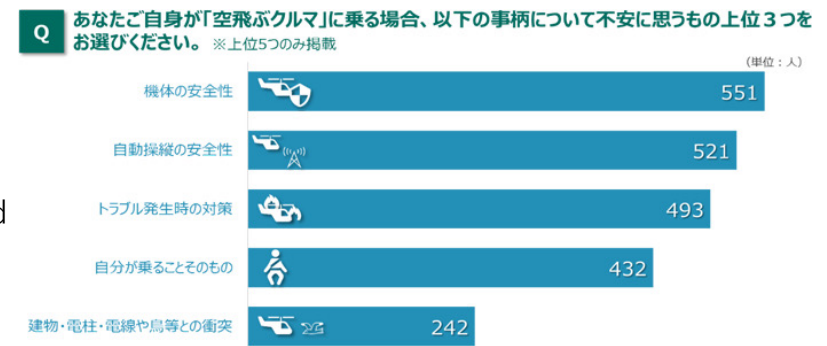
UIC2-Japanは日本無人機運行管理コンソーシアム（JUTM）が事務局機能を担っております。

UAM Social Acceptance Survey on 2022

- With MS&AD
- 1000 people
 - In Metropolitan Area
 - In Suburban Area
 - Man/Female
 - Age

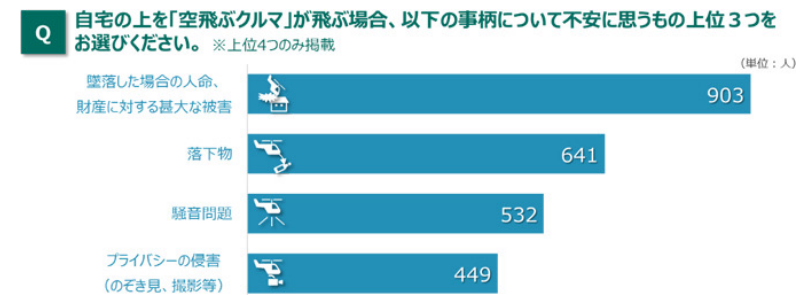
(You can chose three)

What you concern about when you ride on?



(You can chose three)

What you concern about when a eVTOL fly over you?



Aircraft Safety

Autonomy

Trouble onboard

Ride itself

Mid-air collision

Ground risk

Falling Object

Noise

Privacy

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eVTOL and Airworthiness: FAA

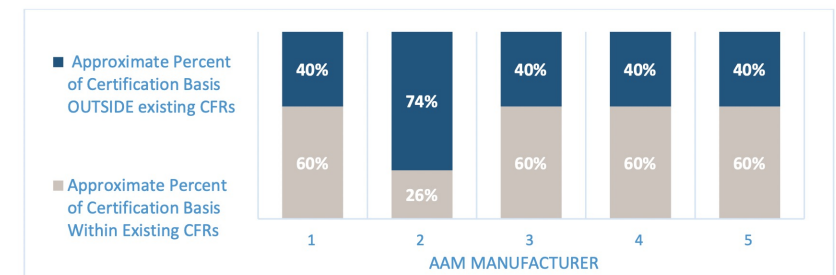
- The certification of Electric Vertical Takeoff and Landing (eVTOL) for airworthiness is challenging. Given their unique features, such as hydrogen fuel cells or highly automated flight control systems, many of eVTOLs do not fully fit into existing airworthiness standards.
- The FAA uses the Special Conditions to address novel design features for which there are no regulations, or the regulations are inadequate. In April 2022, FAA communicated to applicants that the Agency would certify fixed-wing AAM as powered-lift under 14 CFR § 21.17(b) special class path. (There are opinions that 21.17 (a) and Part 23 Amendment 64 could offer more performance-based path.)

Figure 2. AAM Aircraft in the FAA Certification Process as of August 2022



Source: UAM Manufacturers (clockwise from top-left: Alakai Technologies; AirVEV; Courtesy of Joby Aviation. © Joby Aero, Inc.; Beta Technologies; Archer Aviation; and Moog, Inc.)

Figure 3. Certification Basis and Existing Regulations for Small Airplanes

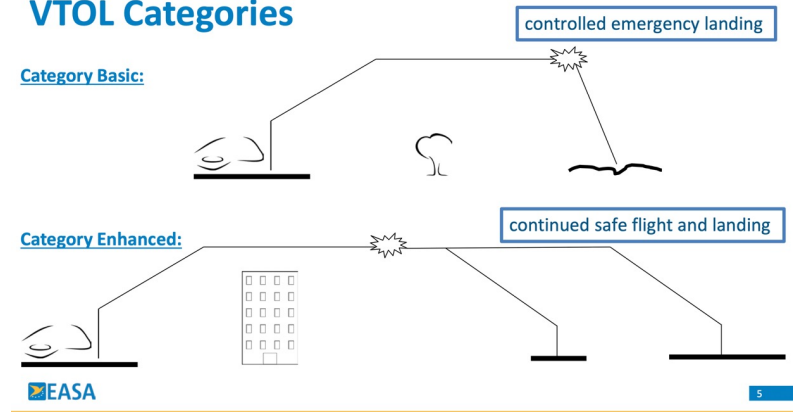


Source: FAA data

eVTOL and Airworthiness: EASA VTOL Special Condition

- According to EASA 21.A.16B regulation, in 2019, EASA formally published its “Special Condition (SC) for Small-Category VTOL”. The SC does not intend to cover traditional rotorcraft either but rather aircraft with distributed lift/thrust and it will be clarified that, for the SC to be applicable, more than 2 lift/thrust units should be used to provide lift during vertical take-off or landing.
- The Objective:
 - Adequate safety objectives for Passengers and 3rd parties
 - Using advantage of possible higher redundancy due to multiple lift thrust units
- The Characteristics:
 - 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), (MOC-3, Issue 2 are now available)
 - Supplemented in future to address aspects such as remote piloting or autonomy
 - Up to 9 Passengers, max. 3175 kg, Special Class Aircraft

VTOL Categories



Safety Objectives

Analogue to CS-27 Category A helicopters and CS-23 Level 4 aircraft

Assessment Level	CS-23		CS-27		JARUS (Fly-by-Wire)		SC-VTOL		JARUS (Autonomy)	
	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	2 to 6	10 ⁻⁸		10 ⁻⁹
I	0 to 1	10 ⁻⁶				10 ⁻⁷	0 to 1	10 ⁻⁷		10 ⁻⁸

The table highlights the 'Enhanced' and 'Basic' categories for SC-VTOL. The 'Enhanced' category (0 to 9 pax, 10⁻⁹ Cat) is highlighted in green, and the 'Basic' category (2 to 6 pax, 10⁻⁸ Cat) is highlighted in yellow. A blue arrow points from the 'Basic' category to the text below.

EASA

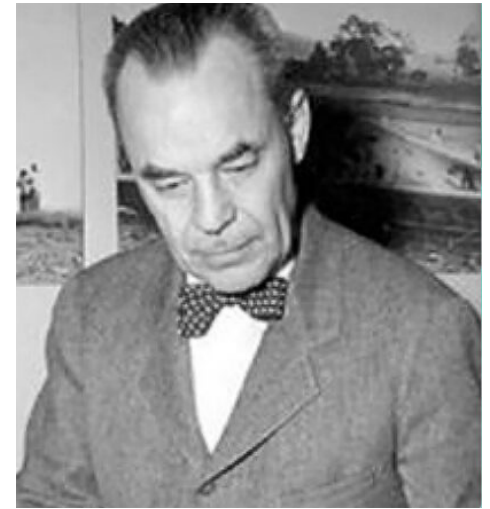
(Basic) Analogue to CS-23 level 1-3, but slightly higher due to Flv by Wire technology

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eVTOL and Crashworthiness

- Crashworthiness is the ability of a structure to **protect its occupants during an impact**. Encourage incorporating crashworthiness best practice;
 - Limiting the loads transmitted to the occupants to survivable and/or non-injurious, humanly-tolerable levels (for a “survivable” impact).
 - Providing a protective cabin surrounding the occupants.
 - Providing a secure tie down of the occupants through the use of seats, restraint systems, seat track, and floor.
 - Eliminating post-crash fire hazards and providing for emergency egress.
 - Mitigating head strike potential by using pre-tensioned restraint systems or cockpit air bags.
- Crashworthiness needs to be a primary design consideration instead of a last resort. Instead of focus on seat, need multiple features that create system for occupant protection.



<https://flightsafety.org/foundation/founders/hugh-dehaven/>

Hugh DeHaven FATHER OF CRASH SURVIVABILITY

DeHaven discovered a clear relationship between airplane design and crash survivability and developed the first systematic statement of the principles of crashworthiness. .

eVTOL and Crashworthiness

- NASA/FAA conducts seminars to familiarize the UAM community to the concepts of vehicle crashworthiness from both a historical perspective but also how it can apply to eVTOL vehicle designs.
- eVTOL: strong market demand/ unique-features/ new players
 - VTOL can be operated similar to a rotorcraft but it can be more diverse in terms of speed range and CTOL capabilities.
 - Composite structure with lots of battery mass and distributed electric motor masses***
 - How does it crash, based upon how it flies considering loss of power, thrust?
 - “Need more empirical data to validate studies on eVTOL crashworthy designs”
- Must consider certification cost verses safety benefit to get the best overall system

At the certification process, how do we demonstrate crashworthiness?

EVTOL Certification-Methods of Compliance

After cert basis determined.....

How do we demonstrate crashworthiness?

- Test or analysis based upon test....
there will be testing.....
- Some form of traditional dynamic/static option
- Longer/More Advanced/Likely Safer/But...More Expensive Paths
 - Automotive path of full vehicle crash response/dummy restraint
 - Potentially extensive modelling that will likely require substantiation via large scale test
- New avenues will be more of a challenge as vehicle type/operations certification is not stable
- Traditionally, Certification moves ahead incrementally



Crashworthiness
April 2020



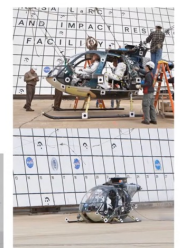
Federal Aviation
Administration

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eVTOL Crashworthiness

- Understanding crash safety
 - Significant research conducted to date on airplanes and rotorcraft
 - Studies underway on eVTOL crashworthy designs
 - Need more empirical data to validate studies
 - Ultralight eVTOLs are available in large numbers and could be tested under a Space Act Agreement
 - NASA Langley's Landing and Impact Research Facility (LIRF) being considered for mothballing due to maintenance expense



Major new effort needed to understand eVTOL crash safety

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- Airworthiness, Crashworthiness and Standardization
- Academic activities on eVTOL Crashworthiness
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Airworthiness and Crashworthiness

- Crashworthiness is covered in SC-VTOL in EASA
 - SC-VTOL. 2270 “Emergency Conditions”: occupant protection in case of an 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
 - SC-VTOL. 2325 “Fire Protection”: Fire initiation, Fire propagation and Post crash fire/hazard protection
 - Minimize the risk of fire initiation due to
 - Systems failures, over heat, energy dissipation
 - Ignition of flammable fluids, gases or vapors
 - Oxygen system
 - Survivable emergency landing
 - SC-VTOL. 2430 (a)(6) “Energy Storage”: Retention of energy during any survivable emergency landing

MOC is developed based on CS27. But VTOL has unique features...

Crashworthiness Standardization Activities

- ASTM
- Working Groups focused on Occupant Protection
 - F3083/F3083M-19 Standard Specification for Emergency Conditions, Occupant Safety and Accommodations
 - WK68781 - Emergency Landing Conditions for eVTOL aircraft assessment
 - F3114-19 Standard Specification for Structures
 - WK68805 - Bird Strike for eVTOL aircraft assessment
 - F3239-19 Standard Specification Aircraft Electric Propulsion Systems
 - WK65629 Energy Shedding (Crashworthiness)
- EUROCAE
- Working Groups focused on VTOL
 - SG-1 Electrical
 - ED-XXX Process Standard for crashworthiness test of battery systems for eVTOL applications
 - SG-2 Lift-Thrust
 - ED-XXX Guidance on designated fire zone for VTOL
 - SG-3 Safety
 - ED-XXX Guidance on the Demonstration of Acceptable Occupant Safety - Injury Prevention 安全性 Measures
 - SG-8 Seat
 - ED-XXX MOPS on crashworthy seat systems for Advanced Air Mobility (AAM) aircraft
 - ED-XXX Guidance on crashworthy seat systems for Advanced Air Mobility (AAM) aircraft

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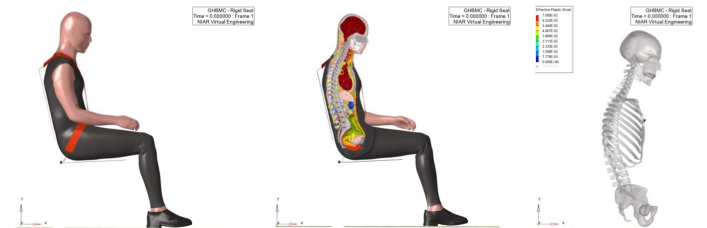
Crashworthiness Certification by Analysis

- https://www.wichita.edu/industry_and_defense/NIAR/Documents/jams-presentations-2021/Crashworthiness-Certification-by-Analysis.pdf
- Wichita University Provides a methodology and the tools required by industry to maintain or improve the level of safety of new composite aircraft when compared to current metallic aircraft using emergency landing conditions.
- The advances in computational tools combined with the building block approach allows for a cost-effective approach to study in depth the crashworthiness behavior of aerospace structures.

PMHS Instrumentation Support Analysis



- Motion of the Rigid Seat was extracted from full scale analysis and used as a boundary condition on a subassembly model with just a rigid seat and the GHMBC 50th
- Results will be used to identify areas of interest and define instrumentation requirements.



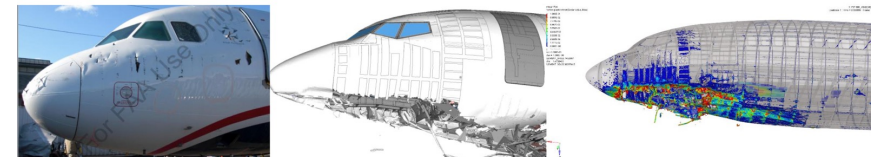
Luis Gomez - NIAR WSU

JAMS Technical Review - September 30, 2021

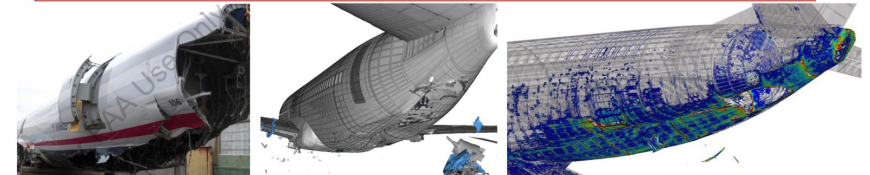


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Phase II – Hudson River Ditching Results



Numerical model nose slams the water due to lack of pilot input. Actual ditching event had a controlled pitch rate.



Luis Gomez - NIAR WSU

JAMS Technical Review - September 30, 2021



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Simulation Studies on eVTOL Crashworthiness in the Conceptual and the Preliminary Design Phase

- Waimer et al (2022) Tenth Triennial International Aircraft Fire and Cabin Safety Research Conference October 17-20, 2022 - Atlantic City, New Jersey, USA
- The presented conceptual and preliminary design phase studies consider generic eVTOL designs for air taxi missions carrying four passengers within a range of approx. 80 km. The investigated eVTOL designs are based on a lift+cruise concept with a fixed wing, eight propellers, battery energy storage and a carbon composite airframe structure. Crash simulations were performed in both studies using the explicit finite element solver LS-DYNA.

DLR.de - Chart 3 - NASA/FAA eVTOL Crashworthiness Workshop #4 - Conceptual Design Phase Study on eVTOL Crashworthiness - April 13, 2021

Outline

Conceptual Design Phase Study

UAM Crashworthiness Requirements.....

- New Missions
- New Vehicles
- Requirements
- Load Cases

New mission, new vehicles!
What are the crash requirements?

Simulation Strategy.....

- Modeling Approach
- Simulation Techniques

Very limited input data!
How can we produce useful results?

Simulation Study.....

- Vehicle Configurations
- Results

What we know: LIFT+CRUISE

Conclusions

Crashworthiness Design Evaluation:
Criteria update for eVTOLS
(not part of this presentation)

→Crash kinematics under real-world crash impact conditions partly not evident.



Crash expert

DLR.de - Chart 30 - NASA/FAA eVTOL Crashworthiness Workshop #4 - Conceptual Design Phase Study on eVTOL Crashworthiness - April 13, 2021

Simulation Study

Combined horizontal/ vertical load cases

Crash sequence: High-wing (exemplarily)

Load case	v_x [m/s]	v_z [m/s]	Roll [°]	Pitch [°]	Yaw [°]	Payload [%]	Friction coefficient
D	8	0	0	0	0	100	0.4
M	8	25	-10	10	-10	100	0.4
M ¹⁾	8	25	-10	10	-10	100	0.8

Concrete impact surface approximation

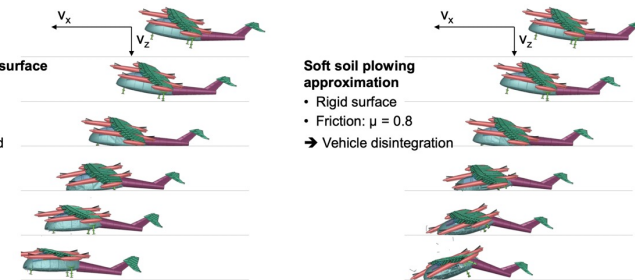
- Rigid surface
- Friction: $\mu = 0.4$

→ Vehicle rebound

Soft soil plowing approximation

- Rigid surface
- Friction: $\mu = 0.8$

→ Vehicle disintegration

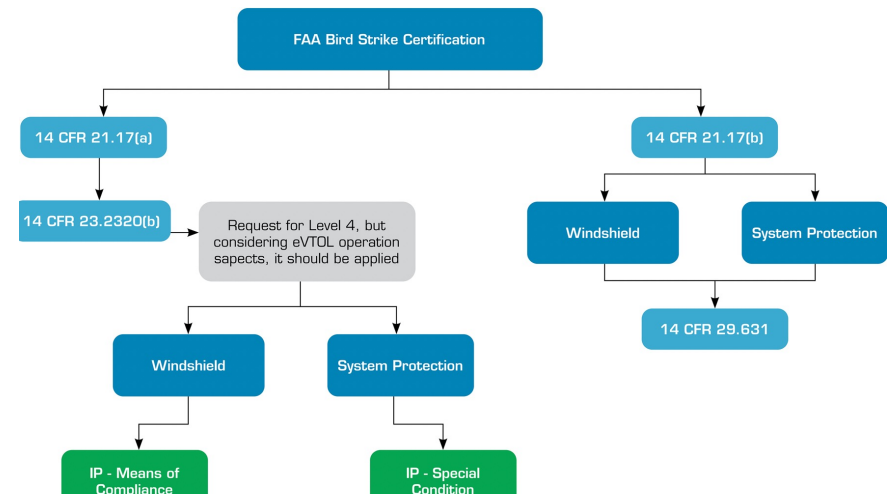
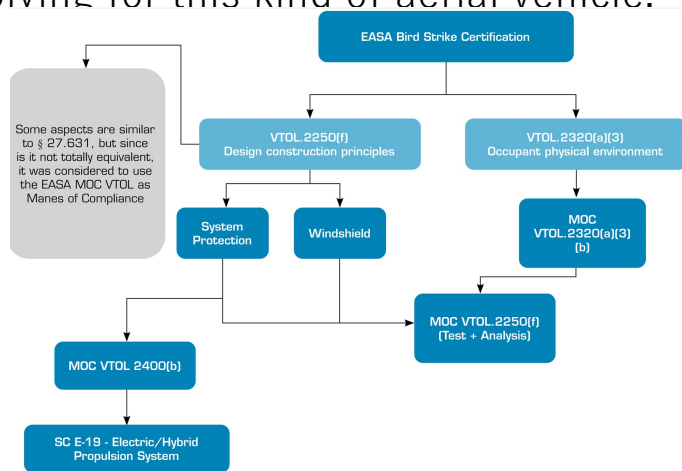


Simulation strategy

- Simulation studies in the early design process can be useful to identify crashworthiness trends
- Computational efficient and parameterized simulation models can be a key

eVTOL Certification in FAA and EASA Performance-Based Regulation Environments: A Bird Strike Study-Case

- Cardoso et al. (2022) Journal of Aerospace Technology and Management, <https://doi.org/10.1590/jatm.v14.1271>
- Considering the expected eVTOL aircraft altitude operation, it is possible to conclude that during a normal operation of an eVTOL, it will be exposed to a scenario where the probability of facing a bird strike will be high, therefore, mitigation measures will be certainly necessary to avoid strikes and guarantee the safety operation in this kind of aircraft on urban air mobility implementation.
- This paper studies the main concerns that can be pointed out due to the different certification approaches that the Federal Aviation Administration (FAA) and European Union Aviation Safety Agency (EASA) have been applying for this kind of aerial vehicle.



eVTOL Certification in FAA and EASA Performance-Based Regulation Environments: A Bird Strike Study-Case

Bird Mass	2.2 lb (1.0 kg) * When considered multiple bird strike, the bird mass to be considered is 0.45 kg.	2 lb (1.0 kg)	When evaluated a single bird mass, the FAA requirement consider a bird mass 0.2 lb lighter than EASA requirement of even 14 CFR 27.631. Although it is not a big difference, it should be considered during the Certification Basis development. Moreover, if multiple bird strike is evaluated, a different bird mass should be considered for EASA. The FAA, on the other hand, may not request multiple bird strike evaluation.
Aircraft Speed	VH * Specifically for windshield protection, panels should be capable of withstanding a bird impact without penetration for maximum speeds above 50 kt.	VNE or VH	While EASA considers the maximum speed in level flight with maximum continuous power (VH), both 14 CFR 27.631 and 14 CFR 29.631 consider also the VNE. Whichever is the lesser should be considered. In addition to this difference, there is another factor that should be evaluated: while EASA considers speeds above 50 kt for windshield evaluation, FAA requirement would consider the VNE or VH as well.
Altitudes	Maximum operating altitude up to 8,000 ft * When considered multiple bird strike, it is required the evaluation up to 4,000 ft.	Maximum operating altitude up to 8,000 ft.	There is no concern regarding the maximum operating altitude aspects since both requirements consider the same altitude operation for the evaluation when a single bird strike scenario is evaluated. However, if multiple bird strike is evaluated, it should be considered the maximum operating altitude up to 4000ft for EASA certification. The FAA, on the other hand, may not request multiple bird strike evaluation.
Multiple bird strike evaluation	VTOL.2250(f) requests a multiple bird strike evaluation.	Not considered in the evaluation.	EASA requirement considers an evaluation of the effects of multiple bird strike in the most critical configurations, considering the potentially vulnerable redundant systems, structures and their effective exposed area. This is required for the structure and systems only. The evaluation is not required for the windshield. Different from this EASA definition, according to the ARAC report, events of multiple bird impacts are rare in the data studied period (as also presented in Table 1) (FAA 2017b).
Bird Strike Requirement	EASA presents a specific requirement that cover both windshield and systems/structure	FAA Part 23 presents a requirement that would cover only the windshield	The structure of the certification basis considering a bird strike requirement will present significant differences between EASA and FAA, since that EASA will cover the demonstration by the current regulation presented in the Special Condition VTOL, while, for FAA, the certification basis will be composed by Part 23, Part 27 or Part 29 requirements in addition to MOC or Special Condition IP, depending on the certification approach decided to be followed.

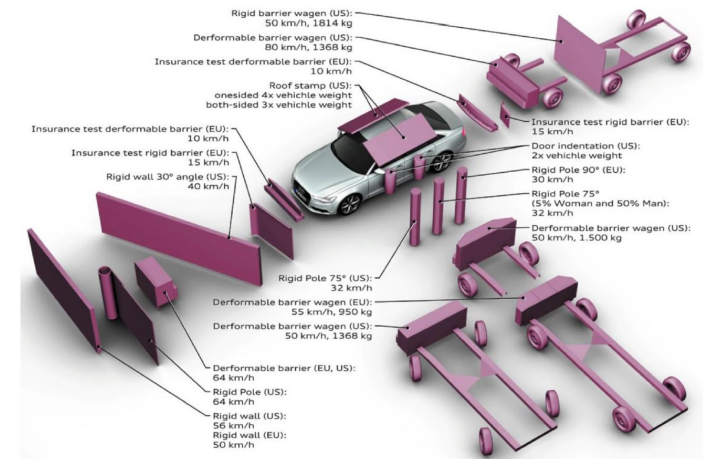
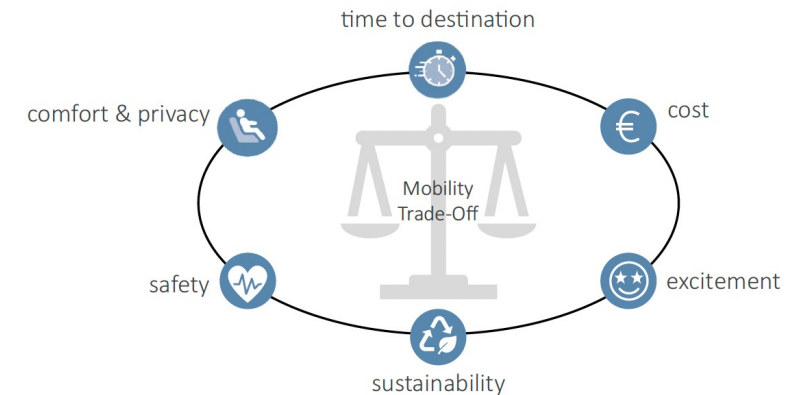
EASA

FAA

Note

Automotive safety approach for future eVTOL vehicles

- Laarmann et al. (2023), CEAS Aeronautical Journal, 14:369–379, <https://doi.org/10.1007/s13272-023-00655-0>
- Mobility tradeoff -> Customer perception of safety is important
- Automobiles are developed from the inside to the outside. Starting point is the passengers. The human body shows ergonomic and biomechanical limits, defining the customer focused design approach's boundary conditions. And about crash prevention, integral safety approach, combination of both active and passive safety measures are taken.
- This paper discuss the advantages of integral safety and applying the automotive safety approach for eVTOL development. Three full-vehicle crash tests are derived.
- The effect of applying standardized full-vehicle crash tests for eVTOL according to the automotive safety approach needs to be further investigated.



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Airworthiness and Crashworthiness

- How to accumulate data
- What system redundancy or features are available to control emergency landing? If failed, what else can be utilize to maintain control?
- Showing how we try to achieve the ability to fly more safe and crash more safe is very important to achieve public acceptance.