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

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ABSTRACT

Considering the new generation of air mobility vehicle that has been developed, the electric vertical take-off and landing (eVTOL) aircraft operation will become a reality in the next years. 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. The paper explores the 14 CFR Part 23-64 and CS-23-5 reorganization to demonstrate how these changes into the requirement structure will be important and influence the eVTOL certification basis construction. Based on the high probability of bird strike events that an eVTOL may face due to its altitude operation, a study-case for a bird strike certification using the known FAA and EASA approaches is performed, considering the current regulation presented into Part 23/CS-23, Part 27/CS-27, Part 29/CS-29 and SC-VTOL-01. The main differences concluded in this evaluation and possible risks and difficulties that an applicant will face during the process are then explored. A final comparison between a bird strike certification process that may be required by FAA and EASA is presented, as well as a recommendation based on the study.

Keywords: Certification; Airworthiness requirements; Performance-based requirement; eVTOL; Bird strike.

INTRODUCTION

A new generation of aircraft, named electric vertical take-off and landing (eVTOL) can provide to the society a different urban mobility experience. The eVTOL will takeoff similar to a helicopter; however, they will be powered by batteries, hybrid engines, or other new technologies that will make them much quieter than the helicopters. Besides, advanced avionics will enable eVTOLs to navigate with high precision, exchange information digitally, and respond to changes in flight conditions autonomously. The assumptions of urban air mobility will suffer highly disruptive effects with the introduction of eVTOLs: Since these aircraft use less or even no aviation fuel, they could reduce operational costs and, considering that no runways are required whereas this kind of vehicle uses aerodromes similar to helicopters that, in fact, could be used by the eVTOL, it reduces the need for new infrastructure (EmbraerX and Atech 2019). Since the *vertiports* would be spread within towns, and the eVTOL operation is expected to be at low altitudes in urban areas where wildlife presence is frequent, bird strike damage is one of the major safety risks that can impact eVTOL operation.

As any other aircraft engaged in the public transportation, the eVTOL needs to face a certification process in order to obtain a Type Certificate, which is a condition to the issue a Standard Airworthiness Certificate (CofA) (EASA 2012a; FAA 2009; ICAO

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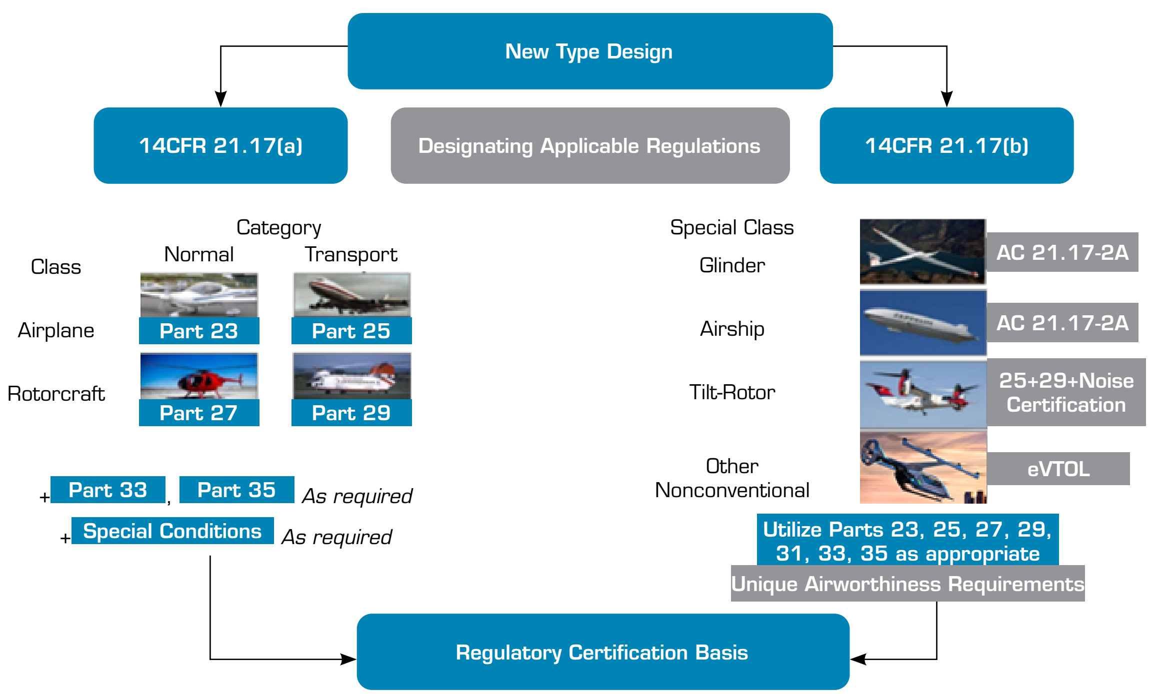
2018). The CofA, from its part, is required by ICAO (2018) for any aircraft engaged in an international operation (USA 1944) and, by FAA and EASA, for any aircraft engaged in public transportation (EASA 2012b; 2018; FAA 2020). According to ICAO's Annex 8, the Type Certificate is a document issued by a State to define the design of an aircraft, engine or propeller type and to certify that this design complies with the appropriate airworthiness requirements of that State (ICAO 2018). Additionally, as defined by §21.41 of 14 CFR 21 (FAA 2009), the Type Certificate includes the type design, the operating limitations, the certificate data sheet, the certification basis and any other conditions or limitations prescribed for the product in subchapter C from Chapter I of Title 14 of Code of Federal Regulations. In the case of aircraft, depending on some of its characteristics, e.g., the passenger-seating configuration and take-off weights, the design is grouped into categories. While there are some differences in EASA's definition for the Type Certificate, for the objectives of the present paper, the use of FAA definition, which is included in the Europeans one, is adequate.

As per §21.21 (FAA 2009), at the end of this process, if the authority considers that the type design meets the applicable airworthiness requirements of this subchapter or that any airworthiness provisions not complied with are compensated by factors that provide an equivalent level of safety, and if it also considers that no feature or characteristic makes it unsafe for the category in which certification is requested, the Type Certificate is issued.

Therefore, is possible to observe that the demonstration of the compliance with the applicable requirements is the main part of certification process. These applicable requirements are designated by FAA according to §21.17 (FAA 2009), and it presents two different possible approaches. As presented in Fig. 1, a new type design certification process developed according to 14 CFR 21.17(a) would present the certification basis constructed according to the applicable airworthiness requirements for each airplane or rotorcraft based on the associated category (Part 23, 25, 27 or 29) in addition to Part 33, 35 or Special Conditions, as required.



Source: Adapted from Webber (2018).

Figure 1. FAA airworthiness certification approaches.

A possible approach for an eVTOL certification basis developed according to §21.17(a), is related with the adoption of airworthiness requirements from Part 23. The amendment 64 from 14 CFR Part 23, and amendment 5 from CS-23 changed prescriptive requirements by performance-based regulations, which enable the applicant to propose airworthiness Means of Compliance (MOC) to address safety rules. This new structure of requirements was conceived to stimulate innovation and the introduction of new technologies through more flexible requirements, reducing paperwork (FAA 2013a). As per AC 21.101-1B and §21.101(d), for a change that contains new design features that are novel or unusual for which there are applicable airworthiness requirements at a later amendment level, this later amendment must be followed to guarantee appropriate safety standards in lieu of a Special Condition. Therefore, since the amendment 64 is composed by performance-based regulations, it is expected that a great number of new design feature will have compliance demonstration through the adoption of 23-64 regulations instead of issuing a Special Condition, which will only be issued as per 14 CFR §21.16 when the subchapter involved does not contain adequate or appropriate safety standards (FAA 2009). Considering the eVTOL certification perspective, although this approach would demand a huge number of Special Conditions, Equivalent Levels of Safety and Exemptions to address the peculiarities of an eVTOL, the paperwork could be significantly reduced by the adoption of requirements from Part 23, since they are now performance-based in the amendment 64.

On the other hand, if the certification approach follows the 14 CFR 21.17(b), the applicable requirements would be constructed by portions of the airworthiness requirements contained in Parts 23, 25, 27, 29, 31, 33, and 35 found by the FAA to be appropriate for the aircraft and applicable to a specific type design (FAA 2009). As per the schematic from Fig. 1, gliders and powered gliders, for example, would follow AC 21.17-2A as guidance to define the acceptable means of showing compliance with Section 21.17(b), while an airship would follow AC 21.17-1A, and a tilt-rotor, which is also a nonconventional aircraft, could have a certification basis composed by requirements from Part 25, 29 in addition to noise certification standards (FAA 2013b; Webber 2018). For an eVTOL certification basis development considering this aircraft as a special class, according to §21.17(b), the product design could be certified based on portions of the airworthiness requirements contained, for example, in Parts 23, 27 and 29, where the applicant would be able to evaluate, for each aspect of the product, the category requirement that would make more sense to be used as applicable in the certification basis.

This paper explores both FAA possible approaches through a case study of bird strike requirements, evaluating how the certification basis could be developed considering the process stablished according with §21.17(a) and §21.17(b).

Since Europe adopts a different approach to designate the applicable requirements (EASA 2012a) and, also considering that EASA published a Special Condition dedicated to eVTOL -SC-VTOL-01 (EASA 2019), it could lead to different applicable requirements and, therefore, certification process. Even though the Special Condition was developed extensively based on CS-23 Amendment 5, which is also largely harmonized with the FAA Part 23-64, it also includes elements of CS-27 and new elements that were deemed appropriate.

The differences of approaches to designate applicable requirements and the existence of a Special Condition could lead to differences on the eVTOL certification process between FAA and EASA, since the airworthiness requirements could be different in each authority. This difference will create a non-isonomic scenario, that is not desirable.

An example of these differences is the requirement related to bird strike protection for airplanes covered on Part 23, which is related only to windshield and pitot tubes protection. According to EASA SC-VTOL-01, though, protection against windshield, structures and system protection is required.

The present paper evaluates the hypothesis of the existence of a difference between EASA and FAA approaches to an eVTOL certification through the analysis of bird strike requirements covered in each certification, as well as the process to be applied for the compliance. In addition, based on the analysis of bird strike requirements, the paper proposes a possible MOC that could be proposed by an applicant to FAA and EASA, to cover the special needs of eVTOL operational scenario, considering both authorities.

CERTIFICATIONS ASPECTS

Before the issuance of the new amendment (amendment 23-64 for FAA and amendment 5 for EASA), the 14 CFR Part 23 and the CS-23 were composed by prescriptive requirements, which addressed specific designs, hence prescribing solutions that could potentially hamper design organizations from finding alternative solutions more economical while providing acceptable levels of safety. These regulations were comprised by a huge number of regulatory materials, which were supplemented by orientation material issued by the authorities (e.g., Advisory Circulars and Acceptable Means of Compliance [AMC]), as well as industry standards (e.g., Society of Automotive Engineers [SAE] and American Society for Testing and Materials [ASTM] standards), to lay out the MOC that an applicant would use to show compliance with applicable airworthiness requirements (FAA 2013a).

Furthermore, in the case of the eVTOL, since the characteristics of the design and operation of this aircraft are not foreseen in the regulation, a significant number of Special Conditions could be necessary. According to AC 20-166A, under §21.16 or §21.101(d), a special condition is issued only if the existing applicable airworthiness standards do not contain adequate or appropriate safety standards for an aircraft, aircraft engine, or propeller because of novel or unusual design features of the product to be type certificated. The FAA uses the Special Conditions to address novel design features for which there are no regulations, or the regulations are inadequate (FAA 2014). Moreover, according to EASA 21.A.16B regulation, EASA shall prescribe special detailed technical specifications, named special conditions, for a product, if the related airworthiness code does not contain adequate or appropriate safety standards for the product (EASA 2012a).

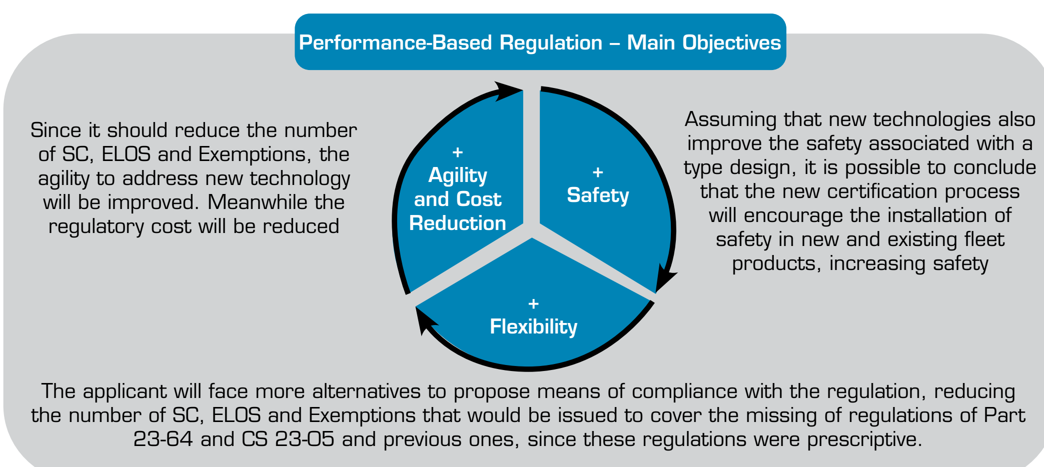
This approach, however, created barrier, once the establishment of specific standards, that are performed through the issuance of Special Conditions, Equivalent Levels of Safety or Exemptions, could take from 6 months to years to be fully completed. The issuance of this kind of document involves a significant time and paperwork, which also adds risk and can delay the completion of a project (USA 2020).

To promote a forum for the United States aviation community to discuss and provide recommendations to assist the FAA in developing the appropriate regulatory approach for addressing a potential reorganization of Part 23, covering design safety regulations for new and existing airplanes, an Aviation Rulemaking Committee (ARC) was created. The 14 CFR Part 23 ARC became effective on August 15, 2011 (FAA 2013a).

After years of an extensive discussion, in 2016, the FAA issued the amendment 64 to 14 CFR Part 23, which became effective in 2017 (FAA 2016). Also, in 2017, EASA published the amendment 5 to its Certification Specifications 23, where the concept of performance-based regulation was incorporated (EASA 2017).

Later on, the FAA published the advisory circular (AC) 23.2010-1, which provides guidance on how to submit a proposed MOC to 14 CFR Part 23 for acceptance by the Administrator in accordance with § 23.2010. According to this new regulation, the applicant can use an MOC already accepted by the FAA, such as an ASTM, or propose to the authority an alternative MOC, that can also be a requirement from Part 23 in an amendment prior to 64, a requirement from Part 25, an AC, or another way to comply with the requirement, which will need to be accepted by the authority. Therefore, different from the old structure, where a prescribed requirement should be complied according to specific MOC mainly defined by ACs, a performance-based regulation gives the opportunity for the manufacturer to propose the way that the product design will meet the safety intent of the specific regulation (FAA 2017a).

Based on those aspects, it is possible to admit that the following objectives will be reached with a performance-based regulation (Fig. 2).



Source: Adapted from FAA (2013a).

Figure 2. Performance-based regulation objectives.

THE CREATION OF EASA SC-VTOL-01

As aforementioned, EASA can issue a Special Condition if the related airworthiness code does not contain adequate or appropriate safety standards for the product. Anticipating the increase application for eVTOL designs certification in near future, and in the absence of certification specifications for the type certification of an eVTOL, a dedicated technical specification in the form of a special condition for eVTOL aircraft was published by EASA in 2019. This special condition addresses the eVTOL characteristics and prescribes airworthiness standards for the issuance of the type certificate, and changes to this type certificate, for a person carrying eVTOL aircraft in the small category.

The Special Condition does not present the MOC for the applicable regulation. Therefore, on May 25th, 2020, EASA published the MOC SC-VTOL, which presents the clarification of EASA's interpretation of the regulation objectives and possibilities to demonstrate compliance with SC-VTOL-01 (EASA 2021a).

BIRD STRIKE CERTIFICATION

Bird strikes are defined as a collision between a bird and an aircraft which may occur during any phase of flight, but are most likely during the take-off, initial climb, approach, and landing phases, due to the greater numbers of birds in flight at lower levels (Bird strike 2022).

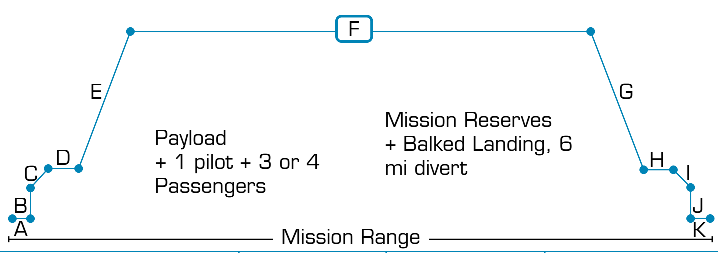
In order to decrease the number of bird strikes or alleviate the consequences of a bird strike, several solutions have been implemented by the aviation authorities worldwide, including enforcing strict regulations on the required safety characteristic (Hedayati and Sadighi 2015).

According to 1990–2020 report from Wildlife Strikes to Civil Aircraft in the United States, (FAA 2021) there is a relation between mean body mass and likelihood of a strike causing damage to aircraft for the 33 species of birds most frequently identified as struck by civil aircraft in the USA. The report states that, for every 100 g increase in body mass, there was a 1.22% increase in the likelihood of damage.

Additionally, the highest probability of bird-aircraft collisions is at low altitudes. According to the data presented in Wildlife Strikes to Civil Aircraft in the United States 1990–2020 report, 82% of the bird strikes for civil aviation in the USA between 1990 and 2020 occurred below 1,500 ft (FAA 2021).

Moreover, when evaluating the strikes occurred by a rotorcraft, 83% of all strikes occurred below 1500 ft. For a rotorcraft, strikes most often occur during the *en route* phase of flight. This characteristic is related to the rotorcraft operation characteristic, since they fly *en route* at significantly lower altitudes than large fixed-wing transport aircraft. A rotorcraft tends to cruise typically at altitudes between 500 and 5,000 ft (Stadtmueller 2016).

While, obviously, there is no data related to bird strike on eVTOL operation, according to a study from Uber Elevate, the eVTOL cruise phase should be performed at 1,500 ft above ground level, as presented in Fig. 3 (Uber 2020).



<table>
<tr><th></th><th>Segment</th><th>Distance (mi)</th><th>Vertical Speed (ft/min)</th><th>Horizontal Speed (mph)</th><th>AGL Ending Altitude (ft)</th></tr>
<tr><td>A</td><td>Ground Taxi</td><td rowspan="2">No Distance Credit</td><td>0</td><td>3</td><td>0</td></tr>
<tr><td>B</td><td>Hover Climb</td><td>0 to 500</td><td>0</td><td>50</td></tr>
<tr><td>C</td><td>Transition + Climb</td><td rowspan="7">Sizing | Repeated 60 | 25</td><td>500</td><td>0 to 1.2*Vstall</td><td>300</td></tr>
<tr><td>D</td><td>Departure Terminal Procedures</td><td>0</td><td>1.2*Vsatall</td><td>300</td></tr>
<tr><td>E</td><td>Accel + Climb</td><td>500</td><td>0 to 1.2 V*stall to 150</td><td>1500</td></tr>
<tr><td>F</td><td>Cruise</td><td>0</td><td>150</td><td>1500</td></tr>
<tr><td>G</td><td>Decel + Descend</td><td>500</td><td>150 to 1.2*Vstall</td><td>300</td></tr>
<tr><td>H</td><td>Arrival Terminal Procedures</td><td>500</td><td>1.2*Vstall</td><td>300</td></tr>
<tr><td>I</td><td>Transition + Descend</td><td>500 to 300</td><td>1.2*Vstall to 0</td><td>50</td></tr>
<tr><td>J</td><td>Hover Descend</td><td rowspan="2">No Distance Credit</td><td>300 to 0</td><td>0</td><td>0</td></tr>
<tr><td>K</td><td>Ground Taxi</td><td>0</td><td>3</td><td>0</td></tr>
<tr><td>L</td><td>Reserves</td><td colspan="4">Balked Landing, 6 mi divert at 500 feet AGL</td></tr>
</table>

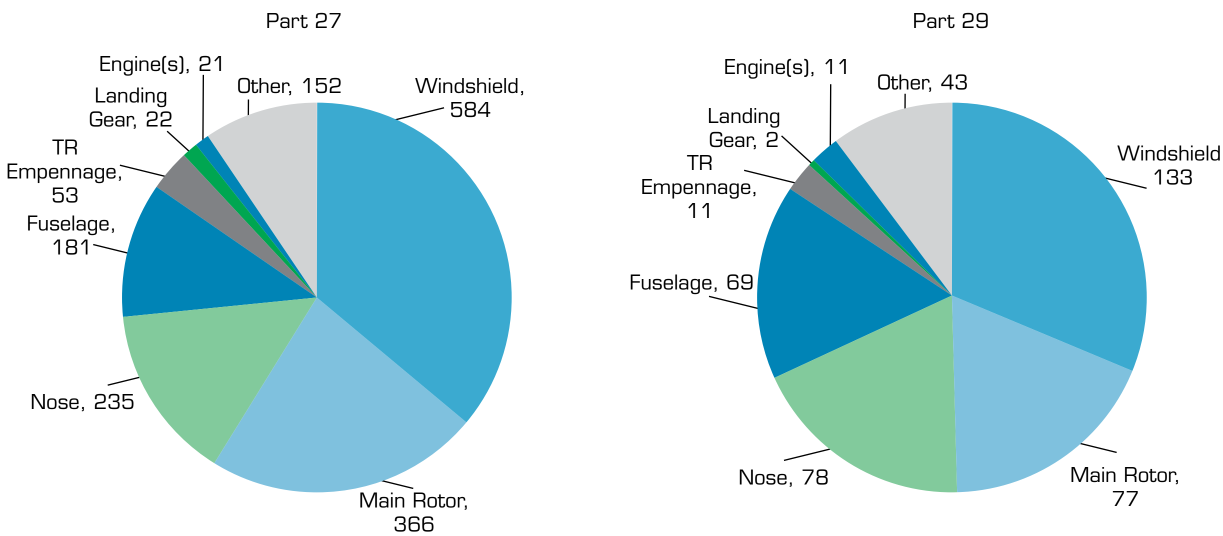
Source: Retrieved from Uber (2020).

Figure 3. UberAir vehicle requirements and missions.

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. Furthermore, the aircraft will need to comply with the type design requirements for bird strike, to guarantee that the product presents the adequate level of safety for this aspect.

Also, it is possible to assume that eVTOL operation should be similar to the performed by a rotorcraft. Therefore, this section presents some specifically data regarding bird strike events related with Part 27 and Part 29 rotorcraft.

According to the Aviation Rulemaking Advisory Committee (ARAC) Rotorcraft Bird Strike Working Group report (FAA 2017b), when evaluating a rotorcraft strike impact location, 85% (Part 27) and 84% (Part 29) occurs in front of the windshield, main rotor, nose and fuselage, as presented in the Fig. 4.



Source: Adapted from FAA (2017b).

Figure 4. Distribution of bird strikes on the NSWD on Part 27 and Part 29 rotorcraft between Jan 1990 and Feb 2016.

Table 1 presents the number of birds reported during a strike event, for both Part 27 and Part 29 certified products. More than 90% of the events occurred with a single bird per strike event on rotorcraft, however, it is important to point out that a single bird may result in multiple strike locations (FAA 2017b).

Table 1. Number of birds reported for a strike event.

Number of Birds Per Strike Event	Part 27	Part 29
A single bird per strike event	1,186 (96.2%)	312 (93.7%)
1-10 bird per strike event	43 (3.5%)	18 (5.4%)
11-100 bird per strike event	1 (0.2%)	2 (0.6%)
Unrecorded number of birds per strike event	1 (0.1%)**	1 (0.3%)

**One record listed zero bird strikes, but rather a bird avoidance that caused a hard landing of Part 27 rotorcraft. Source: Retrieved from FAA (2017b).

BIRD STRIKE REQUIREMENTS FOR AN EVTOL

The bird strike evaluation requirements will be an important issue to the eVTOL due to its operational characteristics, but it is probable that the different approaches lead to different requirements imposed by each authority. In this context, an evaluation regarding all the current requirements related with bird strike applicable to the Normal Category Airplanes/Rotorcraft and

Transport Category Airplanes/Rotorcraft is necessary. A comparison between FAA and EASA Airworthiness Requirements is accomplished, considering the last amendment from each requirement. The engine and propeller requirements are not part of the study in this paper.

14 CFR Part 23 / CS-23

For 14 CFR Part 23 (FAA 1996a) and CS-23 (EASA 2003), in general there are no specific requirements relating to bird strike for Normal, Utility and Aerobatic aircraft categories. The only requirements related with Commuter Category aircraft address the windshield and pitot tubes, in order to guarantee that the windshield will withstand (without penetration) a single impact from a 0.91 kg (2 lb) bird at the aircraft's maximum approach flap speed and the pitot tubes must be far enough to avoid damage to both tubes in a collision with a single bird. Additionally, there is no difference between FAA and EASA requirements.

14 CFR Part 25 / CS-25

Both Part 25 (FAA 2015) and CS-25 (EASA 2016) present a damage tolerance requirement, where the airframe must be designed in order to guarantee capability of continued flight and landing after the impact of a 4 lb weight when the velocity of the airplane is equal to design cruise speed (V_C) at sea level or 0.85 V_C at 8,000 ft, whichever is more critical.

The FAA and EASA requirements for this category of aircraft present differences in the wording, however, the principal requirements are, effectively, the same. The main difference between FAA and EASA requirements is related with the §25.631. The 14 CFR Part 25 (FAA 2015) requires that the empennage structure should withstand the impact of an 8 lb bird at V_C. CS-25 (EASA 2016) has no separate requirement for the empennage, which is therefore covered by the general structural requirement of 4 lb at V_C.

14 CFR Part 27 / CS-27

Neither the FAA (1999) nor the EASA (2021b) regulation presents any requirement for protection against bird strike.

14 CFR Part 29 / CS-29

FAA (1996b) and EASA (2021c) requirements for this type of aircraft are the same. The regulation §29.631 requires that even with an impact with a single 1-kg bird at the greater of the maximum safe airspeed (VNE) or maximum level-flight airspeed at rated power (VH) (at up to 8,000 ft), the rotorcraft needs to guarantee the continue safe flight and landing.

METHODOLOGY

EASA: Certification Basis Development

It is possible to consider that both requirements from SC-VTOL-01 listed below will be applicable for a bird strike certification with EASA.

> VTOL.2250 Design and construction principles
>
> (f) The aircraft must be designed to ensure that after a likely bird impact the capability remains to conduct:
>
> (1) a controlled emergency landing for Category Basic with a maximum passenger seating configuration of 7 or more; or
>
> (2) continued safe flight and landing for Category Enhanced
>
> VTOL.2320 Occupant physical environment
>
> (a) The aircraft must be designed to:
>
> (3) protect the occupants against serious injury due to breakage of windshields, windows, and canopies (EASA, 2019)

The Proposed MOC with the Special Condition VTOL (MOC SC-VTOL) document issued by EASA establishes the safety and design objectives to perform the VTOL.2250(f) and VTOL.2320(a)(3) compliance demonstration (EASA 2021a).

Evaluating the VTOL.2250(f) requirement's MOC, two kinds of evaluation are presented: for a single bird strike and for a multiple bird strike scenario.

MOC VTOL.2250(f)

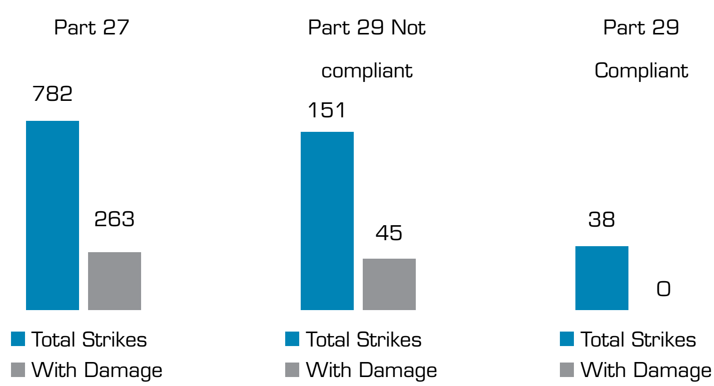
1.Single bird strike evaluation:

(a) In accordance with VTOL.2250(f), VTOL aircraft in the Category Basic with a maximum of 7 to 9 passenger seats or VTOL aircraft in the Category Enhanced must be designed to ensure capability of controlled emergency landing, respectively of continued safe flight and landing, after impact of a 1.0-kg (2.2-lb) bird. This should be ensured in the most critical configuration for the corresponding velocity of the VTOL (relative to the bird along the flight path of the vehicle) up to the maximum speed in level flight with maximum continuous power, at maximum operating altitude up to 8,000 feet whichever is lower.

(b) Compliance should be shown by tests or by analysis based on tests carried out on sufficiently representative structures of a similar design" (EASA, 2021a)

The MOC presented in section 1(a)(b) from the EASA MOC SC-VTOL is very similar to the requirement §27.631 proposed by the Rotorcraft Bird Strike Working Group (RBSWG). This group was tasked by the FAA to provide the ARAC with recommendations on bird strike protection for Parts 27 and 29 airworthiness standards (FAA 2017b).

Based on the data available on the National Wildlife Strike Database (NWSD), that includes the rotorcraft impact locations, phase of flight, time of day that the events occurred and airspeed, the group evaluated that, while only 22% of Part 29 rotorcraft are certified complying with 14 CFR §29.631, this requirement, incorporated into 14 CFR Part 29 only in the amendment 29-40 was highly effective, as observed in Fig. 5, where zero strikes into the windshields certified to §29.631, resulted in damage (FAA 1996b).



Source: Adapted from FAA (2017b).

Figure 5. Windshield Strikes recorded in NWSD.

Based on these evaluations, the RBSWG concluded that an adoption of a similar requirement for Part 27 (FAA 1999) aircraft should be implemented, since this kind of aircraft have more than four times more bird strikes than Part 29 (FAA 1996b) rotorcraft, according to NWSD data (FAA 2017b).

Therefore, the group proposed the creation of a new airworthiness requirement, §27.631, for newly type certificated Part 27 (FAA 1999) normal category rotorcraft, the same requirement applicable to Category B Part 29 (FAA 1996b) rotorcraft, as can be observed:

The rotorcraft with a maximum occupancy (pilot plus passengers) of 7 to 9 must be designed to ensure capability of safe landing after impact upon the windshield with a 2.2-lb (1.0-kg) bird when the velocity of the rotorcraft (relative to the bird along the flight path of the rotorcraft) is equal to VNE or VH (whichever is the lesser) at altitudes up to 8,000 feet. Compliance must be shown by tests or by analysis based on tests carried out on sufficiently representative structures of similar design (FAA, 2017b, p. 4)

Comparing both requirements, it is noticed that the same number of passengers and bird mass are considered, requesting to a design that ensures capability to a safe landing after a bird impact. Both requirements consider the maximum operating altitude up to 8,000 ft. Moreover, for both cases, the compliance is asked to be done by analysis based on tests.

On the other hand, the velocity of the rotorcraft specified in the proposed §27.631 (FAA 2017b) is related to VNE or VH (whichever is the lesser), while the VTOL.2250(f) (EASA 2019) considers only the VH. In addition, it is important to highlight another difference between both requirement, that is the areas to be considered for bird strike evaluation, since §27.631 (FAA 2017b) would require the protection specifically for windshield, while the VTOL.2250(f) consider both windshield, structure and systems (EASA 2019).

Another difference is that EASA requirement is related to paragraph (c) of MOC VTOL.2250(f), that requires a bird impact without penetration for maximum speeds above 50 kt when evaluated a strike into the windshield (EASA 2021a). A possible reason for this is that ARAC group concluded that almost 60% of the bird strikes events for Part 27 rotorcraft occurred with speeds above 80 knots, besides, the lowest speed reported for which the windshield was penetrated was 55 knots (FAA 2017b).

> MOC VTOL.2250 (f)
>
> (c) The following parts should be evaluated for a single bird strike:
>
> (1) The windshield directly in front of occupants and the supporting structures for these panels should be capable of withstanding a bird impact without penetration for maximum speeds above 50kt.
>
> (2) Other structures, systems and equipment should also be evaluated. The selection of the areas to be substantiated should be the result of a comprehensive hazard analysis based on:
>
> (i) Exposed areas of the structure and internal equipment and systems inside of these exposed areas in case of bird penetration or shock loads; and
>
> (ii) Their criticality and their ability to ensure continued safe flight and landing (for Category Enhanced) or controlled emergency landing (for Category Basic) (EASA, 2021a)

According to the letter (d) from MOC VTOL.2250(f) (EASA 2021a), EASA also expects the applicant to perform a comprehensive hazard analysis to evaluate exposure of the eVTOL structure, systems, and equipment. It will be requested to perform an evaluation related with the events that can generate a direct effect for Continue Safety Flight and Landing or (CSFL) Control Emergency Landing (CEL), by the loss of a critical function. In addition, all the induced effects also need to be evaluated, for non-CSFL or CEL systems, for which will have no loss of functionality or redundancy after a strike (Hereson and Rossoto 2019).

Also, different from the current regulation for bird strike considering Part 23, Part 25 and Part 29 presented in this paper, EASA will also request the applicant to demonstrate continued safe flight and landing for an eVTOL after multiple bird strike events, as detailed below.

> MOC VTOL.2250 (f)
>
> 2. Multiple bird strike evaluation:
>
> (a)VTOLs are generally equipped with redundant systems and structures. To ensure continued safe flight and landing (for Category Enhanced) or controlled emergency landing (for Category Basic) following a multiple bird strike, an evaluation should be performed of the effects of such multiple bird strike in the most critical configurations, within the range of airspeed for normal operation up to 4000ft MSL (Mean Sea Level).
>
> (b) The applicant should consider potentially vulnerable redundant systems and structures and their effective exposed area (wing, lift surfaces, rudder, ailerons…).
>
> (c) An acceptable approach is to show that there is no loss of function of the element that is impacted after a single impact with a medium sized bird of 0.450 kg. Alternatively, scenarios evaluating multiple bird impacts distributed across each structure or system can be proposed by the applicant considering medium birds and small birds according to the MOC VTOL.2400 guidance. Multiple bird strike evaluation is not required for the windshield (EASA, 2021a)

The MOC for the VTOL Special Condition VTOL – Issue 2 also proposes that the compliance demonstration with airframe and propulsion systems can be done using the MOC VTOL.2400(b) as a guidance, which describes that the Special Condition E-19 on Electric/Hybrid Propulsion System is an accepted specification to be met by electric/hybrid lift/thrust units that are installed in VTOL aircraft. On that way, it shall be considered as an additional option to be evaluated in addition to the MOC already considered by MOC VTOL.2250(f) (EASA 2021d).

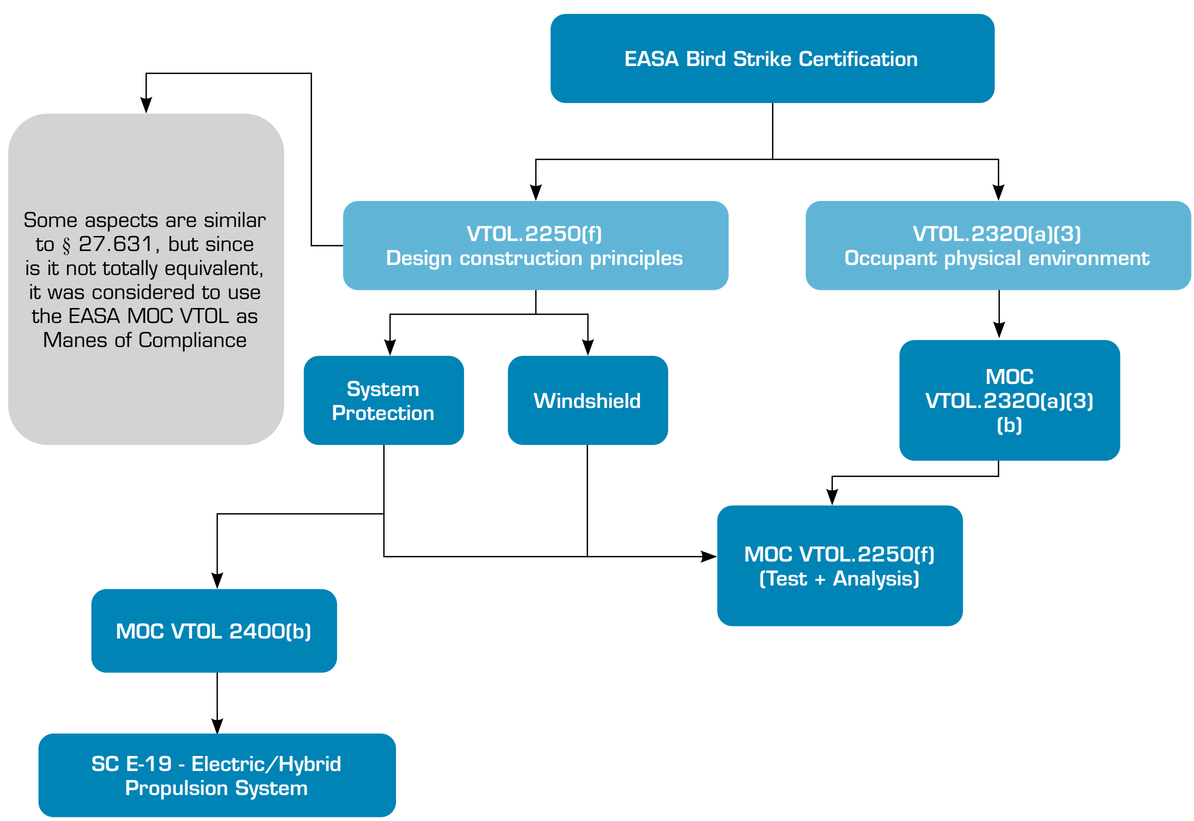
Regarding the VTOL.2320(a)(3), the MOC-2 SC-VTOL states that:

> MOC VTOL.2320(a)(3)
>
> Occupant protection from breakage of windshields, windows, and canopies
>
> (a) CS 27.775 Amdt. 5 (or later) is accepted as a means of compliance.
>
> (b) In addition, for Category Enhanced and Category Basic with a maximum seating configuration of 7 or more, the windshield should be evaluated for a single bird strike in accordance with VTOL.2250(f)" (EASA, 2021d)

Thus, EASA already considered, as an acceptable MOC, the adoption of a requirement from CS-27 category. However, for this case study, the MOC presented in paragraph (b) will be considered, where the requirement VTOL.2320(a)(3) can be demonstrated by the showing compliance with VTOL.2250(f).

Proposal of MOC Structure For EASA

Based on the current regulation presented in SC-VTOL-01 and associated MOC-2 SC-VTOL presented in this section, the following schematic reflets a proposed certification basis (Fig. 6). This structure is defined based on the assumptions described in this paper.



Source: Elaborated by the authors.

Figure 6. EASA bird strike certification.

FAA: Certification Basis Development

Since FAA is adopting a different approach, the study below for a bird strike compliance with 14 CFR Regulations assumes that an eVTOL certification will be conducted based on §21.17(a), using Part 23 category as baseline. When evaluating the Part 23 Amendment 64 requirements, the only specific requirement for bird strike is the §23.2320, as detailed below.

> §23.2320 Occupant physical environment.
>
> (b) For level 4 airplanes, each windshield and its supporting structure directly in front of the pilot must withstand, without penetration, the impact equivalent to a two-pound bird when the velocity of the airplane is equal to the airplane's maximum approach flap speed (FAA, 2016)

This requirement is applicable for level 4 airplanes, which considers a maximum seating configuration of 10 to 19 passengers.

An eVTOL will transport two to six passengers across short to mid-range distances (EmbraerX and Atech 2019). It is possible to take as examples some eVTOLs projects already shared with the market, as EVE, CityAirbus Demonstrator, S-4, The Cora, Lilium Jet and VoloCity, that consider passengers between 2 and 6, which would be classified as a Level 2 for Part 23. Although the §23.2320(b) does not require a bird strike protection demonstration for Level 2, based on the urban air mobility environment that an eVTOL will operate and considering the altitude operation and the high probability of bird strikes until 1,500 ft, it can be assumed that FAA will certainly request a certification demonstration for bird strike protection.

Hence, an evaluation of some possibilities to be proposed to FAA as MOC to bird strike is presented below. Evaluating the Part 23 Accepted MOC Based on ASTM Consensus Standards published by FAA in the Federal Register (FAA 2022), the ASTM F3264-21 Section 7.5 is considered an accepted means for compliance with §23.2320 (Table 2).

Table 2. Part 23 Accepted MOC Based on ASTM - 14 CFR 23.2320.

Part 23 Amendment 23-64 Regulation(s)	ASTM F3264-21 Section(s)	ASTM F3264-21 Subsection(s)
23.2320	7.5 Occupant Physical Environment:	7.5.1 F3061/F3061M – 20 Standard Specification for Systems and Equipment in Small Aircraft 7.5.1.1 F3227/F3227M – 21 Standard Specification for Environmental Systems in Small Aircraft 7.5.2 F3083/F3083M – 20a Standard Specification for Emergency Conditions, Occupant Safety and Accommodations 7.5.3 F3114 – 21 Standard Specification for Structures

Source: Retrieved from FAA (2022).

As presented in Table 2, there are four ASTMs considered subsections from ASTM F3264-21, which can be considered accepted to show compliance with Occupant Physical Environment. In these documents, a reference for bird strike requirement is done only in the ASTM F3114 – 21 Standard Specification for Structures, as described below:

> 4.7.6.1 Windshield panes directly in front of the pilots in the normal conduct of their duties, and the supporting structures for these panes, must withstand, without penetration, the impact of a 2 lb bird when the velocity of the airplane (relative to the bird along the airplane's flight path) is equal to the airplane's maximum approach flap speed (ASTM International, 2021, p. 2)

Bird Strike Protection for Windshield: Certification Basis Analysis

Considering the eVTOL design and operation, it would make more sense to perform the show compliance with §23.2320(b) based on a requirement from Part 27 or Part 29. The recommend requirement §27.631, which was proposed to be created through the ARAC group study would be an option to be used to show compliance with the intent to guarantee safe operation after a bird strike into an eVTOL windshield. Although §27.631 was not officially created by the certification authority and is still just a RBSWG recommendation, it could be proposed as a MOC with §23.2320(b). This MOC would need to be accepted by the authority as per §23.2010(b), which states:

> §23.2010 Accepted means of compliance.
>
> (b) An applicant requesting acceptance of a means of compliance must provide the means of compliance to the FAA in a form and manner acceptable to the Administrator (FAA, 2016)

It is important to emphasize that this kind of approach is possible only because of the Part 23 reorganization. If we consider the requirements from Part 23 Amendment 63, this approach would not be possible, therefore, a Special Condition would be the only alternative to address this certification, what could increase the certification process costs. This is a clear example of the benefits generated by this reorganization. Besides, this flexibility in the certification process will be an important aspect to be considered during the eVTOL certification basis structure.

Nevertheless, if the approach defined to develop the certification basis follow the §21.17(b), it is possible to consider that the certification basis would present the requirement §27.631 into the basis, but this approach would only be possible if the requirement recommended by RBSWG was officially created by the certification authority.

Bird Strike Protection for Structures and Systems - Certification Basis Analysis

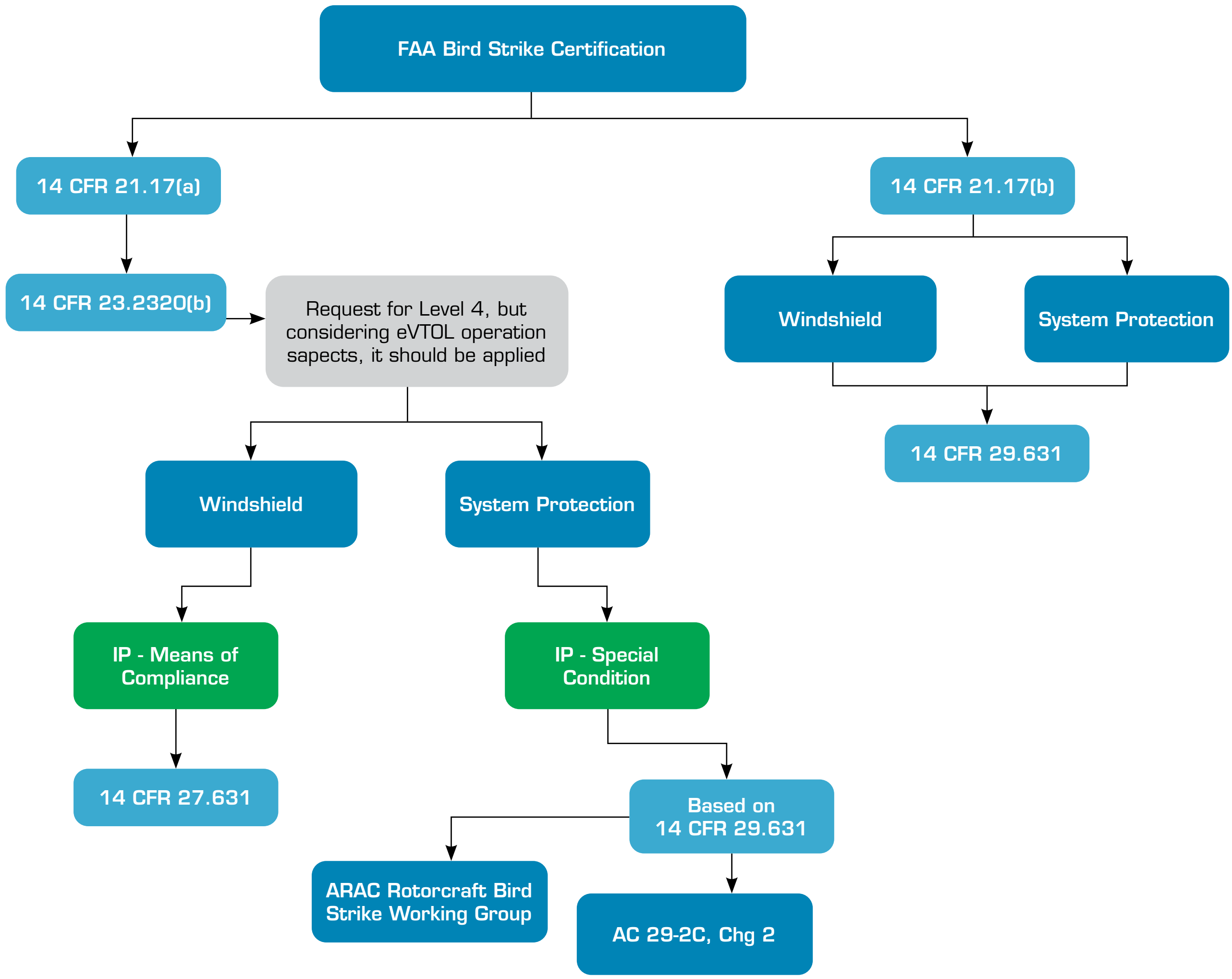
Considering a certification process through the §21.17(a): although the requirement §23.2320 does not consider the protection for bird strike into the structure and systems, based on the high probability of bird strikes in the urban air mobility environment presented in this paper, it is possible to presume that FAA would impose a special condition, since the existing applicable airworthiness standards do not contain adequate or appropriate safety standards for an aircraft.

A possible requirement for the Special Condition could be the requirement §29.631. This requirement defines that after a strike, the rotorcraft is required to be able to perform a safe landing (for Category B rotorcraft, what is adequate considering eVTOL characteristics), which can be understood that the main systems must be properly working even after a bird strike. The compliance with this requirement can be done following the AC 29-2C, which presents the procedures to show compliance with §29.631.

Nevertheless, if the approach defined to develop the certification basis follow the §21.17(b), it is possible to consider that the certification basis would present the requirement §29.631 into the basis, since it shall be considered the most appropriate for this design. In this case, it is also possible to consider that, since the requirement §29.631 is more restrictive than §27.631, as it covers the protection against both windshield and structures/systems, the adoption of only the requirement from Part 29 would be enough.

Proposal of MOC Structure For FAA

Figure 7 presents a summary structure of the possible approaches that could be used to define a certification basis for a bird strike certification considering FAA regulation. The structure is defined based on the authors' assumptions described in this chapter.



Source: Elaborated by the authors.

Figure 7. FAA bird strike certification.

RESULTS

EASA vs. FAA Comparative Analysis and Considerations Between the Certification Basis Defined for Bird Strike

The different approaches presented by EASA and FAA certification can have as outcome different necessities to be performed to show compliance with applicable requirements. Table 3 presents a comparison about the main factors considered in the requirements, between FAA and EASA regulations. The main differences pointed out related with the aircraft speed and the multiple bird strike evaluation requested by EASA are points of concern that an applicant will face to certify an eVTOL.

Due to the different requests and approaches followed by EASA and FAA, unless the applicant decides to comply with the most restrictive aspects required by each authority, an identical eVTOL project shall not be certified in both authorities at the same time, since the discrepancies between requirements may demand differences in the projects to enable a certification. This is an important matter that will need accurate evaluation during an application in order to guarantee an interesting strategy for certification, mitigating any surprises during the process.

Table 3. EASA vs. FAA: Comparison between the main variables considered in the bird strike certification evaluation.

Variables	EASA	FAA	Considerations
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	V_H * Specifically for windshield protection, panels should be capable of withstanding a bird impact without penetration for maximum speeds above 50 kt.	V_{NE} or V_H	While EASA considers the maximum speed in level flight with maximum continuous power (V_H), both 14 CFR 27.631 and 14 CFR 29.631 consider also the V_{NE}. 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 V_{NE} or V_H 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). A rotorcraft system may be vulnerable to multiple bird strike events, where the following systems can be affected, for example: air data sensors, antennas, lights, and various equipment. The ARAC group concluded from the studied data that separation, redundancy, or low criticality of these systems effectively minimizes that hazard, therefore the NWSD data did not indicate a significantly increased risk for multiple birds and thus implies an adequate level of protection is provided by 14 CFR 29.631, where any additional protection was requested by the ARAC (FAA 2017b). This is an aspect that presents potentially risks for certification when the same eVTOL project is considered to be certified in both FAA and EASA.
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.

Source: Elaborated by the authors.

CONCLUSION

Initially, it is important to mention how the regulation reorganization through the issuance of CS-23-5 and 14 CFR Part 23-64 was important to minimize the number of Special Conditions that would be issued for eVTOL certification. Although EASA has been adopting a different certification approach for eVTOL, since they issued the SC-VTOL, the requirements structure reorganization was still important because the SC-VTOL was developed based on CS-23-5, including aspects related with CS-27. On the other hand, the ASTMs, that are MOC already accepted by the authority, do not address all the aspects that will be required during the certification of an eVTOL yet.

Notwithstanding the above, eVTOL manufacturers will face a challenge to certify the same product in both the FAA and EASA authorities, once there are differences between the requirements of each authority. This mean that the same strategy of compliance accepted by one authority will not necessarily be accepted by the other, which will require additional certification efforts and can significantly increase the costs involved in the process. In the specific case of the bird strike studied in this paper, the differences that would be required in each certification process are clearly noticed, mainly related to the multiple bird strike assessment that is required by EASA while in the model proposed by FAA assessment, it would not be required. Another important factor is related to the speeds and areas of the aircraft that will be considered in the demonstration of each requirement.

However, this paper provided a detailed evaluation of the MOC presented in EASA eVTOL against the possible MOC that can be proposed to FAA, as well of MOC already considered in ASTMs. Having all this data mapped in the beginning of the process can mitigate problems during the certification process. Moreover, based on the differences of both certification approaches, it is possible to say that, since an eVTOL certification process is different from the already known, maybe an interesting strategy will be the application of the project in a specific authority (FAA or EASA) instead of facing a double certification at the same time, since this strategy could require different developments in the project, increasing the risks and costs.

AUTHORS' CONTRIBUTIONS

Conceptualization: Cardoso SHSB, Godoy JRS; **Methodology:** Cardoso SHSB; Oliveira MVR; **Validation:** Oliveira MVR, Godoy JRS; **Writing - Original Draft:** Cardoso SHSB; **Writing - Review & Editing:** Cardoso SHSB;Godoy JRS Oliveira MVR.

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