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Treatment of uncertainty in drone design verification: A critical look at the EASA requirements

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Abstract – Drones are widely used in the industrial sector, offering benefits such as access to cost effective collection of geospatial and imagery data. However, such systems are complex and prone to failure, making design verification and EASA (European Union Aviation Safety Agency) certification required for acceptable quality before operations. One aspect then assessed is the level of risk. For operators seeking certification, EASA has developed SC Light-UAS 01, providing process and technical specifications. A premise in these being strong foundations for the assessments, where significant uncertainty, or weak strength of knowledge, may challenge the validation process and decision-making. This paper aims to clarify uncertainty handling and discuss strength of knowledge in relation to the EASA requirements and validation process. For this purpose, we compare the standards defined by EASA with key standards used in the aviation industry, including ASTM (American Society for Testing and Materials) and ISO standards. Our findings reveal that uncertainties and the lack of specific guidance on the verification process can lead to delays, cost overruns, and even failures in drone operations. Furthermore, current standards fail to meet the demands of drone operations due to knowledge gaps. Recommendations to strengthen the design verification process include refining the scope of acceptable means of compliance, fostering collaboration and research among stakeholders. This paper provides implications for a more reliable verification process in various industrial contexts.

Keywords: SORA, design verification, unmanned air vehicle, aviation, risk assessment, means of compliance.

1. Introduction

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are increasingly used in various industries due to their unique capabilities. Unlike conventional aircraft, UAVs can be remotely controlled through ground control stations, making them suitable for hazardous or challenging areas. UAVs comprise interconnected components and subsystems, including flight control systems, sensors, communication systems, power systems, and payload systems, that work together to facilitate their efficient operation.

However, the complexity of UAV systems can lead to failures compromising safety both in the air and on the ground. This makes it crucial to ensure that UAV design and operation meet safety and quality standards through design verification processes. To achieve acceptable risk performance, UAV operators seeking design certification must comply with the requirements and specifications provided in the European Union Aviation Safety Agency's (EASA) Special Condition Light Unmanned Aircraft Systems (SC Light-UAS) 01 document (EASA, 2020).

During the design verification process, a comprehensive assessment is carried out to confirm that the product in focus delivers the required quality. This evaluation step is crucial as it emphasizes the alignment of the product with the specified standards.

Uncertainty and available knowledge may have a significant influence on the design verification assessment. Uncertainties regarding the results could potentially mislead the end-users of the product. Besides, there might be information gaps or weak sources challenging quality of the assessment. Such knowledge issues might be underlying reasons for uncertainties. It is important to capture the strength of knowledge in this process.

Uncertainty refers to the possibility that certain outputs may not coincide with estimates or predictions, e.g., when assessing strategic measures to reduce the number of people at risk, or measures to mitigate the impact of a disaster. If mitigating measures are unclear or if standards like ISO, ASTM (American Society for Testing and Materials), etc., are not carefully addressed, it could lead to confusion, delays, and potentially poorly described risks during the design verification process.

Further, strength of knowledge represents key information regarding input used to analyze achievement of compliance criteria. As such, it encompasses a comprehensive understanding of the relevant standards, their application, and the methodologies used to test and validate design integrity. The strength of knowledge challenge can be exemplified through the ASTM F3322-18 standard, an international standard for systems and components of UAVs, particularly parachute recovery. This includes understanding the applicability of standards for drones with specific characteristics and the methodologies required to appropriately test parachute recovery systems. However, a lack of sufficient knowledge base in this standard can complicate a more efficient and reliable design verification process.

In this paper, the importance of capturing uncertainty and strength of knowledge in the design process, as well as the relevance of standards issued by organizations such as ISO and ASTM, is emphasized. The objective is to enhance understanding of the uncertainties involved in the UAV design verification process and highlight the lack of knowledge underpinning them.

To fulfill this objective, the design verification process is outlined in Section 2, with fundamental uncertainties being highlighted. Section 3 further delves into the uncertainties in the design verification document, exploring how the strength of knowledge is expressed in associated documents. The relevance of standards is discussed in Section 4, where experience data collected by UAV operators in Europe is also considered. Section 5 concludes the paper, providing conclusions and recommendations for improving the UAV design verification process. The importance of capturing uncertainty and expressing the strength of knowledge in a clear and meaningful way to enhance the overall effectiveness and reliability of the process is underscored.

2. Design verification process and its fundamental uncertainties

2.1. *Design verification process*

In the context of aviation regulation, it is important to note that manned aircraft and Unmanned Aerial Vehicle (UAV) operators are subject to different authorization processes under EU air law. Manned aircraft operators require permission based on the operation and aircraft, while UAV operators undergo operational authorization through a risk assessment evaluated by the competent authority (Huttunen, 2019). The European regulatory framework has categorized UAV operations into three categories - Open, Specific, and Certified - based on their level of risk (Reece A. Clothier, 2010). The Open category has limited operations and does not require a risk assessment. The Specific category undergoes a risk assessment using the Specific Operations Risk Assessment (SORA) process for medium-risk level flights. The Certified category follows the same regulations as manned aircraft due to a higher level of risk. SORA assigns specific assurance and integrity levels (SAIL) based on ground and air risks and 24 operational safety objectives to comply with (European Commission, 2019). The higher the SAIL, the higher the level of robustness required. SAIL ranges from I to VI, and SORA determines the level of robustness based on the significance of the operational safety objectives.

Design verification is important in aviation safety and is a key issue for EASA. The certification process is stringent and involves complying with myriad standards and regulations. There are different requirements for the different UAV categories; in SAIL I-II, CE marking, and class identification label or declaration of conformity may suffice, similarly to the Open category. In the case of medium intrinsic risk (SAIL III and IV), a higher level of assurance, such as a design verification on UAV design and technical elements, is required. In SAIL V and VI, the type certificate is mandatory (Sándor & Pusztai, 2022).

EASA has illustrated the SAIL and related requirements as shown in Table 1, linking SAIL vs design verification. To ensure safety and compliance, harmonized regulations aligned with existing manned aviation and a distinct design approach for unmanned aerial vehicles are needed. Two approaches are used to determine the design verification of UAVs: calculating accident rates and fatalities per hour or producing requirements codes (Dalamagkidis et al., 2008; Haddon & Whittaker, 2003). EASA has adopted the latter objective based approach EASA (Hirling, 2021; JARUS, 2019) and introduced a design verification process, called the Design Verification Report, for SAIL levels III and IV.

Table 1. SAIL and related requirements (EASA, 2023).

SAİLs vs Requirements	
Low Intrinsic Risk	This category involves SAIL I and II and requires either a CE marking or a declaration
Medium Intrinsic Risk	This category involves SAIL III and IV, and it requires either a Design Verification Report from the EASA or a declaration supported by evidence.
High Intrinsic Risk	This category involves SAIL V and VI, and it mandates a Part 21 Certification Procedures for Manned Aircraft.

Design Verification Report is a crucial process involving a thorough review of the UAV design documentation, analysis, and testing to provide evidence that the system meets the applicable safety requirements and objectives. Design verification process serves as a third-party validation that the level of integrity claimed by the SORA method is assured, and can be used for:

- Design-related operational safety objectives
- Technical mitigation to reduce the effect of ground impact (M2 in Table 2)
- Containment assessment (part of SORA)

Table 2 illustrates the validation types and requirements associated with the SORA requirement, which is linked to the design verification process (EASA, 2020; JARUS, 2019). Operational safety objectives serve as the foundation for ensuring safe unmanned aerial vehicle (UAV) operations, with SAIL III and IV having 11 design-related objectives aimed at reducing the effects of UA mishaps. M2 mitigating measures, such as design, procedure, and training, work towards minimizing the impact of UAV impact dynamics. Their primary goal is to validate that no fatalities occur in case of impact and that mitigation is automatically activated. Additionally, containment measures are essential in preventing any probable failure of the UAV or external systems from leading to operation outside the designated operational volume. Validation by the EASA is required (EASA, 2021c) to ensure compliance with these objectives.

Table 2. Requirements of Design Verification.

Operational Safety Objectives		
02	Competent entity manufactures UAS.	Design-related technical issues with UAS. Robustness will be higher, but design verification will cover different technical specifications.
04	UAS developed to authority	
05	UAS designed with system reliability	
06	Communication link performance	
10	Safe recovery from technical issue	
12	UAS designed to manage deterioration	
13	External services for UAS operations	
18	Protection from human errors	
19	Safe recovery from Human Error	
20	A Human Factors evaluation	
24	UAS designed and qualified for adverse environmental conditions	
Technical Mitigation		
M2	Effect of ground impact are reduced	M2 criteria: design, procedure, and training.
Step 9# Adjacent area/airspace considerations		
Containment		Containment ensures operation within designated Adjacent Area.

The process of verifying the design starts with submitting an application that includes a detailed description of the design, a risk assessment based on SORA, a design verification basis, a design verification program, a proposal for means of compliance, and a project schedule. Once the application is received, EASA reviews it and may request additional information or clarification. An example design verification process can be examined by reviewing the design verification document of the Volocopter VC200 (EASA, 2021b).

To ensure the effectiveness of the design verification process, EASA has established a set of design-related specifications in a document called Special Condition Light Unmanned Aircraft Systems - Medium Risk (SC Light-UAS Medium Risk) (EASA, 2020). These specifications are intended to ensure that the unmanned aircraft system meets necessary safety requirements and can perform the intended operation in a safe and efficient manner. In order to comply with the specifications identified in SC Light-UAS, either the manufacturer or UAV operators themselves must manage their own MoC process or comply with verification standards according to the MoCs published by EASA (EASA, 2021c). In this regard, EASA initiated the AW Drone project to target the production of more MoC standards in accordance with the specifications in SC Light-UAS and used data from different international standard development organizations in this field (EASA, 2021a).

2.2.Fundamental uncertainties

Despite efforts to standardize the design verification process for UAVs, uncertainties and a lack of a solid knowledge base remain significant challenges. The design verification process for UAVs in the aviation industry is crucial to ensuring their safety and reliability. However, uncertainties and a lack of a robust knowledge base continue to pose challenges in this area. One key aspect of the process is the design verification process, which covers operational safety objectives, M2 criteria, and containment. However, there are uncertainties about whether the criteria and specifications in the design verification process and other related documents are sufficient to achieve an acceptable level of risk. Additionally, MoC for UAVs have not been accepted by the EASA for all aspects of the UAV, which can negatively impact the level of risk associated with unmanned aircraft operations. This lack of a clear set of guidelines and specifications can pose significant challenges for UAV operators and manufacturers. The AW Drone project aims to standardize design verification for UAVs, but uncertainties still exist regarding the adequacy of the MoC specifications. Addressing these uncertainties and improving the knowledge base for UAV operations is essential to promote innovation and advancement while ensuring the safety of all involved.

3. Uncertainties in design verification

This chapter sheds light on the various uncertainties UAV manufacturers and operators face in obtaining design verification from regulatory authorities. First, this chapter discusses the uncertainties surrounding design verification for UAVs, specifically in terms of acceptable MoC and standards for mitigating measures. The lack of specific guidance on which MoC or consensus standards to use in submitting applications for the design verification process creates uncertainty for applicants. The AW Drones project was initiated to address the lack of appropriate MoCs for design-related operational safety objectives, but there are still uncertainties surrounding the use of specific standards. The chapter also highlights the challenges and ambiguities surrounding M2 and M1 mitigating measures and containment. "M1" and "M2" are two categories of mitigating measures used to control and reduce risks associated with UAV operations. M1 measures refer to general risk reduction measures, while M2 measures are more specific and targeted and are implemented in response to identified risks. Examples of M1 measures include redundancy in the UAV system, while M2 measures could include emergency procedures or contingency plans.

3.1.*Uncertainties in the design verification process - in general*

According to SC Light-UAS.2010 (EASA, 2020) the applicant shall use "*an acceptable means of compliance issued by EASA or another means of compliance which may include consensus standards, when specifically accepted by EASA*" when submitting an application for the design verification process and relevant report. However, the document does not provide specific guidance on which AMC or consensus standards to use. This lack of specificity can create uncertainty for applicants unsure about which AMC or consensus standards to use in their application.

EASA guideline (EASA, 2021c) states that SC Light-UAS is objective-based. These MoCs need to achieve two targets:

- Describe/specify the concrete UAV systems design-related auditable or measurable data, and
- Define how to demonstrate compliance with this data (e.g. design review, calculation/analysis, laboratory tests, ground tests, flight tests etc.).

To achieve these targets "*the applicant may propose MoC based on either existing technical specifications or industry standards or their relevant sections*." The challenge is, as EASA also states, that MoCs are not defined yet. The Guidelines determine the content of MoC in general, specifying the required elements according to different parts of SC Light-UAS. The MoC shall define the minimum performance requirements (e.g., minimum climb/descent performance, hovering altitude, with cargo or payload, etc.). If no MoC is available, it is up to the applicant to "*propose new MoC if no adequate specifications / standards can be identified*."

This implies that there are no clear guidelines for the standards and MoC of UAV systems, and design verification process were only issued for UAV systems models that have enhanced containment features (such as the Volocopter VC200 and Nimbus PPL-612 PLUS EVO XL) or M2 mitigation features (such as the SenseFly eBeeX and K250). This fact in itself shows that there is uncertainty surrounding the design verification process and its standards. This uncertainty can be challenging for UAV systems developers, particularly for applicants of operational safety objective No. 4, who must prove that their UAV systems were developed in accordance with recognized design standards. Thus, it can be difficult to develop UAV systems if the regulatory authority is uncertain about the recognized standards.

3.2. *Operational safety objectives*

3.2.1. *Uncertainties in operational safety objectives*

EASA has acknowledged that the lack of appropriate MoCs for design-related operational safety objectives is a critical issue. The onus is on the applicant to suggest and propose suitable means of compliance, which is a challenge. To address this problem, the AW Drones project was initiated in 2019 by EASA, with the primary objective of identifying relevant standards for medium and high-risk specific category operations (EASA, 2023a). The project was successfully concluded in late 2021 and resulted in the creation of a website outlining the initiative's goals. AW-Drones project aims to establish the standards that constitute MoC for one or more operational safety objectives/mitigations. This will significantly assist unmanned aircraft operators in identifying and complying with all relevant standards for every SORA requirement. The Drone Standards Information Portal is a valuable resource that provides comprehensive information on the standards associated with a specific mitigation derived from the SORA methodology. For this reason, this is defined as a 'metastandard' that plays a pivotal role in the standardization of UAV safety protocols (Cain et al., 2021).

The AW Drones project collected potentially relevant standards based on operational safety objectives. In their final report, recommended standards were categorized according to the different sections and annexes of the SC Light-UAS document. This categorization includes the operational safety objectives pertaining to the mitigating measures and containment. The project identified numerous potential standards from a variety of sources, such as ISO, ASTM and EUROCAE (European Organization for Civil Aviation Equipment). However, some of the standards from manned aviation were also included, which may not be appropriate for UAV systems (Guglieri et al., 2011). Furthermore, AW Drones sorted possible standards according to operational safety objectives rather than the SAIL, leaving it unclear to what extent the named standards could be used. The standards applied in manned aviation may be relevant for certification purposes, which raises concerns about the boundaries between design verification and certification. The intricate nature of the verification standards for medium risk level has resulted in no issuance of design verification process for operational safety objectives. The difficulty of devising substitute MoC based on possibly valuable standards may dissuade manufacturers from seeking design verification acceptance.

3.2.2. *Additional analysis of strength of knowledge in MoC*

Dealing with uncertainties and measuring them appropriately poses a significant challenge. According to Aven & Flage (2018), uncertainties are intricately linked to knowledge, which means that describing uncertainties involves not only the knowledge itself but also its quality. To shed light on this connection, it is crucial to explore the relationship between uncertainties and the strength of knowledge and to understand how the strength of knowledge can impact uncertainties. With this in mind, we will explore the inadequacy of knowledge power in the design verification process for UAVs and how this inadequacy may lead to uncertainties that could compromise the reliability of UAV operations.

MoCs were determined in consideration of the criteria designated in the operational safety objectives for the design standards of unmanned vehicles under the AW Drone project (EASA, 2023a). The project primarily identified 11 operational safety objectives for UAV design standards, with M1 criteria for preventing hazards during normal and failure conditions. Additionally, M2 criteria were identified for mitigating the effects of unmanned aerial vehicle impact dynamics. Based on the criteria designated in operational safety objectives, M1, and M2, nine different international standard documents were examined to produce MoCs that meet the criteria defined in SC Light-UAS. In this examination, the AW Drone working group developed a methodology for categorizing and assessing the suitability of the collected standards. In this sense, the MoCs from different standard documents that meet each design criterion were collected, a suitability assessment was performed during the working process, and possible gaps were identified. Eventually, considering the gaps and the cost of compliance criteria, MoCs were given scores ranging from zero to nine (0-9), and MoCs with scores over five were suggested as acceptable standards. When the strength of the knowledge provided by the standards to meet the expected criteria was considered, the following results were obtained:

- A total of 16 standards belonging to the ASTM were identified, and 76 different MoCs were produced. 51 of them (67%) were rated (6-9) and presented to EASA as the acceptable standards
- Two ISO standards were identified, and 20 MoCs were produced. Only one MoC (0.5%) was rated (6-9) and presented to EASA as the acceptable standard
- 15 standards belonging to EUROCAE were identified, and 21 MoCs were produced. 11 of them (52%) were rated (6-9) and presented to EASA as preferred standards
- IEC only produced MoCs for operational safety objectives number four, but they fell below the acceptable limit
- EASA identified three standards and produced six MoCs in the acceptable means of compliance document. Only one MoC (0.16%) was rated (6-9) and presented to EASA as a preferred standard
- Four Aerospace Recommended Practice standards were identified, and four MoCs were produced. Two of them (50%) were rated (6-9) and presented to EASA as the acceptable standards
- In two standards belonging to Aerospace Series; UAV systems were identified, but only one MoC was produced, which was below the acceptable standards
- One standard belonging to the RTCA - Radio Technical Commission for Aeronautics was identified, and only one MoC was produced, which was below the acceptable standards
- Four standards belonging to the IEEE - Institute of Electrical and Electronics Engineers were identified, and five MoCs were produced. All five MoCs were rated (6-9) and presented to EASA as acceptable standards.
- The information presented above indicates that the MoCs developed to reduce potential risks due to the design standard in the UAV aviation field still do not fully meet an acceptable level. A gap analysis has identified the reasons for the standards falling below an acceptable level.

The hypothesis that the main reason for the MoC standards' non-acceptability is the lack of strength of knowledge has been put forward. A strengthening of knowledge analysis was conducted to reinforce this hypothesis, and ASTM standards that produce the highest number of MoCs among standard-setting organizations were selected as a sample and examined. The results are shown in Figure 1.

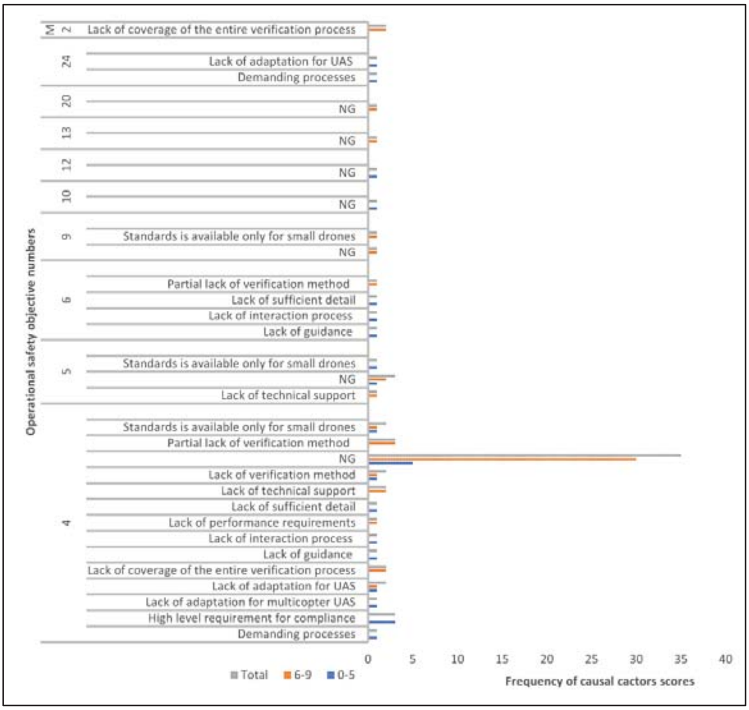

Fig. 1. The numbers of the causal factors identified through gap analysis received a score between (0-5) or (6-9) (EASA, 2021a). For 'NG', no gap is identified.

The following data were used in the analysis:

- Design-related operational safety objectives and specifications in SC Light-UAS
- Relevant MoCs
- Causality in the gap analysis of each MoC
- Scoring given to each MoC in gap analysis (this scoring was already determined by the working group within the AW Drone project).

The analysis process is as follows:

- Each design-related operational safety objective, the MoCs related to these operational safety objectives, and the applicable sections identified in SC Light-UAS were separately identified
- The causality data revealed in gap analysis were categorized as not recommended (0-5) and recommended (6-9)
- To better understand the hundreds of different causality factors identified in the gap analysis, similar and related causality factors were grouped into specific causality sets and assigned general causality names
- Finally, results are presented on a graph constructed based on the causality factors related to "lack of strengthen of knowledge" for ASTM standards and their probabilities of being recommended (0-5) or not recommended (6-9).

Numbers in the Table indicate how often the causal factors identified through gap analysis received a score between (0-5) or (6-9).

The primary causality factors identified for information power improvement based on gap analysis are as follows:

- High-level requirements for compliance
- İnadequate adaptation for UAV systems
- İnsufficient verification methods
- Lack of guidance materials

As seen in Figure 1, many ASTM standards that produce the highest number of MoCs are below the acceptable level compared to UAV aviation standards. The main reason for this is the lack of sufficient knowledge to meet the specifications in SC Light-UAS. This analysis was also conducted on MoCs of all other standard-setting organizations. Causality factors based on information lack that affect the reliability of similar flights and acceptable risk standards were found to be similar but with different ratios in MoCs of other standard-setting organizations during the ASTM analysis.

3.3. *Uncertainties in M2 and M1*

3.3.1. *M2 - Effects of UAV impact dynamics are reduced*

In the case of M2 mitigating measures, the Design Verification Report serves to provide a medium or high level of assurance that the effects of UAV impact dynamics have been reduced. As previously mentioned, K250 from Dronus (EASA, 2022a), among others, has already received a design verification acceptance that verifies compliance with paragraph SC Light-UAS.2512. Mitigation Means are linked with Design, interestingly stating only the integrity of the M2 mitigation, not the assurance process.

Another uncertainty is that SC Light-UAS states that the design verification process may only cover one out of the three criteria for M2 mitigation, which is confusing because parachutes are considered a proper means to reduce ground impact and are referred to in the SORA, but also have design-related issues that should be covered by EASA validation according to SORA. It is unclear why EASA excludes parachutes from design verification, especially considering that parachutes belong to criterion #2 of M2 mitigation.

3.3.2. *MoC on M2 mitigation*

SORA states that for reaching high level of integrity the "*it shall be*" validated by EASA against a standard considered adequate by EASA and/or in accordance with means of compliance acceptable to EASA". The agency has recently released a new Means of Compliance for M2 mitigation (Force, 2023).

In that MoC, there are exact examples of compliance provided by EASA. For parachute recovery systems, the ASTM F3322-18 (ASTM, 2019) standard is acceptable for drones up to 3 m dimensional characteristics and 25 kg Maximum Take-Off Mass. The applicant shall provide the description of the parachute recovery systems and installation, maintenance, and training instructions, so it covers all three criteria of M2. Declaring ASTM F3322-18 as MoC can be regarded as a success of AW Drones as this standard was shortlisted by the project too. While no standard is named for bigger UAVs (up to 8 m in size), the document includes a detailed description of testing parachute recovery systems that support operators with realistic goals and the path to achieving them (Force, 2023).

3.3.3. *M1- Strategic mitigations for ground risk*

The design verification process does not cover the M1 mitigation measure, which means that EASA must validate the high level of design integrity for tethered operations. This is confusing because the same methodology is used in SORA for both M1 and M2 mitigation measures, but only M2 is included in the design verification process, meaning that for M1, a type certificate is required. In other words, the design verification process does not cover M1, so EASA needs to validate the high level of design integrity for M1 in tethered operations, while for M2, it is covered in the design verification process. This is confusing because the same validation methodology is used for both M1 and M2, but only M2 is covered in the design verification process, meaning that for M1, a type certificate is required instead.

3.3.4. *AW Drones project on mitigating measures*

AW Drones project (EASA, 2021a) recommended two standards in connection with M1, as shown in Table 3:

Table 3. Recommended standards for M1 (EASA, 2021a)

Criterion	Recommended standard	Coverage/Gap	Score
M1 Tethered operation Criterion #1 technical design	No standard required	N/A	N/A
	ISO/WD 24356 Requirements for tethered UAV	it is expected to provide generic guidance.	N/A
	ASD-STAN prEN 4709-01 Requirements for the Open category	Draft needs to be checked but it is expected to provide generic guidance.	4
	ISO/WD 24356 General requirements for tethered unmanned aircraft system	Still in planning phase, draft needs to be checked.	N/A

The standards specified in SC Light-UAS 2512 (EASA, 2020) can serve as the foundation for type certification instead of design verification, provided EASA deems them acceptable.

For M2 the following standards were identified as to be recommended, as shown in Table 4:

Table 4. Recommended standards for M2 (EASA, 2021a)

Criterion	Recommended standard	Coverage/Gap	Score
M2 Tethered operation - Criterion #1 technical design	No standard required	N/A	N/A
	F3322-18: Standard Specification for Small Unmanned Aircraft System (sUAS) Parachutes	F3322-18 specifies design, manufacturing, and testing requirements for the parachute system. It doesn't cover minimum ground impact effects or automatic activation for high robustness, which may vary based on the governing CAA.	N/A
	ASTM F3389 Standard Test Method for Assessing the Safety of Small Unmanned Aircraft Impacts	This standard assesses ground impact effects when the UAS is equipped with a parachute, aiming for a 90% reduction in the risk of fatal injuries.	4

The F3322-18 will be used as the basis for certification of UAV systems equipped with parachutes, as these devices are currently excluded from the scope of the design verification process. This means that UAV systems developers and operators seeking certification for parachutes will need to meet the requirements of the F3322-18, which covers the design and performance of parachutes for UAV systems. This includes considerations such as parachute size, shape, and materials, as well as testing and deployment procedures. UAV developers should also be aware of any additional regulatory requirements that may apply to using parachutes in UAV operations to ensure compliance with all relevant regulations and standards.

The challenge encountered with the AW Drones project is due to the absence of distinct guidelines on the appropriate use of specific standards, such as ISO, ASTM, or others. The AW project's standards database outlines the relevant standards, which are labeled as "possibly applicable" or "still in planning," creating ambiguity regarding when to use certain standards. Moreover, prEN 4709-01, a standard that is currently awaiting publication, is primarily suitable for UAV in the OPEN category (CEN, 2019).

3.4. *Uncertainties in containment*

In the case of containment, the applicants seem to be in a better position due to an existing document called "*MoC with Light-UAS.2511 Containment*" issued by EASA (EASA, 2022b). But this MoC is limited to UAVs operated in specific category operations up to SAIL II. Still, it defines that from SAIL III it is expected that the UAV might leave the operational volume not more than once over one thousand flight hours and might exceed the limits of ground buffer only once over one million flight hours. Therefore, it is confusing whether it can be used or not by the applicants.

If we look at Volocopter's design verification acceptance report (EASA, 2021b), it is clear that it concentrated on the following criteria:

- Concept of operation
- Location of the operation
- Operational volume, ground risk buffer
- Visual line of sight operations
- Flight terminations system and command unit
- Adverse weather conditions

The significance of the flight termination system and command unit are evident in the aforementioned MoC (EASA, 2022b), indicating that these matters will likely be incorporated into an MoC that EASA will ultimately release. However, for now, unmanned aircraft operators or manufacturers who apply for design verification in the field of containment must propose their own means of compliance in SAIL III and higher.

The AW Drones Project identified some potential standards (EASA, 2021a), but it is the responsibility of the applicant to develop design solutions for medium-risk operations. Whether these solutions meet the objectives outlined by SC Light-UAS is at the discretion of EASA, which may lead to uncertainties.

4. Discussion

In this study, we investigated the SC Light-UAS criteria by examining uncertainties and related lack of strength of knowledge. Our analysis yielded two major findings: (a) that uncertainties adversely affect the design verification process b) there is a lack of strong knowledge of international standards at an acceptable level to meet the needs of the MoC.

Adverse effect of uncertainties

SC Light-UAS, published by EASA, is an important document that must be considered during the design verification process. The document is prepared with the aim of ensuring the acceptable level of reliability of the design process specified in the operational safety objectives and minimizing accidents (EASA, 2020). According to a study, the reliability and safety of UAVs can be significantly enhanced by incorporating the risk assessment and management principles presented in the SORA process.

EASA emphasizes the technical specifications identified in the SC Light-UAS document, requirements related to design-related operational safety objectives in SORA, and the 'containment' process determined in M2 and step nine. In all these processes, uncertainties can significantly impact the design verification process. For instance, a lack of clear criteria for determining the acceptable level of risk associated with a particular UAV design can lead to delays, cost overruns, or even failures. Furthermore, using complex software and hardware systems in UAVs can make the design verification process more challenging.

The lack of standardization in the design verification process across different regulatory agencies and stakeholders is another challenge that must be addressed (Kasprzyk, 2022). The authors suggest that closer collaboration between regulatory agencies, UAV manufacturers, and other stakeholders is necessary to ensure the design verification process is standardized and effective.

The impact of uncertainties in the design verification process can also be seen in only four applicants who have received design verification reports in the last two years. This can be attributed to various factors, such as incomplete or inconsistent design verification of the applicant, changing design specifications, unforeseen technical issues, and variations in testing conditions or equipment (EASA, 2020). It could be emphasized that strengthening the accuracy and efficiency of testing techniques is crucial to address these difficulties and enhance the design verification process of UAVs.

EASA needs to clarify whether M1 should be included in the design verification process or if a type certification is required for tethered operations. Additionally, if type certification is not required, M1 should be included in the design verification process. In this case, it is surprising that the SORA document's Annex B section on M1 includes details on tethering, as there is no such requirement stated in the operational safety objectives. Therefore, it is necessary to consider the operational safety objectives, design verification process, and corresponding MoC together, and to think of the M1 tethered section together with M2.

Level of strong knowledge in standards for MoC

The development of MoC for UAV certification is a critical step in the process of obtaining design approval at SAIL III and IV levels. However, due to the newness of UAV technology, producing an MoC can be challenging and costly for UAV operators, and a lack of suitable MoCs is challenging for both UAV operators, institutions, and aviation authorities.

To address these issues, the AW Drones project was launched with EASA in 2018 to establish relevant standards for specific category operations with medium and high risk. The project collected possible relevant standards from various sources, including ISO, ASTM, EUROCAE, and the proposed MoCs-related standards were categorized according to the different sections and annexes of the SC Light-UAS document. However, only 52% of the MoCs presented in this project received a recommended status with a score between 6-9. The remaining MoCs, mainly related to design verification, do not contain sufficiently robust information that could be suitable for UAVs, with reasons including "*high level of requirement", "lack of partial or full verification method", and "lack of standard"*.

This results in a challenging situation for both the design verification process and UAV operators. For the design verification process, it becomes difficult to assess design and operational safety of UAVs without a proper MoC, potentially leading to an increased risk of accidents or incidents. Additionally, without standardized MoCs, assessing and approving UAV designs becomes a time-consuming and costly process.

For UAV operators, the lack of suitable MoCs could lead to delays in obtaining design approvals, which could impact their ability to operate in certain areas or perform specific tasks. Furthermore, the costs associated with developing an MoC specific to their UAV design could be prohibitive for smaller operators. This could create a barrier to entry for new players in the market and limit the growth potential of the UAVs industry.

5. Conclusions

After exploring the uncertainties and lack of knowledge in the design verification process of unmanned aircraft systems, this study concludes that these challenges pose significant implications for aviation authorities, drone manufacturers, and drone operators. The lack of specific guidance on acceptable means of compliance and standards for mitigating measures creates significant uncertainties, leading to delays, cost overruns, and even failures. The inadequacy of knowledge power in the development of means of compliance further complicates the design verification process.

The AW Drones project's initiative to identify relevant standards for medium and high-risk specific category operations is a crucial step towards reducing uncertainties. However, more work is needed to ensure the applicability of standards and means of compliance. After analyzing MoCs from various standard-setting organizations, it was found that many ASTM standards with the highest number of MoCs do not meet UAV aerospace standards due to a lack of knowledge to meet SC Light-UAS specifications. This knowledge gap is also present in MoCs from other organizations, highlighting the need for more research and development to ensure these standards and MoCs meet UAV design-related requirements.

To address the uncertainties surrounding design-related operational safety objective, M2 mitigation measures and containment, EASA should provide clearer guidelines on the use of specific standards and expand the scope of MoC with Light-UAS.2511 Containment to cover higher risk operations. This would provide more clarity and assurance for unmanned aircraft operators and manufacturers seeking design verification.

To ensure safe operation of unmanned aircraft systems, it is essential to continue research and development efforts to address uncertainties. By focusing on risk assessment and a strength of knowledge in capturing uncertainties, the design verification process can become more standardized, effective, and efficient. This would facilitate the growth of the UAVs industry and ensure the safety of unmanned aircraft operations.

Abbreviations

ASTM	American Society for Testing and Materials
AW	Airworthiness
CE	European Conformity (French: Conformité Européene)
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
EASA	European Union Aviation Safety Agency
EUROCAE	European Organization for Civil Aviation Equipment
MoC	Means of Compliance
SAIL	Specific assurance and integrity level
SORA	Specific Operations Risk Assessment
SC Light-UAS	Special Condition Light Unmanned Aerial System
UAV	Unmanned Aerial Vehicles

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