THE IMPORTANCE OF RAMS ANALYSIS FOR UNMANNED SYSTEMS

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1 Introduction

1.1 RAMS Analysis for Unmanned Aircraft Systems

Since the Remotely Piloted Aircraft Systems (RPAS) aroused the interest of military industry in early 1900's, these vehicles have become an integral component in military operations today. In addition, their market demand is permanently growing for years because they are no longer only for military purposes but, also for commercial and civil applications such as agriculture and forestry, fire control, communications, etc. (Hayhurst, Jeffrey M., & Miner, 2007)

However, large RPAS operations are currently restrictive to segregated areas and this situation will continue until a complete set of standards are formulated, and a comprehensive RAMS process for RPAS will be necessary to formulate these standards.

The purpose of this paper is giving an introduction of RAMS analyses and techniques and how they can be used to improve RPAS design and performance, provide governmental standards and used in future applications.

To begin with, terminology should be clarified. There is great confusion when it comes to designating unmanned aerial systems or vehicles, as terms such as RPAS, UAS or drones. The terms are often used interchangeably, when in fact there are differences between them. (INTA, s.f.).

Unmanned aerial vehicles (UAV), also called unmanned aircraft (UA), refer to those aircraft that fly without a pilot on board and are part of an unmanned aerial systems (UAS) together with a ground station and datalink. When UAS are commanded by remote pilots from ground stations via datalink, these systems are referred to as RPAS remotely piloted aircraft systems, and their aircraft as remotely piloted aircraft (RPA). When the aircraft is completely autonomous, it is called a UAS or a UAV. When referencing drones, those are unmanned aircraft that can be found on the general market and weigh less than 25 kg.

Nowadays, RPAS are the only systems that can be integrated in non-segregated airspaces, shared with conventional manned aviation, and regulated by the air traffic controllers of each area. In addition, RPAS is perhaps the most appropriate term to refer to such platforms, as they are the only ones that can be integrated together with the rest of manned traffic in non-segregated airspaces and aerodromes, according to the regulations contained in Royal Decree 1036/2017.

1.2 Principles of RAMS analysis

The technological advances allowed us to create complex systems, and the perspective on how they should be designed, built, operated, and maintained has completely changed. The costs of a bad design, especially in critical systems, are often unacceptable. That's why now, in system engineering, it is widely accepted that reliability, availability, maintainability and safety need to be integrated into engineering design process. Moreover, we cannot wait until the product is done to take these needs into account, we must define them in the early phases of the product development, and perform the design according to them, otherwise the cost could be extremely high.

The safety discipline addresses all aspects to ensure that all safety risks associated with the design, development, production, and operations of products are identified, assessed, minimised, controlled and finally accepted through the implementation of a safety assurance programme. A procedure for safety implementation in space sector is defined in ECSS-Q-ST-40C, 6/03/2009.

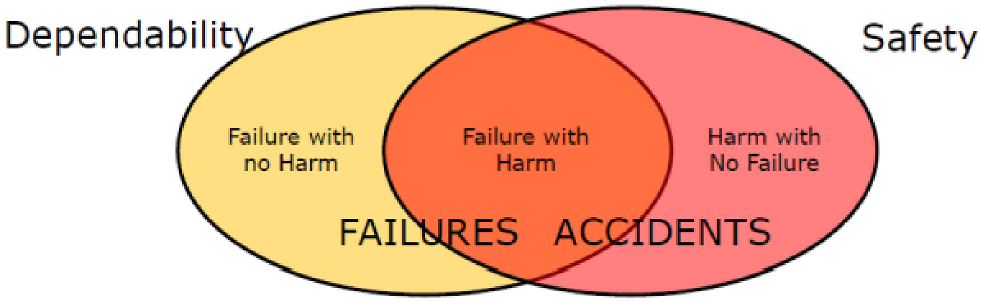
A definition of Dependability concept can be found in paper "Basic Concepts and Taxonomy of Dependable and Secure Computing" (Avizienis, Laprie, Randell, & Landwehr, 2004).

The original description of dependability is "the ability to deliver service that can be justifiably trusted." This definition stresses the need for justification of trust. An alternate definition that provides the criterion for deciding if the service is dependable is "the ability to avoid service failures that are more frequent and more severe than acceptable." As developed over the past three decades, dependability is an integrating concept that encompasses the following attributes:

- Availability: readiness for correct service
- Reliability: continuity of correct service
- Safety: absence of catastrophic consequences on the user(s) and the environment
- Integrity: absence of improper system alterations
- Maintainability: ability to undergo modifications and repairs

It has to be taken into account that those definitions have evolved over time, and different descriptions of the above concepts can be found in the literature which are more suitable for current dependability engineering discipline. For instance, nowadays it is widely accepted that the absence of catastrophic consequences is unachievable and therefore safety discipline stands for reducing the probability of critical failures and the severity of their consequences.

It is important to difference between dependability and safety engineering. Although both activities may overlap in several aspects, they are different areas of engineering oriented to different aspects of the system, malfunction aspects for RAM and harm aspects for Safety, and can use different or similar techniques. In general, Safety has a broader scope than the failures of the system and on the other hand RAM analyses also those aspects leading to failures but not compromising the safety.



It is the overlapping of both areas of engineering that makes it sensible to consider the activities as closely related since many of the concepts, techniques, and tools are common to both. However, from the point of view of project management they are generally separated, with different management and eventually with different dependence in the project structure.

(Levenson, 1995) defines the differences among these terms as follows: "In general, reliability requirements are concerned with making a system failure free, whereas safety requirements are concerned with making it mishap free."

In this regard, it is also worth noting the difference between qualification and certification, being qualification the set of activities that make a product “fitness for purpose”, while the certification are those activities that make it “safe for flight”.

Generally, the terms safety, reliability, security and correctness should not be confused (e.g., a system can be correct and safe, correct, and unsafe, incorrect and safe, incorrect and unsafe). RAM activities go from the Failure Reporting, to Analysis, and, finally, to Corrective Action System in such a closed-loop reporting scheme that provides an efficient means for managing design defects. Note that safety and security are also different concepts: even if their consequences could be similar, the causes are not, since security involves intentional damage (e.g., vandalism, crime, etc.) which is out of the scope of safety analyses.

“RAM” and Safety concepts are different, but the analysis and methodologies (Hazard Analysis, fault tree analysis (FTA), FMEA / FMECA) are common to both, they are not “exclusive” for each area. Depending on the project structure and organization, RAM and Safety activities can be arranged separately. This “independent” arrangement of those activities should be avoided: they share the same techniques, and their outputs should be coordinated.

The development of a safe system relies on the integration of many different engineering skills such as software and hardware engineering.

2 RAMS Analysis in Civil and Military RPAS Certification

In the RPAS sector there are several civil and military standards for RPAS certification, but due to the novelty of this sector and the differences with manned aircraft, most companies face problems during the implementation of these regulations.

Due to the wide diversity of RPAS present in today's expanding market and the disparity of operations they can perform in contrast to manned aircraft, it is important that the requirements applicable to civil and military RPAS are harmonized, by means of common specifications and standards. In this way it is easier for RPAS to be used by both civil and military stakeholders, achieving the required integration into the common airspace that has existed until now for manned aircraft. These common specifications and standards are essential to achieve cost savings during the design and production phases of these aircraft, which allows this young developing sector to continue to evolve as it has been doing so far, maintaining today's levels of technological innovation.

2.1 Civil RPAS Certification

As it has been told, the certification of RPAS allows them to be used for different types of applications present today, such as surveillance, security, search and rescue, environmental operations (i.e., forest fires), parcel services, etc... and promotes their use for other future applications such as air taxis for autonomous air mobility. However, there is a major concern about the compliance of these novel unmanned aircraft with the strict requirements of certification standards, since, in many of their operations, the highest safety standards in manned aviation are adopted for RPAS.

In contrast to the civil certification for manned aviation, to ensure the flight safety of a RPAS, in addition to ensuring the suitability of the RPAS itself, it must be taken into account that the airworthiness requirements also apply to the control station on ground and the datalink between the RPAS and its station, as well as considering human and environmental factors.

Existing means of compliance and guidance material associated with the showing of compliance with system safety assessment requirements used in certification (traditionally the 1309 requirement of the certification standards) was not developed with Remotely Piloted Aircraft Systems (RPAS) in mind and does not fully reflect the unique characteristics of these aircraft. Due to the detail of the current certification standards, the new RPAS/UAS material, which is quite aligned with the new CS23 philosophy, aims to implement objective based requirements so that new developments and emerging technologies can also be certified to the same standards. The degree of detail in the specifications, so far, is such that it would not be possible to certify many new products since it would not correspond exactly to what is covered by that standard.

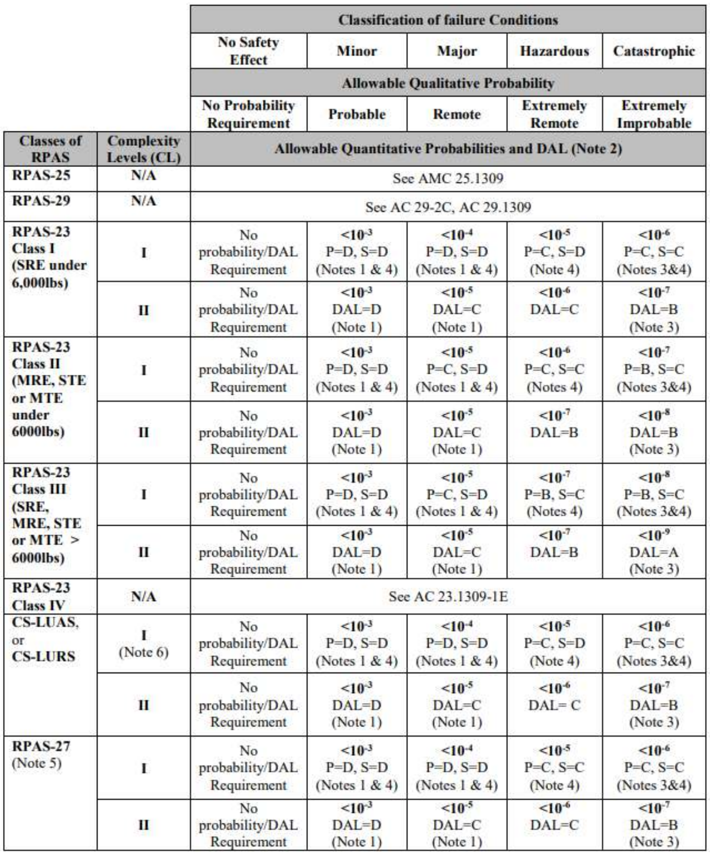
Taking this into account, different methodologies have been developed; in particular, JARUS developed a RAMS methodology aimed to make RPAS operations as safe as manned aircraft, which will be explained in this paper. The goal of this methodology is RPAS not to present a hazard to persons or property on the ground or in the air that is any greater than that attributable to the operation of manned aircraft of equivalent class or category.

The first step to provide the acceptable means of compliance is the definition of the failure condition classification and probability targets.

Table 1 shows the relationship among Aircraft Classes, Probabilities, Severity of Failure Conditions and Software and Complex hardware DALs, required to maintain safe flight and landing to that of equivalent manned aircraft (excluding loss of safe separation).

The complexity level refers to the automation level, and a classification of three complexity levels has been established as follows:

- Complexity level 1: An RPAS that has some automatic functions with limited authority on the RPA and limited capability of automatic execution of a mission. Independent manual reversion is always provided.
- Complexity level 2: Assigned to any other RPAS not classifiable as Level I. The control systems are likely to have full authority on RPAS flight management and are capable of automatic execution of a mission. In the event of a failure, the pilot can intervene if required, unless the failure condition can be shown to be extremely improbable.
- Complexity level 3: Assigned to those UAS that are autonomous. A Complexity Level III UAS is defined as an 'Autonomous aircraft' in ICAO Circular 328



		Classification of failure Conditions				
		No Safety Effect	**Minor**	**Major**	**Hazardous**	**Catastrophic**
		Allowable Qualitative Probability				
		No Probability Requirement	**Probable**	**Remote**	**Extremely Remote**	**Extremely Improbable**
Classes of RPAS	**Complexity Levels (CL)**	**Allowable Quantitative Probabilities and DAL (Note 2)**				
RPAS-25	**N/A**	See AMC 25.1309				
RPAS-29	**N/A**	See AC 29-2C, AC 29.1309				
RPAS-23 Class I (SRE under 6,000lbs)	**I**	No probability/DAL Requirement	$<10^{-3}$ P=D, S=D (Notes 1 & 4)	$<10^{-4}$ P=D, S=D (Notes 1 & 4)	$<10^{-5}$ P=C, S=D (Note 4)	$<10^{-6}$ P=C, S=C (Notes 3&4)
	II	No probability/DAL Requirement	$<10^{-3}$ DAL=D (Note 1)	$<10^{-5}$ DAL=C (Note 1)	$<10^{-6}$ DAL=C	$<10^{-7}$ DAL=B (Note 3)
RPAS-23 Class II (MRE, STE or MTE under 6000lbs)	**I**	No probability/DAL Requirement	$<10^{-3}$ P=D, S=D (Notes 1 & 4)	$<10^{-5}$ P=C, S=D (Notes 1 & 4)	$<10^{-6}$ P=C, S=C (Notes 4)	$<10^{-7}$ P=B, S=C (Notes 3&4)
	II	No probability/DAL Requirement	$<10^{-3}$ DAL=D (Note 1)	$<10^{-5}$ DAL=C (Note 1)	$<10^{-7}$ DAL=B	$<10^{-8}$ DAL=B (Note 3)
RPAS-23 Class III (SRE, MRE, STE or MTE > 6000lbs)	**I**	No probability/DAL Requirement	$<10^{-3}$ P=D, S=D (Notes 1 & 4)	$<10^{-5}$ P=C, S=D (Notes 1 & 4)	$<10^{-7}$ P=B, S=C (Notes 4)	$<10^{-8}$ P=B, S=C (Notes 3&4)
	II	No probability/DAL Requirement	$<10^{-3}$ DAL=D (Note 1)	$<10^{-5}$ DAL=C (Note 1)	$<10^{-7}$ DAL=B	$<10^{-9}$ DAL=A (Note 3)
RPAS-23 Class IV	**N/A**	See AC 23.1309-1E				
CS-LUAS, or **CS-LURS**	**I** (Note 6)	No probability/DAL Requirement	$<10^{-3}$ P=D, S=D (Notes 1 & 4)	$<10^{-4}$ P=D, S=D (Notes 1 & 4)	$<10^{-5}$ P=C, S=D (Note 4)	$<10^{-6}$ P=C, S=C (Notes 3&4)
	II	No probability/DAL Requirement	$<10^{-3}$ DAL=D (Note 1)	$<10^{-5}$ DAL=C (Note 1)	$<10^{-6}$ DAL= C	$<10^{-7}$ DAL=B (Note 3)
RPAS-27 (Note 5)	**I**	No probability/DAL Requirement	$<10^{-3}$ P=D, S=D (Notes 1 & 4)	$<10^{-4}$ P=D, S=D (Notes 1 & 4)	$<10^{-5}$ P=C, S=C (Note 4)	$<10^{-6}$ P=C, S=C (Notes 3&4)
	II	No probability/DAL Requirement	$<10^{-3}$ DAL=D (Note 1)	$<10^{-5}$ DAL=C (Note 1)	$<10^{-6}$ DAL=C	$<10^{-7}$ DAL=B (Note 3)

Table 1: Relationship Among Aircraft Classes, Probabilities, Severity of Failure Conditions and Software and Complex hardware DALs required

Once probability requirement and DAL allocation for each RPAS class and complexity level have been defined, the safety assessment for RPAS will follow the methodology established for manned aircrafts. To do that, special attention should be paid to two types of systems that are critical in RPAS:

- Systems required to maintain safe flight and landing

- Systems required to maintain safe aircraft separation

2.2 Military RPAS Certification

For military RPAS certification, regardless of their size, NATO is interested in standardizing criteria among the different certification authorities of its member countries and, through the STANAG regulations, has developed and evolved RPAS standards that can be used by its member countries and industries to achieve the goal of flight in non-segregated airspace.

The initial approach to operating and certifying military RPAS was military operations in battlefield and restricted airspace, but this causes great restrictions on the use of RPAS because they must often transit entirely in civil airspace, such as during surveillance missions. Therefore, the final approach taken is that military RPAS must be fully integrated with civil aircraft.

The NATO Airworthiness STANAGs, 4671, 4703, 4702 and 4746, are intended for different UAS classifications according to the RPAS size and wing type. These standards, as explained in the following paragraphs, cover the range of the UAS classifications in use today and for the future.

The STANAG 4671 is intended for fixed wing RPAS with a maximum take-off weight between 150 and 20,000 kg. This standard is called USAR "*UAV Systems Airworthiness Requirements*", and its objective is to require a flight safety level similar to that of manned aviation, so it is based on the CS-23 "*Normal, Utility, Aerobatic and Commuter Aeroplanes*", where the traditional aeronautical criteria are maintained in addition to introducing those criteria for the control station on ground and the datalink, which are not contemplated in CS-23.

The STANAG 4703 is intended for fixed wing RPAS with a maximum take-off weight of 150 kg. Civil RPAS of these characteristics are outside the scope of EASA but given the large number or military RPAS within this category, due to their affordable price and technology, it has been considered necessary to comply with all the requirements contained in STANAG 4703, also called USAR-Light. In this case, due to the characteristics of the RPAS, the USAR-Light is not based on FAR or CS but requires the minimum amount of certification evidence that is needed to substantiate an acceptable level of airworthiness.

The STANAG 4702 is intended for rotary wing RPAS with a maximum take-off weight between 150 and 3,175 kg. The objective of this standard is the same as STANAG 4671 for fixed wing RPAS, but with the difference that, due to the characteristics of the RPAS, this one is based on the CS-27 "*Small Rotorcraft*". Following this same approach, the objective of the STANAG 4746, intended for rotary wing RPAS with a maximum take-off weight of 150, is the same as STANAG 4703 for fixed wing RPAS, and contains the minimum set of technical airworthiness requirements intended for light rotary wing airworthiness certification.

3 New European Regulations

Due to the growing need to ensure the free circulation of drones and a level playing field across the European Union, EASA is developing common European rules on drone regulation, adopting the highest safety standards in manned aviation for RPAS.

The process followed to have complete and mature regulations is long and evolves over time until they are finalized. The process starts when the European Commission publishes its resolutions, then the acceptable means of compliance and/or guidance material is published to cover what these resolutions say and explain the means of compliance, for example, EASA publishes AMC-GM 947 including the methodology for performing the risk assessment as well as the establishment of objectives and requirements. Subsequently special conditions are prepared to define exact requirements to be met and airworthiness specifications that will be applicable and EASA will publish acceptable means of compliance and/or guidance material to explain how to comply with each of the published SC requirements. In the future, all of this will be merged to eventually become the entire CS-LUAS or CS-VTOL.

The great difficulty today is that most of the special conditions are still to be written or completed. For example, today there are published medium risk and high risk SCs for LUAS, as medium risk and high risk LUAS are currently the most relevant, but they are focused only on certain UAS, with a certain size, etc... so more special conditions will have to be issued in the future to cover a wider spectrum. Finally, organizations such as Eurocae, working in coordination with EASA, publish standards that explain how to perform certain activities.Once this process has been explained, the current rules under development are based on an assessment of the risk of operation and the characteristics of the UAV, and thus aim to establish a balance between the development of the UAV for the manufacturers and the use that the operators are allowed to do with the UAV. To achieve this balance, it is necessary to consider the safety of the airspace, since UAVs share airspace with other UAVS or manned aircraft, fly in inhabited areas and between infrastructures, as well as other aspects such as privacy, environment, noise pollution, security, etc.

These new regulations follow the CONOPS concept, whose meaning is Concept of Operations, where the applicable certification depends on the operations to be carried out by the RPAS. Therefore, it is ensured that each type of operation is covered, considering the certification required for each aircraft, taking into account its intrinsic characteristics (size, speed, payload…) and the minimum training requirements for the remote pilots. In this way, all drone operators, both recreational and professional, will have a clear concept of what is allowed and what is not allowed during their operations, having the possibility to operate their drones in all the European Union.

These common rules will contribute to stimulate investment, innovation, and rapid expansion of this sector.

The main value of this regulation, (where EASA has put together the officially published regulations with the related acceptable means of compliance and guidance material, many of which are still under development), are that it allows the safe operation of drones while allowing this industry to continue to evolve rapidly, with high innovation, as it has done so far. As stated above, another factor considered by this regulation is the risk to people on the ground and other aircraft, as well as the privacy, security, data protection, and environmental issues created by this unmanned aircraft. This regulation has had to pay special attention to some of these risks that were not so present in manned aviation.

These regulations have evolved very quickly in recent years, so it is advisable, before starting a project, to check which edition is applicable to avoid the risk of developing a product that is useless in the end.

More detailed information about this process can be consulted on (EASA, 2021).

3.1 Categories of UAS operations – 'Three pillars' concept

It was never intended that all RPAS would be subject to type certification and compliance with AMC RPAS.1309, so the establishment of three categories of UAS operations has been proposed as a general concept: 'open', 'specific' and 'certified'. These categories have different safety requirements, proportional to the risk of the RPAS and its operations. Based on the needs of the RPAS market and its rapid evolution, priority has been given to the development of a regulation for the 'open' and 'specific' category operations, which, together with the 'certified' category, are summarized in this article. (JARUS & EUROCAE, 2015), (EASA, 2021).

3.1.1 Open category

This category represents very low risk operations and is the main reference for the majority of leisure drone activities.

Open category operations are limited considering different parameters such as a maximum take-off weight (MTOW) of the RPAS of 25 kg, maintaining visual line of sight (VLOS) with the drone, flying within 120 meters from the closest point of the ground, not carrying dangerous goods or drop items and a maximum distance from any airport. RPAS belonging to this category do not need a dedicated risk assessment or Civil Aviation Authority (CAA) involvement.

3.1.2 Specific category

The "specific" category is characterized by covering a wide variety of operations to be performed with RPAS, generally riskier operations than those performed by an RPAS in the "open" category, which include strict operational limitations. A lot of operations in the specific category are beyond visual line of sight (BVLOS). RPAS in the "specific" category do not meet the criteria of the open category and present a potential risk to people and property. For this reason, this new category requires an operational authorization from the National Aviation Authority, which can be issued, outside the traditional regulatory framework used for the "certified" category of RPAS or for manned aviation, focusing on RPAS operations to mitigate existing risks. However, in this "Specific" category, the application of the "1309" methodology may also be adopted to support the risk assessment method. It should be noted for this category that the safety levels achieved by applying the risk assessment method should be comparable to those achieved in the "Certified" category.

The specific operation risk assessment (SORA) of the operation, is a risk assessment methodology considered an acceptable means of compliance with the UAS Regulation to obtain the required operational authorization to operate a UAS within the "Specific" category. The SORA process assesses the additional risks that have arisen from the new operations that are not covered by the "Open" category. The risks related to the proposed concept of operations (ConOps), which describes the UAS, the operational airspace and the operations to be performed, are assessed using the SORA methodology to establish an appropriate level of confidence that the operation can be carried out with an acceptable risk level. In this way, the risks are assessed and the required limits for a safe operation are determined, validating that the proposed operations comply with acceptable risk levels, and if not, the SORA process is a guide to find the most appropriate mitigations to reduce the risk to an acceptable level.

The SORA process is used to identify the operational safety objectives (OSOs) that define the necessary requirements for technical systems, training, and procedures, based on the risk to nearby areas and airspace in case of a fly-away, resulting in an infringement of adjacent areas on the ground and/or adjacent airspace. These operational safety objectives are the result of the level of confidence that the UAS operation will remain under control, which is represented by the specific assurance and integrity level (SAIL) and are determined by consolidating the ground risk analysis (risk of the RPAS hitting a person on the ground taking into account their mitigations such us buffer zones, parachute…), and the air risk analysis (risk of a mid-air collision in the operational airspace defined in the ConOps and taking into account their mitigations such us operating during certain time periods or within certain boundaries). In cases of UAS operations where the SORA process has determined a high robustness level, it is required verification by EASA.

Additionally, it is also possible to follow another equivalent methodology accepted by the National Aviation Authority to identify and mitigate the risks, mainly through operational restrictions and limitations, and thus comply with the operational safety objectives.

3.1.3 Certified category

In the certified category are included all operations with the highest level of risk, such as operations over assemblies of people in urban or rural environments, and which in addition to goods, in the case of package delivery services, may also involve the transportation of people, such as air taxi or even involving the transportation of dangerous goods, which may result in a high risk to third parties in the event of an accident.

Due to the high risk of these operations, the approach used to ensure the appropriate level of safety for these flights will be very similar to that used for manned aviation, characterized by the fact that it will use the traditional regulatory framework and set of certificates, where it is required compliance with the 1309 requirement and related AMC, (JARUS, 2015). In addition, a licensed remote pilot and an operator approved by the authority is also required.

It shall be noted that some of the riskier operations in the 'specific' category, those that in the SORA analysis have a high ground risk class or a high specific assurance and integrity level, fall into the "certified" category.

3.2 Special Conditions for Light UAS and VTOL

There are special detailed technical specifications emitted by EASA for a product according to the Part 21, named special conditions, if the related airworthiness code does not contain adequate or appropriate safety standards for the product. This is because the product has novel or unusual design features relative to the design practices on which the applicable airworthiness code is based; or the intended use of the product is unconventional; or the experience from other similar products in service or products having similar design features has shown that unsafe conditions may develop. When these SCs are consolidated, the idea is that they become part of the corresponding regulatory frame of the CS-LUAS or the CS-VTOL. For reference, (EASA, 2021), (EASA, 2021) and (EASA, 2019).

An example of the rapid evolution that the entire regulatory framework is experiencing is the need for these special conditions for LUAS Medium and High Risk and VTOL, where the certification basis for UAS have been defined until today with special conditions based on the documentation published by JARUS or have also been derived from the CS for manned aircraft, together with special conditions due to the specific aspects of UAS. Therefore, in the case of UAS with a maximum take-off mass closer to traditional manned aircrafts or used for transportation of people, the certification basis may be established from CS for manned aircraft, complemented with the airworthiness standards of a CS-UAS.

This special condition is to facilitate the use of UAS for manufacturers and operators. Manufacturers can declare compliance with these requirements and operators can use those declarations to facilitate their risk assessments.

EASA future CS organization is presented in Figure 1.

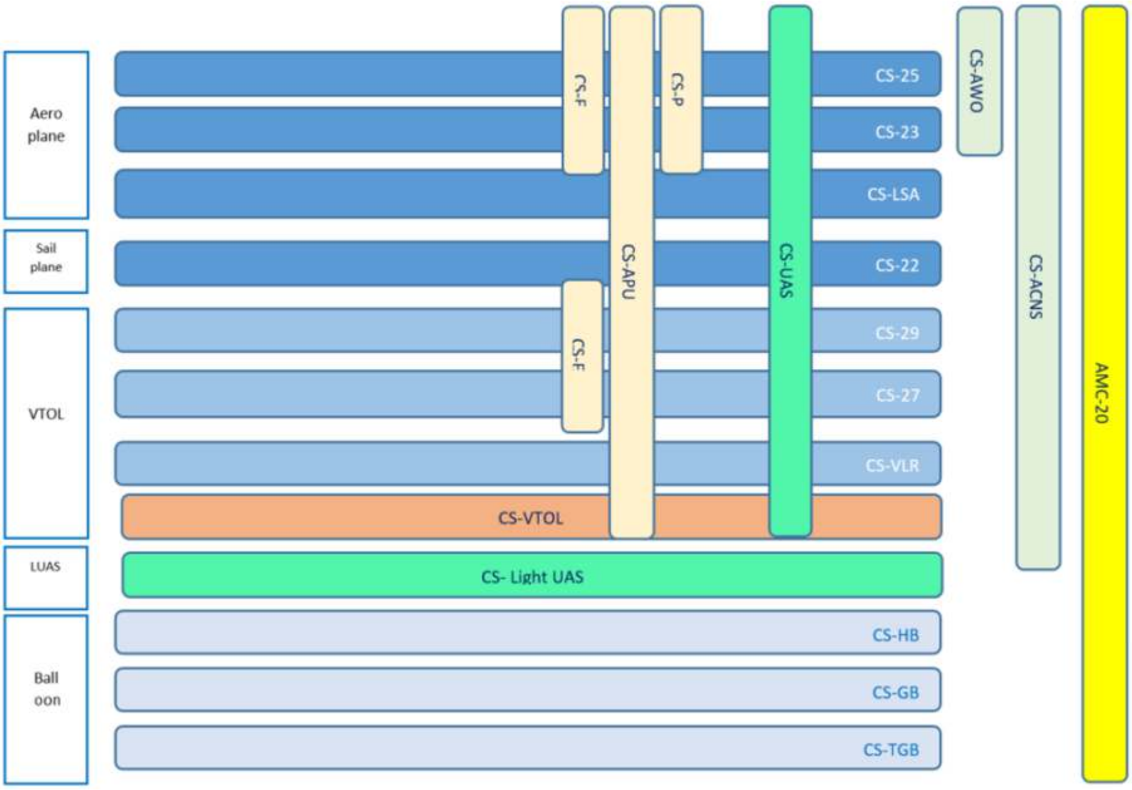


Figure 1: CS Organization

To cover aspects related to new ways of approaching VTOL, beyond the conventional helicopter, for example in the case of RPAS to be used for people transportation in the future as a promising solution to implement UAM ("Urban Air Mobility") by using them to accommodate the high demand for cargo deliveries as well as passenger transportation in urban areas, a company interested in all this (e.g. in a multicopter electric propulsion VTOL RPAS); must take into account this special condition, as explained in figure 1 crosswise between CS-UAS and CS-VTOL.

VTOLs could significantly reduce the heavy traffic congestion during peak times and improve the efficiency of urban traffic networks.

Different models, such as simulations (Sarkar, Yan, Girma, & Homaifar, 2021) and Bayesian networks (Bauranov & Rakas, 2019) have been used to study the risks associated with manned eVTOLs, and the impact of automation system failures on pilot workload and flight safety.

In the last years, NASA has been conducting investigations in Advanced Air Mobility aircraft and operations, giving a framework for specific ideas that could use Crash Mitigation to improve vehicle safety through a crashworthy systems level approach with several designs highlighted.

The European Aviation Safety Agency (EASA) issued a Special Condition (SC) for Small category VTOL aircraft. This SC is for small (5 or less passengers) aircraft with a total vehicle mass of 2,000 kg or less, which would not encompass the entire fleet of proposed design vehicles at present. (EASA, 2019)

4 Future

Safety analyses have traditionally been performed by the safety engineers based on an informal model of the system, which could lead to errors or incompleteness in the analyses (Joshi & Heimdahl).

Due to the complexity that UAVs are acquiring over time, adopting technological innovations such as artificial intelligence, more complex and totally new architectures, greater connectivity with the rest of the aircraft with which they share airspace, etc., there are situations in which these aircraft will work as a System of Systems (SoS), and therefore, both the complexity of the design itself and the complexity of the corresponding RAMS analyses are making it necessary to use Model-based systems engineering. Using precise formal models of the system as the basis of the analysis may help reduce errors, give a deeper insight, and allow fault detection and fault diagnosis.

In the last years, different approaches to perform model-based designed UAVs have been made, especially for the flight control (Weibin Gu, 2020) and software (Zuo, et al., 2012).

On the other hand, one of the most innovative and ambitious complex applications of UAVS that will soon arrive in urban mobility is the autonomous electric vertical take-off and landing aircraft, also called eVTOL. The revolutionary eVTOL air taxi will change the way of transporting people on demand around big cities, autonomously and in a short period of time, without taking into account the delays caused by traffic problems.

One problem that companies developing these air cabs have to deal with is that, as we have seen throughout the paper, they require certification by the FAA and by EASA, and this is a long and expensive process, similar to that of commercial aircraft.

Air taxis are intended to be remotely piloted, without pilot on board, but due to the complexity of these operations carrying passengers in urban or rural environments, it is highly probable that the first type of air taxi operations will be conducted with a pilot on board. In a second phase the air taxi will become remotely piloted.

5 Conclusions

Until now, the use of UAVs has progressed driven by technological advances, but has been slowed down by regularization and certification, as it is necessary to ensure the safety of all citizens during their use. However, the implementation of the new regulations explained throughout this article will allow this sector to advance more rapidly without being slowed down by these long certification processes and thus adapt more easily to present and future technological advances.

Thanks to the advantages provided by UAVs, such as ease of use, reduced risk to humans as an unmanned vehicle, low pollution and environmental impact, versatility or low economic cost, among others, they are gradually becoming a main option to replace the operations of some manned aircraft, or other means of transportation such as cars or trains.

Therefore, these new regulations, together with the technological evolution in the design of UAVs will allow the full implementation of Complexity Level III UAS, i.e., fully autonomous aircraft, and will lead to a revolution in the use of these aircraft in both civil and military areas. Many sectors will evolve drastically, as UAVs will be able to be used for various purposes, some of them unimaginable until now.

Some sectors are already using UAVs for surveillance applications, search and rescue, agriculture, in some cities for parcel transport or military applications. These sectors will evolve along with the development and maturation of these aircraft and their use.

However, UAVs will have a huge impact in some sectors where their use was inconceivable until now, and therefore they will experience a real revolution. For this it will be necessary to use them in more integrated applications in cities with the dangers that this entails for people, but in order to do so, it is essential to control the air traffic of UAVs in a non-segregated airspace. This is the case, for example, of passenger transport with autonomous air taxes, their use for medical emergencies, supplies for humanitarian work or expand the internet access, among others. These developments will dramatically increase the value of UAVs to everyday society and undoubtedly will shape its future.

It is very important to note that Figure 1 of this article shows the future of the regulatory framework, but in the meantime, it is important to be aware of new publications, otherwise there is a risk of creating a product that is useless in the end.

6 Acronyms and Abbreviations

Acronym / Abbreviation	Description
AC	Advisory Circular
AMC	Acceptable Means of Compliance
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority
CL	Complexity Level
ConOps	Concept of Operations
CS	Certification Specification
DAL	Development Assurance Level
EASA	European Union Aviation Safety Agency
EUROCAE	European Organisation for Civil Aviation Equipment
eVTOL	Electric Vertical Take-Off and Landing
FAA	Federal Aviation Administration
FAR	Federal Airworthiness Regulations
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FTA	Fault Tree Analysis
GM	Guidance Material
ICAO	International Civil Aviation Organization
INTA	Instituto Nacional de Técnica Aeroespacial (National Institute for Aerospace Technology)
JARUS	Joint Authorities for Rulemaking of Unmanned Systems
kg.	Kilogram
lbs.	Pounds
LUAS	Light Unmanned Aeroplane Systems
LURS	Light Unmanned Rotorcraft Systems
MoC	Means of Compliance
MRE	Multiple Reciprocating Engine
MTE	Multiple Turbine Engine
MTOW	Maximum Take-Off Weight
NAA	National Aviation Authorities
NATO	North Atlantic Treaty Organization
OSO	Operational Safety Objectives
RAM	Reliability, Availability and Maintainability
RAMS	Reliability, Availability, Maintainability and Safety
RPA	Remotely Piloted Aircraft
RPAS	Remotely Piloted Aircraft Systems
SAIL	Specific Assurance and Integrity Level
SC	Special Conditions
SORA	Specific Operation Risk Assessment
SoS	System of Systems
SRE	Single Reciprocating Engine
STANAG	Standardization Agreement
STE	Single Turbine Engine
UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aerial Systems

Acronym / Abbreviation	Description
UAV	Unmanned Aerial Vehicles
USAR	UAV Systems Airworthiness Requirements
VLOS	Visual Line of Sight
VTOL	Vertical Take-Off and Landing

7 Bibliography

Bauranov, A., & Rakas, J. (2019). Urban air mobility and manned eVTOLs: safety implications.

Avizienis, A., Laprie, J.-C., Randell, B., & Landwehr, C. (2004). Basic Concepts and Taxonomy of Dependable and Secure Computing. *IEEE TRANSACTIONS ON DEPENDABLE AND SECURE COMPUTING*.

EASA. (2019). "Vertical Take-off and Landing (VTOL) Aircraft: Special Condition for small-category VTOL aircraft.

EASA. (2021). *Easy Access Rules for Unmanned Aircraft Systems (Regulation (EU) 2019/947 and Regulation (EU) 2019/945).*

EASA. (2021). Special Condition - Light Unmanned Aircraft Systems - High Risk.

EASA. (2021). Special Condition - Light Unmanned Aircraft Systems - Medium Risk.

EUROCAE. (2020). *Applicability of Safe Design Standard for UAS in Specific Operations Category.*

Hayhurst, K., Jeffrey M., M., & Miner, P. (2007). *Preliminary Considerations for Classifying Hazards of Unmanned Aircraft Systems.*

INTA. (n.d.). *Instituto Nacional de Técnica Aeroespacial* . Retrieved from https://www.inta.es

JARUS & EUROCAE. (2015). *JARUS WG6 – EUROCAE WG73 Airworthiness AMC RPAS.1309 Conciliation Team Report.*

JARUS. (2015). *AMC RPAS.1309 - Safety Assessment of Remotely Piloted Aircraft Systems.*

JARUS. (2015). *Scoping Paper to AMC RPAS.1309 - Safety Assessment of Remotely Piloted Aircraft Systems.*

Joshi, A., & Heimdahl, M. (n.d.). Model-Based Safety Analysis of Simulink Models Using SCADE Design Verifier. *Lecture Notes in Computer Science.*

Levenson, N. (1995). *Safeware: System Safety and Computers.*

Mayer, J. E. (n.d.). *NATO - UAS - State of the Art of Airworthiness Certification.*

Sarkar, M., Yan, X., Girma, A., & Homaifar, A. (2021). A Framework for eVTOL Performance Evaluation in Urban Air Mobility.

Weibin Gu, K. P. (2020). UAV Model-based Flight Control with Artificial Neural Networks: A Survey. *Journal of Intelligent & Robotic Systems*, 1469–1491.

Zuo, M., Liu, Y., Qian, Y., Hu, X., Zhao, X., & Wang, J. (2012). Model-Based Design of UAV Autopilot Software. *International Conference on Computer and Information Application (ICCIA 2012).*

Note: The status of some of the references used in this paper may be superseded in the near future and others may still be under development.

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