Integration of UAS in the civil airworthiness regulatory system: present and future

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ABSTRACT

The last years are witnessing a number of initiatives worldwide devoted to assess the safety levels of the unmanned aircraft. These initiatives are very heterogeneous; some of them are centred in airworthiness aspects while others focus on operations. From the point of view of a potential UAS manufacturer the actual situation is plenty of uncertainties in relation to the regulations to be applied for certifying the design, manufacturing and maintenance, and from the point of view of the potential operator the situation is analogous with respect to operational procedures. In the present work the emphasis is on the manufacturer's situation. The objective of this work is to clarify the present civil airworthiness regulatory scene by summarizing all the regulatory efforts up to date and preparing a comparative analysis of them. In this comparison, the manned regulations are included too. The most representative state-of-the-art UAS are analyzed from the point of view of the existing and the future regulatory framework. The main aspects to be considered are related to the airworthiness certification (performances, structural design, etc) for which a quantitative comparison is established in order to clarify how the new regulatory framework, mainly based on the conventional aircraft certification codes, will affect future UAS, compared to the existing regulations.

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Introduction

The so-called UAS (Unmanned Aircraft Systems) are complete systems designed for flying without a human pilot on board and include, following EASA (1, 2), not only the UAV (Unmanned Aircraft Vehicle) but also the systems that allow the proper operation, as the control station, the communications link and the launch and recovery systems.

From 1917, when the first controlled flight of an unmanned aircraft (Curtiss N-9 US NAVY) took place (3), the development of the UAS has been notable especially in the military field and during recent war periods. This great evolution of the UAS has caused an important diffusion of these systems nowadays, making it necessary to establish an adequate regulatory frame which allows the safe operation of these aircraft in military, civil or commercial missions.

Nowadays the problem is partially solved, being the general solution to require operating the UAS outside of the non-segregated airspace or, sometimes to book timer fractions inside it in such a way that the UAS could be safely operated.

A relevant milestone was the accident of a Predator B UAS (Maximum Take-off Weight, MTOW, 4763 kg) in Sierra Vista (Arizona, USA) in April 25th 2006. This fact highlighted the necessity of facing the problem of the regulation of the operations. The aircraft was performing surveillance tasks in the border between the United States and Mexico when the blockage of one of the consoles of the ground control station stopped the communications link with the vehicle and the control was lost. A chain of failures in the troubleshooting procedure lead to the unexpected closure of the fuel valve. From that moment the aircraft began losing height and went out of the sight line of the control station, making the control of the vehicle irrecoverable. Although there were no human damages, the NTSB (US National Transport Safety Board) investigated this accident thoroughly and issued, subsequently, several recommendations related to the design, operation and safety, addressed to organizations that operate UAS (4, 5).

Many regulatory initiatives have emerged, trying to organize the UAS operations in the non-segregated airspace (EUROCONTROL, JAA/EUROCONTROL UAV-TF, EASA A-NPA Nº 16/2005, EUROCAE WG-73, EDA, DoD, FAA, RTCA, NATO). By the moment, none of them have led to a firm regulation which could unify the requirements for UAS operation, exhibiting an equivalent level of safety (ELOS) similar to the manned aircraft (conventional). The absence of a set of unified regulations is leading presently to a slowing down of the development and usage of the UAS.

The UAS will have to use the airspace to perform their missions, civil or military. Such airspace has a structure, management and control designed to be exploited by manned aircraft, which are required to have a very high level of safety. The level of safety of the conventional aircraft relies in their intrinsic characteristics, the maintenance technicians and operating personnel. From a point of view different from aircraft characteristics, such level of safety also depends on the qualities of the navigation aids and the air traffic control and management which supervise and organize the UAS missions.

Up to date the unmanned aircraft vehicles operations are restricted to the segregated airspace; that is, airspace regions where the conventional aircraft also flies but in which some areas, previously announced, are segregated for special traffic. In order to access these areas, some segregated airways are provided trying to minimize conflicts between UAS and within the airspace of each nation in order to avoid the establishment of international agreements in this matter.

The question that now arises is how the operation of UAS could be allowed in the non-segregated airspace, at the same time as the conventional aircraft, helping UAS to develop all their potential. To this end it is necessary to convince the airworthiness and operations authorities that the unmanned aircraft are able to develop the same level of safety as the manned ones. So the UAS are not a hazard for the other traffic and for the persons and goods on ground.

For reaching such scenario it is necessary to solve not only the lack of regulations but also the development of high reliable technologies that allow UAS to reach equivalent levels of safety as the manned aircraft. Keeping in mind the options stated by several regulators (1, 6, 7, 8), it is possible to enumerate the premises that all integration regulation initiatives should consider:

- UAS should reach equivalent levels of safety as conventional manned aircraft.

- UAS operations should not increase the risks for the users of the non-segregated airspace, nor third parties.

- UAS should use the same ATM procedures and the same flight rules as the other users of the airspace.

- The air traffic services given to the UAS should be transparent to the other users and the air traffic controllers.

These integration premises can be resumed as four problems to be solved: airworthiness certification, interaction with ATM, interaction with other aircraft and flight crew certification. In this work only the first problem will be considered. In the first part, the existing airworthiness certification initiatives will be resumed. Then, the recent EASA Policy will be analyzed. This analysis will be extended, in the third section, to a case study in which 23 real UAS will be analyzed from the point of view of the new regulatory framework and the existing certification codes for manned aircraft trying to quantify the impact of the application of these regulations to a relevant design aspect, such as the structural weight.

1 Current State of the Airworthiness Certification Initiatives

In order to guarantee equivalent levels of safety as the conventional aircraft, it will be necessary to provide internationally accepted standard and recommended practices to assess the safety of the vehicle and its operations. They should include the safety evaluation of all systems on board and their integration characteristics required to develop their design missions. In this way it would be possible to certify the “intrinsic” or “potential” airworthiness of the UAS (9). Also it will be necessary to certify the “real” airworthiness, that is, the ability of the UAS of continuously being airworthy through a proper operation and maintenance so the UAS permanently keep its “intrinsic” airworthiness. This means that it will be important to foresee the qualifications for the maintenance and operations personnel, in a way similar as the conventional aviation.

From the point of view of the existing regulations for the airworthiness certification of the vehicle, up to date there is no civil code of regulations edited by any authority. Nevertheless there are several military codes and several civil regulation initiatives. A summary of the actual situation is presented afterwards. From the point of view of the civil initiatives, the situation is rather different in the United States than in Europe.

In the United States of America, the FAA (Federal Aviation Administration) has established the Unmanned Aircraft Programme Office (UAPO), who is in charge of the UAS integration process into the U.S. NAS (U.S. National Airspace). By the moment, until a new FAR for UAS appears (expected by the end of 2011), UAPO has developed a set of certifications and authorizations for UAS. In the case of civil operations, it will be necessary to ask for a special airworthiness certification in the experimental category. As the experimental category is very wide and comprises a great variety of aircraft, the case of UAS is specially considered in FAA Order 8130.34 (10). It should be pointed out that FAR Part 21 (11) prevents the use of the UAS in commercial missions. Finally it is important to note that FAA Order 8130.34 (10) is not a detailed airworthiness code, but a set of operational limitations.

In the case of public operations, FAA will issue a Certificate of Authorization (COA) or Waiver which represent a temporary procedural interim mechanism authorizing UAS flight for a special purpose and into a limited area. The objective of the FAA together with the public organization operating the UAS, is to obtain the same ELOS with the COA than the manned aircraft. Finally, for the issue of the COA, the FAA has published some recommendations (12), in which the military code MIL-HDBK-516-B (13) is strongly recommended as a guidance code.

There is another possibility of operating an UAS in the NAS, and it is under the FAA’s Advisory Circular AC 91-57 (14) related to model aircraft. In order to clarify the applicability of this AC for the operation of UAS, the FAA has published its opinion (15) and has created (16) the Aviation Rulemaking Committee for Small UAS (sUAS), who has regulated the commercial applications of small UAS for which the AC 91-57 is not applicable. The recommendations of the sUAS ARC for creating a new regulatory framework for these aircraft has been published elsewhere (17) and look like a sFAR code. The philosophy followed by the sUAS ARC has been to adopt the same certification criteria as in the Light-Sport aircraft category, in which the manufacturer must show compliance with some identified consensus standards instead of creating a new detailed airworthiness code. Nevertheless the sUAS should comply with the essential requirements published in Appendix B of (17).

Between civil and military initiatives, and between the United States and Europe, it is the NATO code STANAG 4671 (18), ratified in 2007. This document contains a set of airworthiness regulations addressed to certify military fixed wing UAS with a MTOW between 150-20000 kg which will operate in the non segregated airspace. The purpose of this code is to obtain ELOS for the affected UAS similar to the fixed wing aircraft certified with FAR Part 23 and EASA's CS-23 codes (from which it comes from). At the same time it includes some special features of the UAS are recognized through new subparts, so Subparts A to G come from CS-23 and from H to I, they are new parts devoted to communications, command and control data link and ground control station, all of them specific UAS topics.

In Europe, and in the military field, there are two codes: the British DEF STAN 00-979 Part 9 (19) and the French USAR (20). The first one is the ninth volume, devoted to UAV systems, of a collection that compiles airworthiness and design requirements for aircraft under the responsibility of the Defence Ministry of the United Kingdom. The Part 9 includes certification requirements for UAS including design, development and testing topics, directed to the operation of such UAS in any class of airspace. This code has been used to complement JAR/CS-23 codes in the codification of NATO STANAG 4671.

The French code, USAR, has been developed by the Délégation Générale pour l'Armament (French Defence Ministry) and it is compulsory for all military French UAS. It is based on the EASA's CS-23 code, tailored to fixed wing UAS (tactical, MALE, HALE and UCAV). This code is the basis for the previously considered NATO STANAG 4671.

From the civil point of view, the regulatory competence in Europe for unmanned aircraft with an operative mass over 150 kg relies on EASA, as it is established in its Basic Regulation (21), art. 4, section 4. For that reason, on 2005, the Agency began the rulemaking process issuing an A-NPA (Advance-Notice of Proposed Amendment), A-NPA 16-2005 (1) centred on the establishment of a policy (and later on a Certification Specification code) on UAS certification.

Before 2005 and almost at the time of appearing the older Basic Regulation (22) which created EASA, a joint JAA-Eurocontrol initiative appeared: "The Joint JAA/Eurocontrol Initiative on UAVs – UAV Task Force". That project aimed at the development of a model for regulating UAS. The initiative was fruitful and its Final Report (8) appeared on May 2004, which is essential to understand the actual point of view of EASA on UAS integration. This Report presents a deep multidisciplinary analysis on the future establishment of a regulatory frame for UAS, including safety/security, airworthiness, operational approvals, maintenance and licenses, but not ATM. It is composed of a central body, two Annexes and five attachments. The conclusions of this work have been capital to form the EASA's view, so the approach followed by the Agency in its A-NPA 16/2005 is based on the scheme marked in the JAA/Eurocontrol Task Force.

The EASA's A-NPA is the basis for the future European regulation on UAS, with a MTOW greater than 150 kg and not explicitly excluded by the Basic Regulation (21). The philosophy of the document follows the conclusions of the JAA/Eurocontrol Task Force, maintaining the two possible approaches for the new regulation:

1. Conventional: tailoring to UAS, in specified conditions, the existing code for manned aircraft.

2. Safety objectives: creating completely new regulations based on complying total safety objectives and centred on the most relevant hazards.

Among these alternatives, the first one was selected for the new regulation but the second one would be used when necessary (for instance through the issue of restricted airworthiness certificates), as it was established in the JAA /Eurocontrol Task Force Final Report.

For selecting the appropriate manned airworthiness CS code used as the design standard for every UAV system, the A-NPA document presents two alternatives too that in future regulations will be reduced to one:

- Alternative 1: Impact energy method. The method compares the hazard presented by a UAV with that of existing conventional aircraft to obtain an indication of the appropriate level of requirements which should be applied. The most significant feature of this proposal is that it relies on a comparison with existing conventional aircraft design requirements which contribute to a currently accepted level of safety, and avoids controversial assumptions about future contributions to that level of safety from operational, environmental or design factors. The comparison criterion is based on the fact that the capability of a vehicle to harm any third parties is broadly proportional to its kinetic energy on impact. For the purposes of the comparison method it is assumed that there are only two kinds of impact: either the impact arises as a result of an attempted emergency landing under control (unpremeditated descent scenario), or it results from complete loss of control (loss of control scenario). Once the kinetic energy for each scenario is computed it is possible to determine the appropriate CS code to be applied. Then it would be necessary to construct a certification basis which addresses the same aspects of the design as the existing codes, and to the level indicated by the kinetic energy comparison. Special conditions would be required for any novel features of the design not addressed by the existing codes.

- Alternative 2: Method based on UAV safety objectives. Safety objectives have been used as a means to define and justify the civil aircraft characteristics. These safety objectives are oriented to on board people protection and are defined by the FAR/CS 25/23 regulations. As there are no people on board of UAV, safety objectives criteria for UAV must be redefined and oriented to on ground people protection. By comparing today aircraft safety objectives (as they are defined in the regulations) to the UAV proposed safety objective, a correspondence between CS-23/25 and UAV categories is established. Three main parameters have been considered: statistical aircraft fatal losses, technical aircraft losses defined in the regulations and catastrophic failures.

Following its rulemaking procedure, EASA published the A-NPA 16/2005 as a "policy document" in order to receiving proposals from other institutions and completing the regulation before arriving at a consolidated version. During this process, the Agency and interested parties (National Authorities, manufacturers, etc) interacted, and the results were compiled in the CRD 16/2005 document (2). This document was issued on December 2007 and was opened for comments until February 2008. It compiled 320 comments from 45 different sources. These comments or suggestions, after being studied by EASA, can be identified as accepted, partially accepted, considered (accepted but meaning no changes in the text) or rejected. The main topics affected have been:

- Development for a global new regulatory mainframe for UAS: the A-NPA is only a first step.

- Regulation for UAS with MTOW<150 kg (out of EASA's scope): the EASA response is that the Agency is not competent in this area, as it is stated in the Basic Regulation (21,22) but the Member States are. Nevertheless the Agency agrees in the high interest of having a harmonized opinion and also in the collaboration of EUROCAE WG-73 as a developer of a set of certification guidelines. Nowadays it is JARUS[1] who is in charge of harmonizing and developing the draft versions on a new European rule for this light UAS category (LUAS) taking as basis the CS-VLA and CS-VLR airworthiness European rules.

- Coordination with military working groups: considered. There are comments that suggest using the USAR code for military UAS.

- Conventional vs. safety target approach: the comments related with retaining the conventional approach based on the existing CS codes have been accepted.

- Total System Approach (TSA[2]): the Agency answers that the European Single Sky is the final aim but it is far from the currently objectives.

- Regulation of the Sense & Avoid systems: there were many comments related the necessity of regulation for these systems. EASA maintains the opinion that Sense &Avoid systems should be regulated by the organization responsible of ATM.

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[1] JARUS: Joint Authorities for Rulemaking on UAS; an international coordination group initiated and chaired by CAA The Netherlands, formed by eleven European National Authorities and coordinated with Australia, Canada and USA Authorities.

[2] TSA: Total System Approach; progressive integration of the complete aviation system.

- Security: considered. EASA will have to toughen its rule in order to improve the protection against intruders.

- Design Organization Approvals, DOA, for UAS manufacturers: partially accepted.

- Airworthiness certificate and control stations: accepted comments related the request of one airworthiness certificate for each UAV-control station.

- Environmental protection and noise: considered. The rules related to noise emissions and environmental protection should be the same as for existing manned codes, but the possibility of amending them is opened, if necessary.

2 Recent Advances: EASA Policy Statement

After a public discussion in the EU after the A-NPA and CRD publication, the Agency has finally stepped forward in the rulemaking procedure for UAS and has issued a new Policy Statement document (23) on September 2009. This policy establishes general principles for type-certification (including environmental protection) of an Unmanned Aircraft System (UAS). The policy complies with the current provisions of the Basic Regulation (21), Regulation (EC) Nº 1702/2003 (24) and all Management Board Decisions relating to product certification. This policy shall be used by the Agency's staff when certificating UAS. The policy represents a first step in the development of comprehensive civil UAS regulation and may be regarded as providing guidance to Part 21 Subpart B of Regulation (EC) Nº 1702/2003: Type-certificates and restricted type-certificates; operational regulations pertaining to UAS are not addressed within this document. This policy statement is therefore an interim solution to aid acceptance and standardisation of UAS certification procedures and will be replaced in due course by AMC and guidance material to Part-21 when more experience has been gained.

The main topics covered by the policy statement are the following:

- Routine case: The issue by the Agency of a type-certificate (TC) will be based upon the applicant demonstrating compliance with a defined type-certification basis and a certificate of airworthiness (CofA) is granted to an individual UAS when compliance with the approved type design has been shown. Any applicant applying for UAS type-certificate is required to demonstrate their capability by holding a design organisation approval (DOA), issued in accordance with Part-21 subpart J.

- Alternate approach (within the scope of Part-21): to facilitate an early introduction of civil UAS operations, it will be possible to apply for an airworthiness approval. This approach recognises that some UAS may benefit from a stepwise approach in conjunction with the issue of a restricted TC and/or restricted CofA. This alternative may be based on the safety target approach, using an overall target level of safety defined by the Agency, in lieu of a specified airworthiness code.

- UAS control stations and other remote equipment performing functions that can prejudice take-off, continued flight, landing or environmental protection, shall be considered as part of the aircraft and included in the type-certification basis.

- The applicable airworthiness code or codes to be used as reference for establishing the type-certification basis will be proposed by the applicant using a methodology for selecting the applicable manned aircraft code defined in A-NPA 16/2005. A tailoring of the code should be proposed by the applicant, in a justified manner.

- The Agency acknowledges that USAR (20) developed by the French Military Authorities, and later updated by NATO FINAS group to STANAG 4671 (18), has been developed using a methodology closely related to the one described in the EASA's policy. At an applicant's request, the Agency may accept USAR version 3, STANAG 4671 (18), or later updates, as the reference airworthiness code used in setting the type-certification basis provided that the code identified by the methodology of the Policy does not indicate that safety standards in excess of CS-23 are required, and the safety targets included in the system safety assessment reflect values resulting from the application of this policy.

- There are several special conditions covered in the Policy, for which the Agency includes some guidance. These conditions are the following: emergency recovery capability, command and control link, level of autonomy, human machine interface, control station, types of operation and system safety assessment.

- Other issues considered are the application of Part-21 subpart I for noise certificates, and Annex I of Part-M of Regulation (EC) Nº 2042/2003 (25) for the continuing airworthiness, and the Agency's point of view on the certification of "detect and avoid" systems.

Finally, it will be necessary to wait until all these aforementioned initiatives culminate in a specific airworthiness code for UAS although the main bases have been already established. Figure 1 summarizes the actual UAS regulatory scene, and the relationship among all actors in the international playfield.

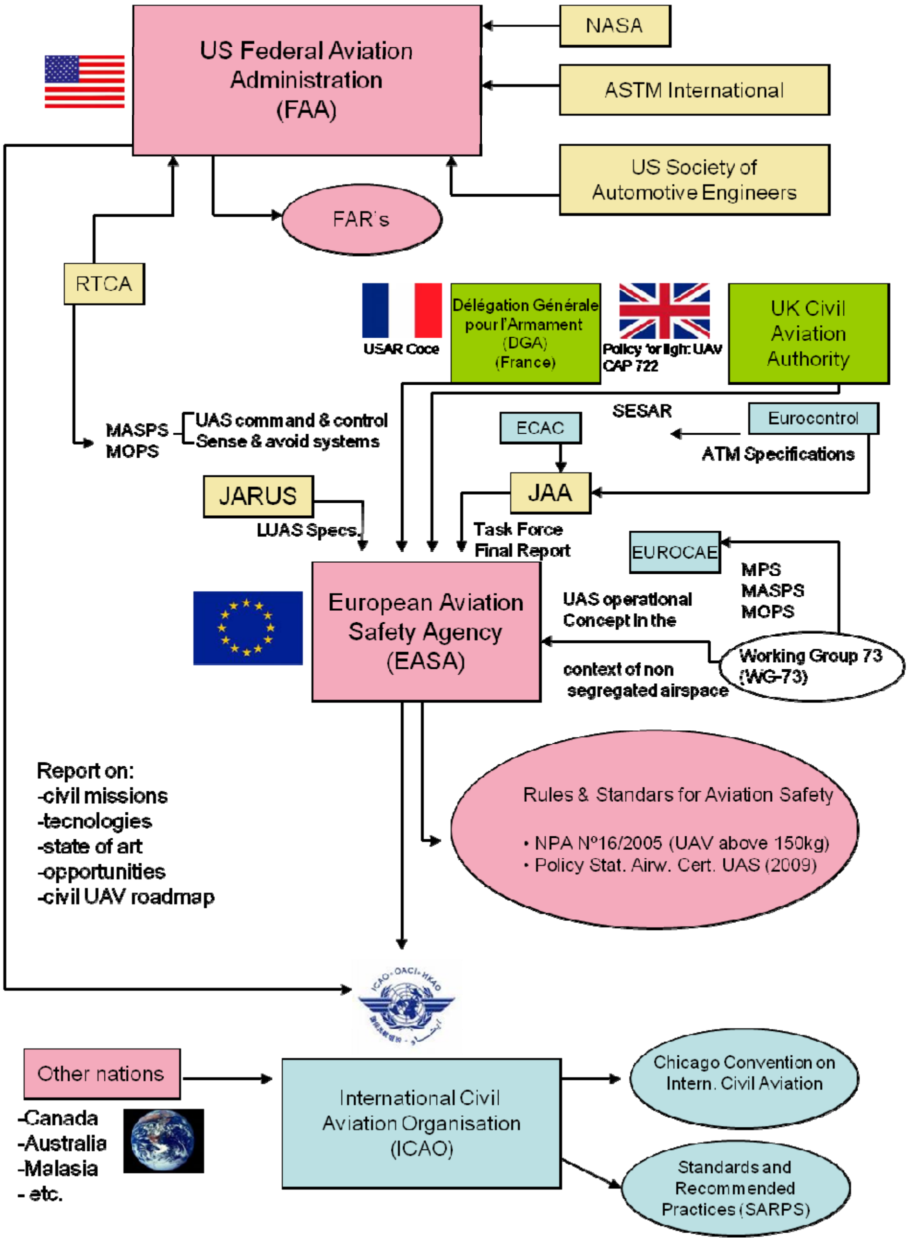


Figure 1.- Actual regulatory international playing field for UAS

3 Study Case: Application of the EASA Policy Statement to Existing UAS

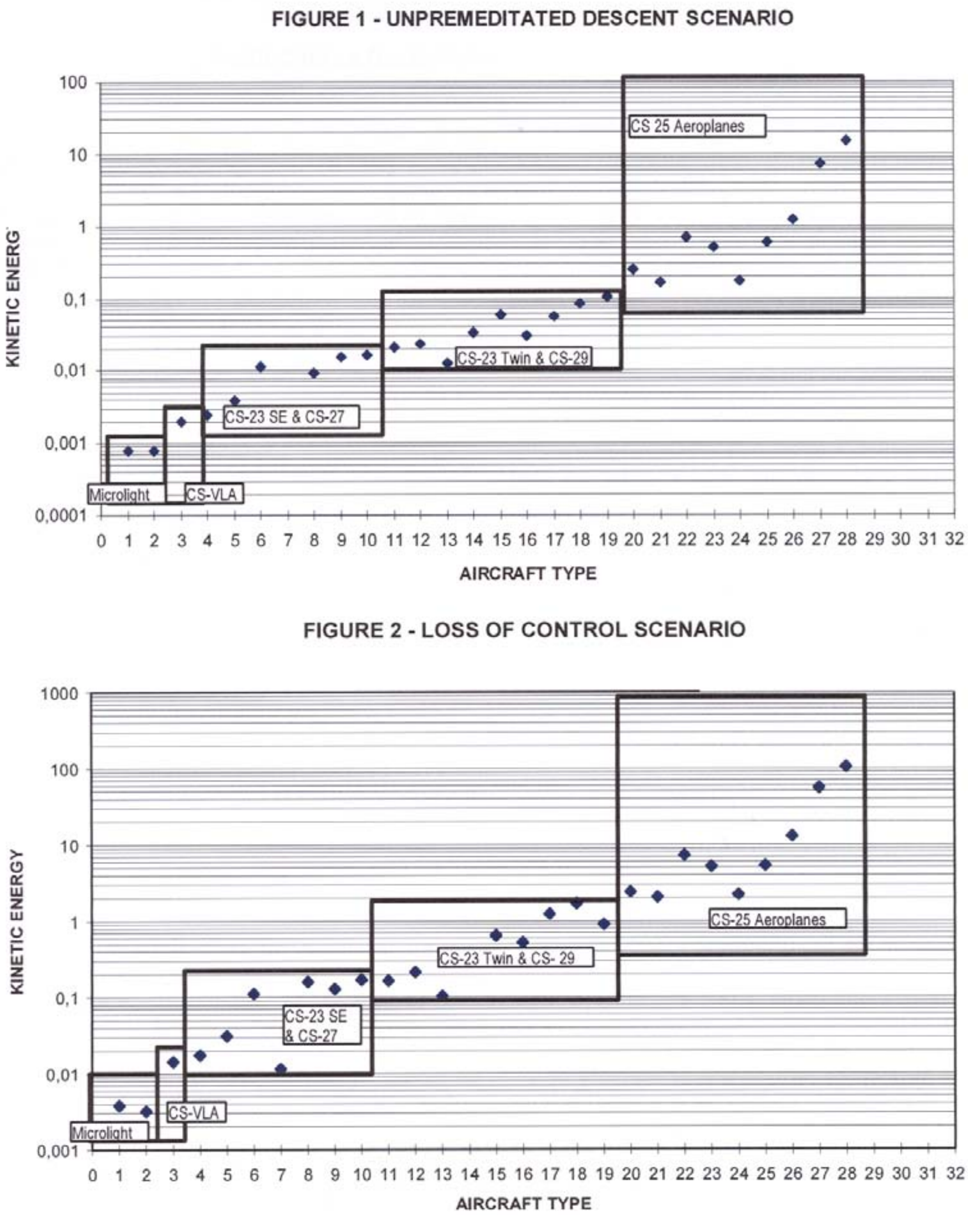
As it has been summarized before, there are a number of initiatives worldwide devoted to establish requirements that allow the integration of UAS in the non-segregated airspace maintaining the same ELOS as for the manned aircraft. These initiatives are very inhomogeneous, some of them are centred in airworthiness aspects while other do the same in relation to operations. From the point of view of a potential UAS manufacturer, the actual situation is plenty of uncertainties concerning with the regulations to be applied for certifying the design, manufacturing and maintenance; and from the point of view of the potential operator the situation is analogous in relation to operational procedures.

The objective of this section is to present a case study in which representative state-of-the-art UAS will be analyzed from the point of view of the existing and foreseen regulatory frameworks. EASA's Policy Statement is the regulatory initiative selected for the study; so the UAS will be analyzed following the methodology presented in the Policy. The output of this exercise will be the manned code or codes associated to each UAS studied. Then a quantitative analysis, centred in structural aspects, will be applied to the UAS trying to extract general conclusions about how new regulations are going to affect future UAS design.

Table 1 summarizes the main data of twenty-three state-of-the-art UAS. Their sizes and missions are representative of the actual market, the MTOW ranging between 3 and 11600 kg. First, the methodology for selecting the applicable airworthiness code(s) complied in Appendix 1 of the EASA's Policy Statement is applied to the selected UAS. This methodology comes from the "Alternative 1" published in the EASA A-NPA Nº 16/2005 (1). As explained in Section 3 of this document, it is necessary to calculate the kinetic energy on impact in two scenarios: unpremeditated descent and loss of control. Thus, the kinetic energy has been calculated for the 23 selected UAS for both scenarios. These values have been introduced into Figures 1 and 2 of the Appendix 1 of the A-NPA. Figure 1 provides an indication of the standards to be applied to any feature of the design whose failure would affect the ability to maintain safe altitude above the ground. Figure 2 provides an indication of the standards to be applied to any feature of the design whose failure would affect the ability to maintain control (particularly rate of descent). Clearly, this must include the primary structure. An analogous exercise has been done for "Alternative 2" of the A-NPA Nº 16/2005 for comparison purposes, although this alternative has not been adopted in the EASA's Policy Statement. For applying "Alternative 2", it is necessary to estimate the crash energy (proportional to the kinetic energy) and the lethal crash area (correlated from an expression that relates MTOW and wing area). Then the number of potential ground victims is estimated, based on the lethal area and on population density. The crash probability and safety objectives can thus be determined. On comparing today manned aircraft safety objectives (as defined in the regulations) to the UAS proposed safety objectives a correspondence between CS-23 categories/CS-25 and UAS categories is established. Through the values estimated for the lethal crash area, the A-NPA provides a first equivalence table between the UAS and the manned airworthiness codes. A second equivalence table relates the UAS safety objectives, measured in terms of crash probability per flying hour, with the various CS-23 categories or military category. The results obtained on applying these methods to the selected UAS are compiled in Table 2.

In parallel to the methodology developed by EASA, there are other researchers in the United States (26, 27) that also work on the way of selecting an airworthiness code to be used for UAS among those existing for manned aircraft. In this case study these investigations are taken into account too for comparison purposes.

The aforementioned research work (26,27) is established under the philosophy of safety target approach, following the orientation of the 1209 AMC section of EASA CS-25 code where a risk reference system is proposed relating the category of an event including injuries and/or fatalities with its frequency of occurrence. The problem now is to define an ELOS for UAS based in this concept. The worst scenario is the one in which there are fatalities, so the ELOS need to be defined exclusively on the fatality rate. When the ELOS has been defined, the target level of safety (TLS) can be determined as the maximum acceptable frequency of an accident, among all the possible accidents. Having in mind that the scenario includes fatalities, in the particular case of UAS, the accident involving fatalities are only two types: ground impact and mid-air collisions. Both of them implies a figure for the fatality rate of $f_F = 10^{-7}$ h^{-1}, or less, to be consistent with that of the manned aircraft. Nevertheless the mid-air collision scenario



Aircraft Key:

1. Flex wing microlight,
2. 3-axis microlight,
3. Piston Single - CS-VLA
4. Piston Single 2 seat,
5. Piston Single 4 seat,
6. Large Piston Single
7. Helicopter 2 seat
8. Mid-size Helicopter
9. Mid-size Helicopter
10. Mid-size Helicopter
11. Piston twin
12. Piston twin,
13. Piston twin
14. Piston twin
15. Light Corporate Jet
16. Large Helicopter
17. Large Helicopter
18. Large Helicopter
19. Small Twin Turboprop
20. 50 seat Turboprop
21. 50 seat Turboprop
22. 100 seat airliner
23. Corporate Jet
24. Corporate Jet
25. 50 seat airliner
26. Single-aisle Airliner
27. Wide Body Airliner
28. Wide Body Airliner

Figure 2.- EASA A-NPA Nº 16/2005 (1) Appendix 1- Figures 1 (unpremeditated descent scenario) and 2 (loss of control scenario) corresponding to the Impact Energy Methodology. Also depicted in the EASA Policy Statement (22).

	Type	Range (km)	Endurance	Altitude (m)	MTOW (kg)
ALADIN	Micro	15	more than 1 h	150	3
MANTA	Mini	37	6 - 8 h	4870	27,7
FULMAR	Mini	800	8 h	2000	20
FUROS	CR	20	6 h	3000	11
TARIDAN MASTIFF	CR	30,5	7 h 30 min	4480	138
LIPAN M3	SR	40	5 h	2000	60
RHEINMETALL KZO	SR	100	3 h 30 min	2000	161
OUTRIDER TACTICAL UAV	MR	>200	4,9 h	4570	174,73
RQ-2 PIONEER	MR	185	5 h	4600	204,12
T-16 ARCTURUS	LALE	37	12 - 24 h	3657,6	37
APOENA 3000	LALE	3000	24 h	3000	82
RQ-1 PREDATOR	MALE	726	24 h	7620	855
MQ 9 REAPER	MALE	5926	14 - 28 h	7500	4760
RQ-4 GLOBAL HAWK	HALE	25928	24 - 48 h	20000	11600
nEUROn	HALE	100	100min	14000	6500
EADS BARRACUDA	UCAV	high range	long endurance	6096	3250
X-45 A	UCAV	920	long endurance	10670	5528
IAI SEARCHER	LADP	250-300	18 h	6096	426
RQ 5 HUNTER	LADP	150	8 - 10 h	4876,8	726
MANTARRAYA	DEC	100	4 h	3000	60
RADIO PLANE OQ 2	DEC		1 h	2440	47
TREK AEROSPACE DRAGONFLY	MRE (Rotary)	925	3 h	3900	485
CL-327 GUARDIAN	MRE (Rotary)	200	6,25 h	5500	350

Table 1.- Main characteristic of the state-of-the-art UAS selected. (LALE - Low Altitude Low Endurance; LADP – Low Altitude Deep Penetration; DEC - Decoy)

will not be considered because it is almost impossible to be modelled due to enormous difficulties in modelling the exact UAS trajectories, the daily air traffic (only a small portion is ATM controlled), the absence of flight plan and the differences in on board "sense and avoid" systems installed.

Although a TLS for the fatality rate cannot be directly used as a design standard, it is possible to determine the appropriate system reliability under various conditions to achieve it. A mathematical expression can be obtained for the best variable to reflect the TLS in a ground impact, which is the minimum required time between impacts, $T_{GI,min}$:

$$T_{GI,\min} = f_{GI,\max}^{-1} = \frac{A_{\exp}\rho}{f_F} P(\text{fatality/exposure}) \quad \textbf{(1)}$$

being A_{exp} the ground area in which general people is exposed to potential harm due to a ground impact, ρ the population density, f_F the fatality rate required, and P(fatality/exposure) the fatality probability given the exposure. The reference data for calculating the $T_{GI,min}$ have been an A_{exp} equal to the reference UAV area (wing surface) augmented by a small buffer to account for the width of an average human (26, 27), a population density of 200 people per km^2 (26,27), a fatality rate f_F of 10^{-8} h^{-1} (27), and a fatality probability P(fatality/exposure) equal to the following expression (26,27):

$$P(\text{fatality/exposure}) = \frac{1}{1+\sqrt{\frac{\alpha}{\beta}}\left[\frac{\beta}{E_{imp}}\right]^{\frac{1}{4p_s}}} \quad \textbf{(2)}$$

being α the impact energy threshold required for a fatality probability of 50% with p_s=0,5, β the impact energy threshold required to cause a fatality as p_s goes to zero, and p_s is a sheltering parameter $\in[0,1]$ which determines how exposed is the population to an impact. The values of the previous parameters have been investigated by Dalamagkidis et al (26, 27),

	Impact Energy	UAV Safety	
	Kinetic Energy	**Lethal Crash Area**	**Crash Probability**
ALADIN	Microlight/CS-VLA	Ultralight	Military
MANTA	Microlight/CS-VLA	Ultralight	Military
FULMAR	Microlight/CS-VLA	Ultralight	Military
FUROS	Microlight/CS-VLA	Ultralight	Military
TARIDAN MASTIFF	Microlight/CS-VLA	CS-VLA	Military
LIPÁN M3	Microlight/CS-VLA	Ultralight	Military
RHEINMETALL KZO	Microlight/CS-VLA	Ultralight /CS-VLA	Military
OUTRIDER TACTICAL UAV	Microlight/CS-VLA	CS-VLA	Military
RQ-2 PIONEER	Microlight/CS-VLA	CS-VLA	Military
T-16 ARCTURUS	Microlight/CS-VLA	Ultralight	Military
APOENA 3000	Microlight/CS-VLA	Ultralight	Military
RQ-1 PREDATOR	CS-23 Single Engine	CS-23 M<6000 lbs reciprocating	Military
MQ 9 REAPER	CS-23 Twin/CS-25 aeroplanes	CS-23 commuters	CS-23 M<6000 lbs reciprocating
RQ-4 GLOBAL HAWK	CS-25 aeroplanes	CS-23 commuters	CS-23 M<6000 lbs reciprocating
nEUROn		CS-23 commuters	CS-23 M<6000 lbs reciprocating
EADS BARRACUDA	CS-25 aeroplanes	CS-23 M>6000/commuters	CS-23 M>6000 lbs
X-45 A	CS-25 aeroplanes	CS-23 commuters	CS-23 M<6000 lbs reciprocating
IAI SEARCHER	Microlight/CS-VLA	CS-VLA	Military
RQ 5 HUNTER	CS-23 Single Engine	CS-23 M<6000 lbs reciprocating	Military
MANTARRAYA	Microlight/CS-VLA	Ultralight	Military
RADIO PLANE OQ 2	Microlight/CS-VLA	Ultralight	Military
TREK AEROSPACE DRAGONFLY	CS-27	CS-VLA/CS-23 M<600 lbs reciprocating	Military

Table 2.- Applicable airworthiness code(s) for the selected UAS following the methodology developed by EASA.

being the most appropriated ones: $\alpha=10^6$ J, $\beta=100$ J and $p_s=0,5$.

Using equations (1) and (2), the values for $T_{GI,min}$ have been estimated for the 23 selected UAS and the results have been compared with those obtained for a group of real UAS by Dalamagkidis et al (26, 27). The results are plotted in Figure 3. The continuous line show the linear correlation (in log scale) presented in (26, 27) for the requirement versus the MTOW and the dotted line is a linear upper envelope, which corresponds to multiplying the requirement derived by 3. The selected UAS fall within the margin between the two lines and demonstrates the existence of a linear behaviour between MTOW and $T_{GI,min}$. Using this figure Dalamagkidis et al derived a classification of UAS based in the order of magnitude of their MTOW (and correspondingly of their $T_{GI,min}$), where each subsequent class will require an accident rate an order of magnitude smaller than the previous. The classification can be consulted at (26, 27), and Table 3 shows the application of this classification method to the UAS considered in the present work.

On comparing Tables 1 and 2 with Table 3 the first conclusion that can be extracted is that the results are quite different. The EASA's methodologies associate more complex codes to the UAS than the TGI method. While EASA recommends using CS-VLA, the TGI method chooses the FAA's AC 91-57 (13). The difference is very notorious because the AC91-57 is an Advisory Circular for model aircraft meanwhile the CS-VLA is a formal code for very light fixed-wing single-engined aircraft, with a MTOW lower than 750 kg. For larger UAS, the TGI method associates FAR Part 103 (Ultralight Vehicles; empty weight lower than 115 kg) and FAR Part 23, while the EASA's method assign CS-23 and CS-25

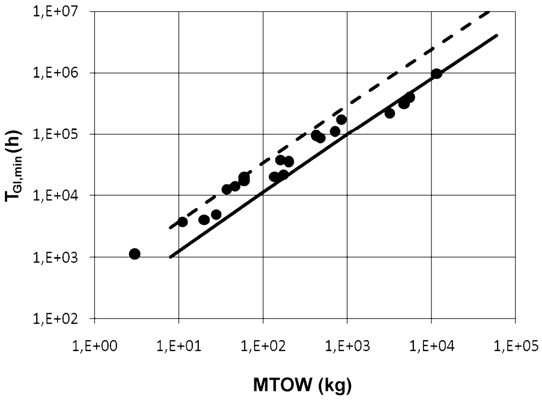


Figure 3.- The calculated TGI requirement (solid line) versus the corresponding MTOW for the UAS selected following (26,27). Dashed line represents three times the TGI requirement, and dots are the UAS selected.

	Category ($T_{GI,min}$)
ALADIN	Mini (AC91-57)
MANTA	Mini (AC91-57)
FULMAR	Mini (AC91-57)
FUROS	Mini (AC91-57)
TARIDAN MASTIFF	Small (AC91-57)
LIPÁN M3	Small (AC91-57)
RHEINMETALL KZO	Small (AC91-57)
OUTRIDER TACTICAL UAV	Small (AC91-57)
RQ-2 PIONEER	Small (AC91-57)
T-16 ARCTURUS	Small (AC91-57)
RQ-1 PREDATOR	Light (FAR103/23)
MQ 9 REAPER	Light (FAR103/23)
RQ-4 GLOBAL HAWK	Light/Normal (FAR 23)
EADS BARRACUDA	Light (FAR103/23)
X-45 A	Light (FAR103/23)
IAI SEARCHER	Small/Light
RQ 5 HUNTER	Light (FAR103/23)
MANTARRAYA	Small (AC91-57)
RADIO PLANE OQ 2	Small (AC91-57)
TREK AEROSPACE DRAGONFLY	Small (AC91-57)
CL-327 GUARDIAN	Small (AC91-57)

Table 3.- Classification, for certification purposes, based on $T_{GI,min}$ requirements (26,27) for the selected UAS.

for the larger UAS. Essentially the EASA's philosophy associates more formal codes to the different UAS, so the requirements to be applied to the future UAS will be more demanding than in the TGI method.

Finally, the impact of the associated codes to each UAS is presented. The regulatory framework for the analysis is the one selected in the EASA Policy Statement, so the codes are listed in the first column of Table 1. In order to quantify the effect of applying the EASA's code to every UAS, it is important to notice that a key feature of actual UAS is their low wing loading. This aspect makes them very sensitive to gusts and thus, the maximum limit load factor usually comes from the analysis of the gust response. Assuming that this is the case for the selected UAS, the positive gust limit load factor has been calculated for each UAS following the Pratt discrete gust criteria recommended in the CS-VLA, CS-23 and CS-25 regulations for the cruise design speed. The calculations have been made twice, applying two scenarios: in one case, the cruise design speed has been established as the real maximum cruise velocity of each UAS, obtained from the manufacturer data. In the other case, the design cruise speed has been established following the associated EASA code (column 1, Table 1). The gust intensity is 50 fps (at sea level and decreasing linearly with altitude) and the altitude, the manufacturer's altitude for each UAS. In the majority of the UAS the second value is substantially greater than the first one, so the positive limit gust load factor does the same.

Moreover, it is well known that a relationship exists between the limit load factor (the maximum of maneuver and gust load factors) and the structural weight, and there are conceptual methods for estimating this weight in which the limit load factor is an explicit parameter (29, 30, 31). The previous references show also several procedures for estimating the structural weight in terms of the MTOW, for different aircraft categories. Table 4 shows the results obtained for the structural weight of the selected UAS after applying the Roskam's (30) method: first the UAS structural weight is estimated in terms of the "real" limit load factor as a fraction of the MTOW (the selected fractions change with the aircraft category, according (30)); and second, the structural weight is obtained according to the EASA code limit load factor (this new structural weight comes also from Roskam (30)). Table 4 also collects the "real" and "regulations" gust limit load factors for comparison purposes.

When comparing the values for the gust load factor, there are two different situations. On one hand, there

	"Real" n_g	"Regulations" n_g	"Real" W_{str}	"Regulations" W_{str}	Regs W_{str}/Real W_{str}
			kg	kg	%
ALADIN	6,61	6,61	0,64	0,64	0,00
MANTA	3,36	5,64	5,93	7,03	18,52
FULMAR	4,19	6,17	4,28	4,86	13,48
FUROS	6,45	7,24	2,35	2,44	3,77
TARIDAN MASTIFF	2,67	4,46	29,53	34,94	18,31
LIPÁN M3	5,25	5,98	12,84	13,39	4,27
RHEINMETALL KZO	3,43	3,89	34,45	35,88	4,14
OUTRIDER TACTICAL UAV	2,28	3,76	37,39	44,03	17,76
RQ-2 PIONEER	2,88	4,52	43,68	50,66	15,98
T-16 ARCTURUS	5,34	6,43	7,92	8,40	6,12
APOENA 3000	3,43	5,19	17,55	20,08	14,42
RQ-1 PREDATOR	2,78	4,56	266,76	309,64	16,08
MQ 9 REAPER	2,08	2,84	1485,12	1626,96	9,55
RQ-4 GLOBAL HAWK	1,50	2,16	3422,00	3846,69	12,41
nEUROn	1,66	1,91	2028,00	2109,97	4,04
EADS BARRACUDA	2,81	2,81	958,75	958,75	0,00
X-45 A	2,30	2,30	1630,76	1630,76	0,00
IAI SEARCHER	3,10	4,75	91,16	104,83	14,99
RQ 5 HUNTER	2,36	4,13	226,51	268,24	18,42
MANTARRAYA	4,58	4,58	12,84	12,84	0,00
RADIO PLANE OQ 2	4,67	5,75	10,06	10,75	6,93

Table 4.- Real UAS gust limit load factor and structural weight, and calculated values according EASA selected manned airworthiness code.

are four cases in which the load factor does not change. This fact suggests that the manufacturer has considered the EASA associated code as the design standard. On the other hand, the most UAS experience remarkable changes in the limit load factor up to 75% higher in the worst case. These changes also imply appreciable changes in the aircraft structure to withstand such loads, increasing the structural weight. The variation in the structural weight is depicted, in Figure 4, in terms of the kinetic energy. In this Figure the different UAS have been grouped in different boxes depending on the associated manned airworthiness code, resembling Figure 2 from the EASA A-NPA and Policy Statement.

The changes in structural weight not only represent a change in the UAS structural design, but also influence on other design aspects. For instance, in the majority of the cases with an increase in the structural weight, this results in the manufacturer's declared maximum cruise velocity being different from the design cruise speed. This last speed is greater than the declared one, so the loads calculated for the design cruise speed derived from the code for the same gust intensity are greater. But it also means that the powerplant installed in the UAS may not be capable of reaching this higher speed, so a need for a stronger powerplant arises. The installation of a new engine may introduce new modifications in the UAS design, opening the door of a complete UAS refurbishment.

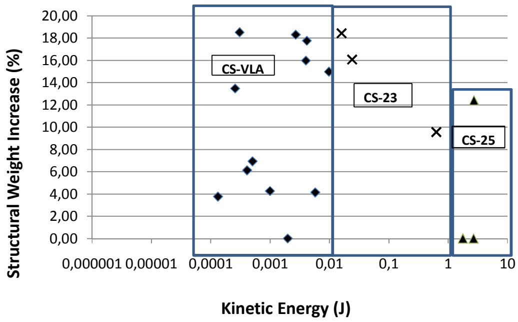


Figure 4.- Structural weight increase (%) for the UAS selected in terms of the kinetic energy.

So, if an airworthiness manned aircraft code is applied to an existing UAS perhaps this UAS could not be certified under that code, unless a complete set of major modifications are implemented on that UAS. In some cases these modifications would not be possible.

4 Conclusions

A comprehensive outlook of the regulatory framework for UAS has been presented. If the actual market for civil UAS wants to grow, it will be necessary to integrate the operations of such vehicles into the same air space (non segregated) than the manned aircraft. To reach such scenario, a set of airworthiness codes or standards will have to be elaborated in order to ensure the same safety levels than the conventional aircraft. Although the actual initiatives are somewhat confusing and disperse, the EASA Policy Statement is a remarkable basis for the new regulatory process.

The comparison of the EASA Policy Statement with other philosophies shows that this one is a restrictive approach, so a guarantee of safety. The case study applied to twenty-three state-of-the-art UAS confirms this result.

Most UAS assessed would not be able to comply with the EASA codes, essentially for they would not withstand the gust loads, due to a low structural weight. This could imply that the powerplant would not be adequate to develop the cruise design speed required in the airworthiness code. The former conclusions indicate that the manufacturers of future UAS should take the EASA code (or an alternative equivalent) from the first steps of the design process to avoid troubles in the certification.

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