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UNMANNED SYSTEMS PAPER

Current Status and Future Perspectives for Unmanned Aircraft System Operations in the US

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Abstract An aircraft (manned aircraft) may enter safely and legally into the US National Airspace System if and only if it has an airworthiness certificate complying with Federal Aviation Administration requirements. Although corresponding requirements, procedures and regulations for unmanned aircraft are in early development stages, they are expected to be similar to those set for manned aviation. This paper presents a brief overview of current airworthiness certification procedures and requirements for manned aviation, followed by a survey of the current status of Unmanned Aircraft System (UAS) regulations in the US but also internationally. Future perspectives of UAS regulation are discussed along with a proposed UAS classification for certification purposes, presentation of a possible certification roadmap, as well as regulatory paths for ultra-light UAS.

Keywords Airworthiness · Certification · Classification ·
National airspace system (NAS) · Ultralight · Unmanned aircraft systems (UAS)

Nomenclature

AC	Advisory Circular
AIAA	American Institute of Aeronautics and Astronautics
AMA	Academy of Model Aeronautics
AMC	Acceptable Means of Compliance
A-NPA	Advance Notice for Proposed Amendment

Unmanned Aircraft Systems have seen unprecedented levels of growth within the US and Worldwide. This invited contribution reviews their current operational status within the US aiming also at predicting their future potential.

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ASRS	Aviation Safety Reporting System
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
CAA	Civil Aviation Authority (United Kingdom)
CAS	Civil Airspace System
CASA	Civil Aviation Safety Authority (Australia)
COA	Certificate of Authorization
CoE	Center of Excellence
DoD	Department of Defense
EASA	European Aviation Safety Agency (European Union)
EUROCAE	European Organization for Control of Aviation Equipment
FAA	Federal Aviation Administration (US)
FAR	Federal Aviation Regulations
HALE	High Altitude Long Endurance
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronic Engineers
JAA	Joint Aviation Authorities (Europe)
JCGUAV	Joint Capability Group on Unmanned Aerial Vehicles
LSA	Light-sport Aircraft
MASPS	Minimum Aviation System Performance Standards
MTOW	Maximum Take-Off Weight
NAS	National Airspace System
NOTAM	Notice to airmen
R/C	Remotely Controlled
RTCA	Radio Technical Commission for Aeronautics
SAE	Society of Automotive Engineers
STANAG	Standardization Agreement
UAS	Unmanned Aircraft System

1 Introduction

The need to regulate civil aviation ensuring safety and healthy competition dates back to the 1920s, with several relevant conventions addressing such issues and concerns. The most significant such convention took place in Chicago in 1944, right after the end of the Second World War with more than fifty States attending. The accomplishments of that conference set the groundwork for aviation safety and international cooperation on regulations, standards and procedures development, all relevant even to this day. Attending States also founded the International Civil Aviation Organization (ICAO) as a means to secure progress accomplished during the conference, as well as future cooperation [26].

Although Unmanned Aircraft System (UAS) operations were very limited before the 1944 Chicago Convention, Article 8 refers specifically to pilot-less aircrafts [28] and provisions within still apply to current systems. Some of those provisions are that a UAS cannot fly over another State without special authorization by that State (Article 8); UAS are required to bear registration marks (Article 20) and they must have a certificate of airworthiness (Article 31) [28]. Nevertheless, it should be noted that the Chicago Convention applies to civil aircraft and as a result, UAS used in military or law enforcement services could/may have additional restrictions [28].

Currently, most UAS applications and use focus on military domains, with several systems being in service and more under active development. Over the last decade, benefits of UAS use in civil application domains are being noticed by the public sector to the point where several organizations/agencies (including the US Coast Guard, Customs and Border Protection, Department of Homeland Security, Department of Agriculture as well as local law enforcement agencies) are launching initiatives to introduce UAS in their infrastructure [38]. However, despite significant interest for commercial applications, efforts in that area are limited, mainly because of very strict and prohibitive Federal Aviation Administration (FAA) regulations that do not allow for this kind of operations. Moreover, because of lack of regulations, current UAS operations may be based on the wrong interpretation of FAA policies as admitted by the FAA in [17]. As a result, it is essential not only to review the current regulatory status and existing airworthiness certification avenues available, but also evaluate any future possibilities that may be arise, allowing UAS operators to fly lawfully as well as safely in the National Airspace System (NAS).

Before discussing current and future UAS certification procedures, it is important to present fundamental differences between UAS and manned aircraft. These differences will invariably dictate some of the changes and additions required in current regulations to allow safe UAS operations.

- **Maximum take-off weight:** Manned aircraft have a Maximum Take-Off Weight (MTOW) of at least 100 kg (more for powered vehicles) and up to 600 metric tons (Airbus A380). UAS span the entire spectrum from a few grams and up to 12 metric tons.
- **Applications:** The vast majority of manned aircraft are employed in point-to-point operations of transporting goods and people, while UAS may be also used for applications that require them to loiter over a specific area for several hours, even days.
- **Sacrificability:** A manned aircraft crash is considered a catastrophic accident that should be avoided as much as possible. In the case of UAS, it is acceptable to allow the UAS to crash in order to minimize damages to people and property.
- **Awareness:** The pilot of an aircraft is aware of the surroundings as well as of the performance of the aircraft. A UAS operator is limited to the information provided by instruments. In addition to that, in some cases UAS operators may operate more than one vehicles and/or may not be fully qualified pilots.
- **Authority:** In manned aircraft the person ultimately responsible for their operation is the pilot, when for UAS the controlling authority may reside with a remote operator or with the UAS itself. This also means that after the occurrence of non-catastrophic failures the UAS should be capable of continued safe flight and landing.

The rest of the paper is organized as follows: Section 2 refers to regulating safety in UAS, while Section 3 provides a summary of airworthiness certificates. The international status quo is the topic of Section 4, while Section 5 discusses the development of airworthiness regulations. The last section concludes the paper.

2 Regulating Safety

There are two approaches to defining UAS safety and airworthiness requirements. The first is to determine acceptable levels of risks to third parties. This is usually quantified as the number of fatalities and/or injuries per hour of flight or as an accident rate. It should be noted that the former metric is not an intrinsic characteristic of the platform, since it also depends on the type, frequency and duration of the missions [20]. As a result, application of this method to the commercial sector where UAS roles can change frequently, presents difficulties. On the other hand the use of the accident rate may penalize lighter or smaller vehicles, since after an accident involving such vehicles a lower number of fatalities is usually expected. Regardless of the metric used, this approach has the advantage of allowing UAS to fly without full compliance with a comprehensive code of requirements [28], but at the expense of posing operational restrictions.

The second approach is to produce a code of requirements, usually in the form of standards, for various UAS subsystems and for all stages of its design the final system must adhere to [20]. The advantage of this method is that complete re-certification of a system is not required when its mission or one of its subsystems changes. It also allows type certification procedures for UAS similar to manned aircraft instead of a lengthy airworthiness examination of each UAS. This is the primary approach taken by regulatory bodies for drafting requirements for civil, manned aircraft. It should be noted that even in this case, there are provisions that define safety levels used to evaluate new technologies or designs that are not covered by existing code [28]. These requirements can be found in paragraph 1309 of current certification specifications for aircraft and provide a "safety net" by setting a minimum allowed safety performance, the rest of the regulations notwithstanding.

Regardless of the specifics of the approach, the primary intent of current flight regulations has been to reduce the probability of harm to third parties as required by ICAO Annex 8 and the Chicago Convention [20, 28]. Nevertheless new standards are drafted with the safety of the passengers and crew as their goal, under the assumption that it will also reduce the risk to people on the ground [7, 28]. In contrast to their manned counterparts, unmanned systems only pose a risk to people on the ground and a smaller risk to people on board other aircraft from a midair collision. In fact sacrificing the system to avoid fatalities can be an acceptable policy. As a result regulations need reflect this characteristic.

3 A Brief Overview of Airworthiness Certificates

In order for any aircraft to fly in NAS, it must have an airworthiness certificate. According to FAA, there are two conditions that need be met in order for an aircraft to be considered airworthy; it must conform to its type certificate including any supplemental certificates, and it must be in a condition that ensures safe operation [13]. For aircraft that are not type certified, compliance with the second condition is adequate.

3.1 Standard Certificates

Standard airworthiness certificates are given to aircraft that comply with their type certificate in any of the categories defined in Federal Aviation Regulation (FAR) Part 21, including:

– Normal, utility, acrobatic and commuter aircraft (FAR Part 23)
– Transport aircraft (FAR Part 25)

- Normal rotorcraft (FAR Part 27)
- Transport rotorcraft (FAR Part 29)
- Manned free balloons (FAR Part 31)

In addition to the above categories, type certification is available for primary, restricted, US Army surplus and imported aircraft, as well.

3.2 Special Certificates

For aircraft that do not meet requirements for a standard certificate but are still capable of safe flight, special airworthiness certificates are available [13]. There are six types of such special certificates:

- **Primary:** Aircraft type-certificated under the primary category (airplanes that are unpowered or single-engine, with MTOW of at most 1,500 kg and an unpressurized cabin with a maximum capacity of 4 people).
- **Restricted:** Aircraft type-certificated under the restricted category. The restricted type is for aircraft that have special purpose applications (agricultural, forest and wildlife conservation, weather control, aerial surveying, etc.).
- **Limited:** Aircraft type-certificated under the limited category. This category is for aircraft that are required to operate under certain restrictions.
- **Light-sport (LSA):** This category is for aircraft other than helicopters that do not exceed 600–650 kg, have a maximum speed of not more than 120 knots and a capacity of not more than two persons. Additional requirements are made on the presence of certain equipment. The certification process includes FAA inspection of the documentation accompanying the aircraft as well as the aircraft itself. Upon successful completion of these inspections the FAA issues a special airworthiness certificate that may include operational restrictions.
- **Experimental:** This category is for research and development, to show aircraft compliance with a type certificate, to demonstrate functional and reliability requirements, to train flightcrews or perform market surveys. Kit-built aircraft may also qualify for an experimental certificate under certain conditions. Several operational requirements exist for experimental aircraft depending on their characteristics.
- **Special flight permits:** These permits are given to aircrafts that would not qualify for other airworthiness certificates, usually for flight testing purposes.

3.3 Vehicles

There are certain types of aircraft like moored balloons, unmanned balloons, unmanned rockets and ultralights that are considered “vehicles” and, thus, are allowed to fly without an airworthiness certificate. More specifically most requirements regarding pilot certification, operating and flight rules, vehicle registration and marking, maintenance certification that are normally applicable to aircraft, do not apply for this category [34]. Nevertheless operational restrictions are in place. For example the following pertain to the operation of ultralight vehicles (FAR Part 103):

- Single occupant.
- Daylight operations.

- Recreation or sport purposes only.
- No flight over congested areas in cities, towns or open areas when crowds are present.

3.4 Remotely Controlled Models

Model airplanes are regulated on a voluntary basis, based on AC91-57 with few operational restrictions. In addition to that an independent organization, the Academy of Model Aeronautics (AMA) issues normal or restricted flight permits after inspection of the model, provides insurance for its members and organizes areas to safely practice aeromodelling. It is noteworthy that the AMA poses additional restrictions to the ones in FAA AC91-57, both in design (e.g. the weight of the models and their propulsion methods) as well as in operation [1].

Despite the fact that Remotely Controlled (R/C) model airplanes have been suggested to present a mid-air collision risk to other aircraft [36], there is only a small number of incidents reported in the Aviation Safety Reporting System (ASRS) database, all occurring between 1993 and 1998. Furthermore, the occurrence was either due to model operators violating restrictions or because the pilot of the manned aircraft was unaware of authorized R/C model activity. As such, current regulation for this category of vehicles can be considered adequate to ensure appropriate levels of safety for people and property.

4 Status Quo

4.1 International

Several states like Australia, Canada, Finland, Italy, Malaysia, Sweden, UK and the US, are currently implementing procedures to issue special operating authorizations for UAS [23]. Furthermore, many states foresee international civil UAS operations in the near future [23], a fact that has motivated the ICAO to explore UAS regulations.

ICAO involvement with UAS dates back to April 2005, when it decided to consult some of its member states regarding current and future UAS activities in their NAS, and the need for ICAO guidance material [23]. An informal, exploratory meeting followed in May 2006 in Montreal, Canada, where attending delegates of fifteen states and seven international organizations agreed that ICAO was not the appropriate body to lead the regulatory effort and that although it could guide and coordinate to some extent the regulatory efforts, the latter should be based on the work of RTCA, EUROCAE and other bodies [23]. In a second ICAO meeting during January 2007 in Florida, a UAS study group was established with the goal of supporting the regulation and guidance development within ICAO [25]. Furthermore in a working paper presented by the US in the 36th ICAO Assembly in September of 2007 the need to amend the accident definition with occurrences involving UAS and appropriate investigation of such accidents was put forth [24].

In Europe, the Joint Aviation Authorities (JAA)/Eurocontrol UAV Task force issued a report in 2004 [28] for regulations on civil UAS. A year later

European Aviation Safety Agency issued an Advance Notice for Proposed Amendment based on that report, titled "Policy for Unmanned Aerial Vehicle (UAV) certification" [11].

The French Flight Test Center adopted certification specifications for normal, utility, aerobatic and commuter manned airplanes to UAS [11]. Civil Aviation Authority (CAA) and Civil Aviation Safety Authority (CASA) also had similar programs to regulate UAS operations in their respective airspaces [10, 32].

Japan had 2,000 Yamaha Rmax unmanned helicopters in service for agricultural purposes by 2002 with more added each year [38]. These systems are required to fly at a maximum altitude of 150m.

In the military domain, the Joint Capability Group on Unmanned Aerial Vehicles of the NATO Naval Armaments Group approved the first draft of Standardization Agreement (STANAG) 4671 on Unmanned Aerial Vehicles Systems Airworthiness Requirements in March of 2007 [27]. STANAG 4671 is currently in the process of national ratification. This will allow UAS to fly over different countries, something that is not currently allowed by the ICAO without permission from the countries whose airspace the UAS will enter [20].

For safety reasons UAS flight in the US and worldwide is currently segregated from the rest of the air traffic with the use of NOTAMs [19].

4.2 Light UAS

Most of the documents previously mentioned concern civil UAS with MTOW above 150 kg [11, 27]. In Europe, airworthiness certification for lighter vehicles as well as public UAS remains with national authorities [11]. Although national authorities retain control for certification of vehicles lighter than 150 kg, there is currently little or no information available on general certification requirements for this category of UAS; the only exception is a recommendation of the JAA/Eurocontrol UAS task force [28].

In the UK, the CAA has published a "Policy for light UAS systems" [21] consistent with the aforementioned recommendations in [28]. Eligible UAS under that policy are those that do not exhibit a maximum kinetic energy on impact over 95 KJ. UAS also need be operated within 500 m of the pilot and at altitudes not exceeding 400 ft [21]. In order for such vehicles to be certified, a positive recommendation is required from an accredited organization that has inspected the design and manufacture of the vehicle followed by successful completion of a reliability flight test program [21]. Furthermore the CAA waives Certificate of Authorization (COA) requirements for UAS with weight less than 20 kg, provided that they operate within a specified safety distance from airports, congested areas, third party vehicles, structures, etc. Finally for vehicles less than 7 kg, most of the requirements are waived.

In Australia, CASA exempts only ultra light UAS (less than 0.1 kg) and requires from the rest of the light UAS to operate away from populated areas at a maximum altitude of 400 ft [19].

It is clarified that there is a difference in using the term 'light' in the airworthiness certification literature of manned aircraft versus that used for UAS. In the former category, light aircraft are those that do not exceed an MTOW of 600–650 kg depending on their use. On the other hand the aforementioned weight requirements for light UAS (less than 150 kg) correspond better to the ultra light category as defined in the FAR Part 103.

4.3 United States

The first efforts towards UAV regulation were taken as early as 1991, when the FAA issued a notice for proposed rule making and formed an industry support group [31]. Over the following year work progressed mostly with development of Advisory Circulars (AC) regarding design, maintenance, pilot qualification and equipment requirements, among other topics.

The University of New Mexico published in 2001 the first version of the High Altitude Long Endurance (HALE), UAV Certification and Regulatory Roadmap [31], which was sponsored by the NASA Erast Project. Since then, newer versions have been published with feedback from other stakeholders. The goal of that document was to be a basis of discussion between the FAA, the industry and other stakeholders for establishing regulation for aircraft airworthiness, flight standards and air traffic that will allow safe operation of HALE UAS in the NAS. This effort was continued with the Access 5/UNITE program also sponsored and funded by NASA with participation of FAA, DOD and other stakeholders. The aim of this project was to integrate HALE UAS in the NAS [2] but it was terminated early in February of 2006 due to budgetary reasons [2].

Currently, flight of public UAS is authorized on a per-case basis after a COA application. A COA is issued after submission of required documentation and an analysis performed by the FAA Air Traffic Division to determine that an equivalent level of safety with that of manned aviation can be achieved. It may contain operational restrictions and is normally effective for up to one year. Towards that end, the FAA has issued "AFS-400 UAS Policy 05-01" [14] which is used as the basis for the evaluation of applications for COA.

It should be noted though that according to that policy the FAA accepts COA applications only for public UAS. Civil UAS can get a special certificate under the experimental category with the limitations imposed for that category in FAR Part 21 [18] and possibly additional provisions set by the FAA, specifying other operational requirements [22]. Despite the regulatory problems, a significant interest for the use of UAS was demonstrated with the number of COA applications. In 2005 the FAA issued 50 COA and 55 more were issued in the first six months of 2006 [39].

Quite recently the FAA in cooperation with Lockheed Martin, begun development of a five year roadmap for integration of UAS in the NAS [35] and declared an initiative to "Develop policies, procedures, and approval processes to enable operation of unmanned aircraft systems (UAS)" for 2008 [16].

In addition, several organizations including American Society for Testing and Materials (ASTM), RTCA, Society of Automotive Engineers, American Institute of Aeronautics and Astronautics and Institute of Electrical and Electronic Engineers have been tasked to develop airworthiness and safety standards for UAS, to be included in the certification process for flight in NAS/Civil Airspace System. Significant work has been accomplished by the ASTM and the RTCA as presented below.

4.3.1 ASTM

The ASTM F38 committee has produced more than 10 standards. One of the most known, the F2411-07 Standard Specification for Design and Performance of an Airborne Sense-and-Avoid System, has been adopted by the US DOD according to ASTM. Others include "Standard Practices for Unmanned Aircraft System Airworthiness", "Standard Practice for Quality Assurance in the Manufacture of Light Unmanned Aircraft System" and "Standard Practice for Unmanned Aircraft System (UAS) Visual Range Flight Operations".

The ASTM through its standard practice document [4], proposes two certification pathways; type certification leading to a standard airworthiness certificate for large UAS and a "Light UAS" special airworthiness certificate similar to that for LSA. The special airworthiness certificate for the LSA category is issued by the FAA if the aircraft complies with all eligibility requirements in [13] and after the manufacturer of the aircraft provides all the necessary documents that certify compliance with industry consensus standards [34]. The only requirement mentioned by the ASTM for eligibility in the "Light UAS" category is an MTOW of at most 600 kg. In addition to that, the ASTM is currently working on a standard guide document for mini UAS airworthiness, as well as a review of requirements for unmanned rotorcrafts.

4.3.2 RTCA

In October of 2004, RTCA formed committee SC-203 with participation from government and industry representatives from several countries. The first task was to develop "Guidance Material and Considerations for UAS", a document that was issued in March of 2007. In addition to that the committee has been working on Minimum Aviation System Performance Standards for:

- UAS
- Command, Control and Communication Systems for UAS
- Sense and Avoid Systems for UAS

Nevertheless no such standards have been published yet.

5 On Developing Airworthiness Regulation

There are two main models for the development of regulation; the traditional model and the "industry consensus" model. The traditional model is based on sufficiently mature technologies for which standards have been developed and possibly implemented. In this case the regulatory body undertakes the task of assessing the technology and standards available and develops appropriate regulations. Because of the aforementioned requirements this process is slow, costly and in some cases counter-productive since developed technology and standards is not necessarily adopted.

The "industry consensus model" was recently used for the regulation of the LSA category. In this case the FAA participated actively in the development of standards and as a result these standards were immediately incorporated into the regulatory framework upon publication. This approach is faster and more cost-effective, since the burden of drafting the standards is mostly with the industry.

Regardless of the actual development model used, there seems to be consensus in the literature that the airworthiness and type certification process for UAS should be based on that of manned aircraft of the same category, as defined primarily by their MTOW [11, 20, 28]. This is achieved by removing the non-applicable paragraphs and adding any additional requirements where needed, just like other special aircraft categories.

A proposed classification of UAS for certification purposes is presented next, followed by proposed elements of the UAS certification roadmap, concluding with possible certification paths for UAS of low MTOW.

5.1 UAS Classification for Certification Purposes

Manned aircraft have been classified in different categories (e.g. large airplanes, sailplanes and power sailplanes, very light airplanes, etc.) that have different airworthiness requirements. Unfortunately, to this day, there is no consensus on the categorization of UAS.

One of the most comprehensive categorizations based on weight, endurance and operational altitude has been presented in Table 1 including both fixed-wing and

Table 1 UAV categorization for differentiation of existing systems

	Mass (kg)	Range (km)	Flight alt. (m)	Endurance (h)
Micro	<5	<10	250	1
Mini	<20/25/30/150[a]	<10	150/250/300	<2
Tactical				
Close range (CR)	25–150	10–30	3.000	2–4
Short range (SR)	50–250	30–70	3.000	3–6
Medium range (MR)	150–500	70–200	5.000	6–10
MR endurance (MRE)	500–1500	>500	8.000	10–18
Low altitude deep penetration (LADP)	250–2500	>250	50–9.000	0.5–1
Low altitude long endurance (LALE)	15–25	>500	3.000	>24
Medium altitude long endurance (MALE)	1000–1500	>500	3.000	24–48
Strategic				
High altitude long endurance (HALE)	2500–5000	>2.000	20.000	24–48
Stratospheric (Strato)	>2.500	>2.000	>20.000	>48
Exo-stratospheric (EXO)	TBD	TBD	>30.500	TBD
Special task				
Unmanned combat AV (UCAV)	>1.000	1.500	12.000	2
Lethal (LET)	TBD	300	4.000	3–4
Decoys (DEC)	150–250	0–500	50–5.000	<4

Source: [5]

[a]Varies with national legal restrictions

rotorcraft UAS. Although this categorization is not for certification purposes, it demonstrates the range of UAV characteristics and capabilities.

Of particular importance to the development of UAS airworthiness regulation is to achieve a level of safety that is at least equivalent to that of manned aviation, while avoiding unnecessary restrictions that may impede UAS commercialization. The most common metric of safety is that of expected fatalities after an accident and a key factor that has been found to affect it, is the aircraft mass [6, 20, 37].

To determine the risk to human life after a UAS ground impact, the fatality expectation model proposed in Dalamagkidis et al. (submitted for review) and presented in Eq. 1 may be used. The model calculates the expected number of fatalities as a function of the aircraft's kinetic energy at impact and the area exposed to the crash. To get a conservative estimate, the worst case between impact at two times the operational velocity, and impact at terminal velocity were used to calculate the kinetic energy imparted.

The rest of the parameters used for the model are an average population density $\rho = 200$ people per km^2, $f_s = 0.5$, $\alpha = 10^6$ and a $\beta = 10^2$, that correspond to the average ground impact scenario of same study. Different parameter values may be more suitable for other scenarios; nevertheless this will not affect the conclusions drawn.

$$E(\text{fatalities}|\text{GI}) = A_{exp}\rho \cdot \frac{1}{1 + \sqrt{\frac{\alpha}{\beta}}\left[\frac{\beta}{E_{imp}}\right]^{\frac{1}{4ps}}} \tag{1}$$

Using a maximum acceptable rate of fatalities requirement (f_F), the time between ground impact accidents (T_{GI}) can then be calculated from Eq. 2.

$$T_{GI} = E(\text{fatalities}|\text{GI})^{-1} \cdot f_F \tag{2}$$

Based on the two above equations the T_{GI} for 43 UAS of various types and sizes was calculated to maintain an expected number of fatalities of less than 10^{-7}/hr. The latter limit provides an equivalent level of safety to that of current manned aviation (Dalamagkidis et al., submitted for review). The T_{GI} requirement for each UAS is plotted against its MTOW and presented in Fig. 1. The existence of an approximately linear relationship between the MTOW and the T_{GI} is evident.

Using Fig. 1 a natural classification of UAS may be based on the order of magnitude of their MTOW, where each subsequent class will require an accident rate an order of magnitude smaller than the previous. Such a classification is presented in Table 2 although the reliability requirements for each class may vary, depending on the model parameters used.

Another way to categorize UAS that is also of interest for certification purposes is based on their level of autonomy.

- Remotely piloted: A certified pilot remotely controls the system.
- Remotely operated: The UAS is given high-level commands (waypoints, objects to track, etc.) and its performance is monitored by a trained operator.
- Fully autonomous: The system is given general tasks and is capable of determining how to accomplish them. It can monitor its health and take remedial action after the occurrence of faults.

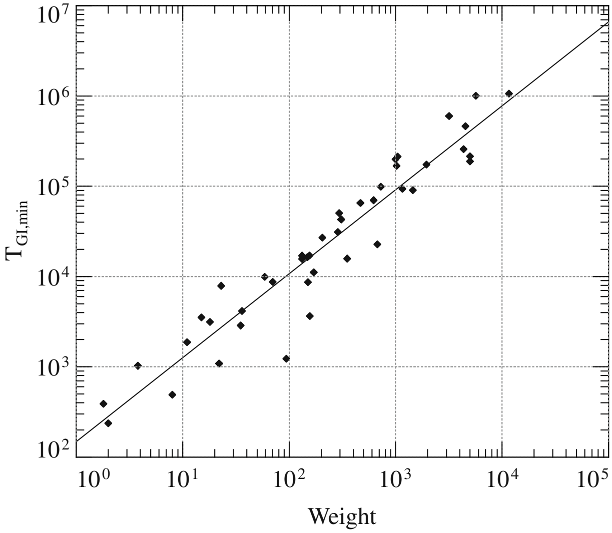

Fig. 1 The calculated T_{GI} requirement versus the corresponding MTOW for 43 UAS of different types and sizes. The calculations are done for a population density of 200 people per square kilometer. The relationship is approximately linear with respect to their logarithms

Regardless of the level of autonomy, UAS airworthiness requirements are likely to also include provisions for human override capabilities, compliance with Air Traffic Control (ATC) instructions, satisfactory system failure handling and collision avoidance among other things [11].

Finally UAS - like other aircraft - can be categorized based on their ownership as *public* or *state* when they are owned and operated by public entities like federal agencies or local law enforcement and *civil* when they are owned by industry or private parties [22].

Table 2 Proposed UAS classification for certification purposes.

Category		MTOW	Notes
Number	Name		
0	Micro	0–1 kg	Most countries don't regulate this category since these vehicles pose minimal threat to human life or property.
1	Mini	1–10 kg	This category corresponds to converted R/C model aircraft. The operation of the latter is based on AC91-57 which the FAA has decided is not applicable for UAS.
2	Ultralight	10–100 kg	Ultralight manned aircraft airworthiness requirements are dictated in FAR Part 103.
3	Light	100–1,000 kg	Airworthiness certification for this category may be based either on LSA (Order 8130) or normal aircraft (FAR Part 23).
4	Normal	1,000–10,000 kg	Based on MTOW these vehicles correspond to normal or transport aircraft (FAR Parts 23 and 25).
5	Large	10,000+ kg	These vehicles correspond to the transport category (FAR Part 25).

5.2 Elements of a UAS Airworthiness Certification Roadmap

As mentioned in Section 4.3, currently there are only two avenues for UAS certification, either by applying for a COA in the case of public UAS or by applying for a special certificate in the experimental category for civil UAS. The latter presents problems for the industry because it takes time and there are no clearly defined procedures for UAS. In addition to that experimental certificates are quite restrictive and do not permit commercial applications.

Current certification paths are counter-productive for the FAA as well, because they force FAA to allocate resources for thoroughly investigating each application instead of producing the required regulation [3]. In the FAA aviation safety business plan [15], the FAA presents a strategic target of developing Order 8130.UAS that will define procedures for obtaining experimental airworthiness certificates by the end of April 2008.

Although the FAA is under pressure to present a UAS airworthiness certification roadmap, the document is still in development and not currently available. In addition to that, the process of UAS integration in the NAS is expected to take several years, since the required technology needs to be developed, tested and verified and then standards need to be drafted before the FAA produces the required regulations.

To speed-up this process, a step-by-step integration of UAS in the NAS is proposed starting with the small and simple designs and progress towards the larger and more complicated ones. This process has the advantage of allowing fast integration of the smaller and "safer" classes of UAS and aiding in developing technology, expertise and standards that can be used to regulate the larger classes. In addition to that integration can be achieved incrementally, at first UAS will be restricted to low population/low air traffic areas but gradually this restriction will be relaxed [9] as technology matures. As a consequence the micro/mini and ultra light categories should be the main focus of current regulatory efforts.

In parallel with standards and regulations development, other efforts are required to streamline the integration process of UAS in the NAS. Of foremost importance is to found test centers to evaluate UAS and their subsystems for both R&D as well as certification purposes. Recently the UAS Center of Excellence of the University of North Dakota demonstrated an interest for building such a test center [8].

Equally important is the development of a database like the ASRS [30] to store flight logs and all incidents and accidents from UAS operations. This database will provide invaluable information for UAS developers and operators as well as insight for standardization and regulation efforts. Furthermore the UAS reliability data are also useful for insurance providers, since companies operating civil UAS will be liable for damages incurred due to UAS operations and will require indemnification [29].

5.3 Certification Paths

5.3.1 Micro UAS

A micro UAS flying at 12 km/h has a kinetic energy of less than 11 ft–lb, which is equal to the strictest, blunt trauma injury threshold level used in [33]. To approach the corresponding fatality threshold, the vehicle would need to impact a person at a speed of at least 21 km/h. Taking into account the small area affected from an impact and possible sheltering, it is proposed that micro UAS are allowed unlimited access for low altitude flying provided that sufficient clearance is maintained from airports and other sensitive areas.

5.3.2 Mini UAS

This class of UAS can be considered as vehicles instead of aircraft, thus allowing operations under very few restrictions as is the case currently for ultralights and model airplanes. Although Micro/Mini UAS are comparable to R/C model airplanes, the FAA specifically states that according to their current policy, flight of UAS under AC91-57 is not allowed [17]. Nevertheless it is possible with a small number of operational and design restrictions to permit such UAS to fly in the same spirit as AC91-57. This is also presented as a possibility in [17], where it is stated that the FAA will investigate the feasibility of a class of small UAS that will not require airworthiness certification.

A non-exhaustive list of proposed restrictions for mini UAS, based on AC91-57 is presented below:

- Design standards:
  - The vehicle must provide the means for a pilot to assume full control or at a minimum, autonomously and safely terminate flight after an operator-initiated abort command.
  - The vehicle may also provide a facility for the operator to define a safety region that should contain all operations during autonomous flying. The vehicle should demonstrably obey the defined region.
- Operating standards:
  - The vehicle may not operate at altitudes above 400 ft or beyond visual line-of-sight of the operator.
  - The vehicle may not operate within 3 miles of an airport.
  - Vehicles in the Mini class should operate at a sufficient distance from crowded and noise sensitive areas.
  - For vehicles equipped with emergency pilot override, a trained pilot should be present at all stages of operations.
  - Sufficient separation from other air traffic should be maintained. If the vehicle is not equipped with an adequate see and avoid system, the operator will be responsible to terminate flight or assume control to guarantee appropriate separation.

These restrictions would allow immediate access of mini UAS to the NAS and facilitate the development of new technology for larger vehicles without the lengthy process of obtaining an experimental airworthiness certificate. On the other hand such restrictions are incompatible with some civil and public UAS applications. In this case, the requirement for airworthiness certification of mini UAS under the ultralight class is proposed.

5.3.3 Ultralights and Larger UAS

Although ultralights normally don't have airworthiness certification requirements, for the corresponding UAS class it is expected that it will have to follow some design standards and get a special certificate. More specifically three major design requirements are expected to be imposed:

- Presence of a collision avoidance system in the form of "sense-and-avoid", possibly assisted by TCAS II or ADS-B in larger vehicles depending on their operational characteristics.
- Presence of a fail-safe system for continued safe flight in the presence of non-catastrophic failures and controlled flight termination in the presence of catastrophic failures.
- Some capability for direct communication with ATC.

It should be noted that model airplanes regulations as well as those for ultralights, limit their allowed operations to sport or recreational purposes only, which is incompatible with UAS applications. As a result an investigation is warranted on what additional requirements are posed because of this difference in usage.

In the previous sections it was demonstrated that UAS safety performance requirements depend on two main factors, weight and the application. As a result during definition of Acceptable Means of Compliance for UAS this needs to be taken into account so that no unneeded burden is put for certain types of UAS. This practice is not new. In fact in [12], four classes of aircraft in the normal category are defined. Class I includes single reciprocating engine aircraft under 2,700 kg and has a maximum acceptable frequency of catastrophic events of 10^{-6}/h. Class IV is aimed at commuter airplanes and the corresponding frequency is 10^{-9}.

Similarly, several classes can be defined in the UAS normal and heavy categories like MALE and HALE for which airworthiness studies have already been conducted. This will allow faster and easier integration of UAS in the NAS by taking advantage of the work already accomplished. The requirements for each class can be different, since for example HALE vehicles operate at altitudes that are normally free of other air traffic.

6 Conclusions

Currently regulations involving public and civil UAS operations are in their early stages of development. However, there is also considerable activity in Universities, research labs and commercial entities that has resulted in a significant number of civil UAS in various stages of development. People and organizations involved in these activities in the US should be aware of current FAA policy and the limitations imposed therein.

More specifically current UAS developers and operators in the US, should be aware of the following publications:

- **AC 91-57 Model aircraft operating standards:** This document applies only to R/C aircraft and not to any type of UAS.

- **FAA-2006-25714 Unmanned aircraft operations in the NAS:** Provides clarification of current FAA policy on UAS.
- **AFS-400 UAS operations in the US NAS:** Describes the COA application procedures.
- **FAA Order 8130:** Provides procedures and forms for applications for special airworthiness certificates, including those in the experimental category. This document is slated to be updated in April 2008 with UAS specific procedures.
- **FAA UAS Certification Status Memorandum:** Provides points of contact within the FAA for UAS airworthiness matters.

Updated documents, required forms, news and other information is available on the FAA UAS website: http://www.faa.gov/aircraft/air_cert/design_approvals/uas/

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