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Perspectives on Unmanned Aircraft Classification for Civil Airworthiness Standards

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Preface

The goal of NASA's Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project is to conduct research that would reduce or eliminate technical barriers to integrating civil UAS into the NAS [NASA-UAS]. Among the many dimensions of this goal, one area being investigated is the development of airworthiness standards. A key question covered in this paper is how to group UAS of similar physical, performance or other characteristics, such that appropriate airworthiness standards, ultimately including reliability and design assurance requirements, can be assigned. To that end, this paper discusses some relevant aspects of the current regulatory framework for aircraft certification and summarizes many UAS classification approaches offered to date, with a concise synopsis and relevant citations, in order to achieve a good understanding of the work done globally. This work builds on research from two contracted efforts, captured in [MTSI-2012] and [SRRC-2011]. The body of work reviewed comes from regulatory agencies and other organizations that are stakeholders with respect to UAS access to the NAS.

This paper presents one view of the purpose and intent of the Federal Aviation Regulations with respect to airworthiness certification, and how those regulations may apply to UAS. It is not intended to be a complete or expert treatment of the subject. This paper should not be considered or used as an authoritative source for regulatory guidance, nor does it represent current or future US Government or Federal Aviation Administration policy.

This paper, like any paper that attempts to survey a rapidly changing subject, will always remain temporally incomplete due to constant evolution in the thinking of the worldwide certification community. In that light, this paper presents observations on the current trends in classification approaches for UAS and potential implications of those.

Abstract

The use of unmanned aircraft in the National Airspace System (NAS) has been characterized as the next great step forward in the evolution of civil aviation. Although use of unmanned aircraft systems (UAS) in military and public service operations is proliferating, civil use of UAS remains limited in the United States today. This report focuses on one particular regulatory challenge: classifying UAS to assign airworthiness standards. This paper provides observations related to how the current regulations for classifying manned aircraft could apply to UAS. The current aircraft classification approach proceeds along two dimensions: aircraft classes and operational categories. Classification is used in two ways. First, aircraft that have meaningful differences are certified differently. Second, classification is used to group aircraft with similar risk profiles. This report finds that existing aircraft classes are well aligned with UAS classes; however, the operational categories are more difficult to align to typical UAS usage. Specifically, the factors used to group manned aircraft into similar risk profiles do not necessarily capture UAS risks. UAS risk is investigated through gathering UAS airworthiness classification approaches from a broad spectrum of organizations, and then identifying the sets of classification factors from these approaches. Presumably, each organization develops a classification approach to address the risks that they deem most relevant to safety. One observation is that aircraft weight is commonly used in classification. Another observation is that classification approaches rarely exclusively use weight. Importantly, most classification systems also include some operational aspects in their classification system, such as the intended operational area.

Abbreviations

AC	Advisory Circular
AGL	Above Ground Level
AIC	Aeronautical Information Circular
ATM	Air Traffic Management
ANO	Air Navigation Order
ARC	Aviation Rulemaking Committee
ASTM	no longer an abbreviation, formerly American Society of Testing and Materials
BLOS	Beyond Line-of-Sight
BMVBS	The German Ministry of Transport, Building, and Urban Development
CAA	Civil Aviation Authority
CAAI	Civil Aviation Authority of Israel
CAP	Civil Aviation Publication
CARs	Civil Aviation Regulations
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulations
CBP	Customs and Border Protection
CFR	Code of Federal Regulations
COA	Certificate of Authorization or Waiver
COE	Center of Excellence
CofA	Certificate of Airworthiness
CPA	Conventionally Piloted Aircraft
CPL	Commercial Pilot License
CS-LURS	Certification Specification for Light Unmanned Rotorcraft Systems
DAL	Design Assurance Level
DAP	Directorate of Airspace Policy
DCA	Department of Civil Aviation
DETEC	Department of the Environment, Transport, Energy and Communications
DW	*Deutsche Welle*
DGAC	Directorate General for Civil Aviation
DoD	United States Department of Defense
EASA	European Aviation Safety Agency
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
FINAS	NATO Flight In Non-Segregated Air Space
FL	Flight Level
FOCA	Federal Office of Civil Aviation
ft	feet
g	gram
GAO	General Accounting Office
GJ	gigajoule
GTOW	Gross Takeoff Weight
HALE	High Altitude Long Endurance
IABG	*Industrieanlagen-Betriebsgesellschaft*, German industry group
IAI	Israel Aerospace Industries
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
J	joule
JAAA	Japan Agricultural Aviation Association
JAPCC	Joint Air Power Competence Centre

JARUS	Joint Authorities for Rulemaking on Unmanned Systems
JUAS	Joint Unmanned Aircraft Systems
JUAV	Japan Unmanned Aerial Vehicle Association
KE	kinetic energy
kg	kilogram
km	kilometer
kts	knots
lbs	pounds
LBA	*Luftfahrt-Bundesamt*, civil aviation authority of Germany
LOS	Line-of-Sight
m	meter
MALE	Medium Altitude Long Endurance
MASPS	Minimum Aviation System Performance Standards
MIL-HNBK	Military Handbook
MIT	Massachusetts Institute of Technology
MGTOW	Maximum Gross Takeoff Weight
MoD	Ministry of Defence
MSL	Mean Sea Level
MTOW	Maximum Takeoff Weight
MTSI	Modern Technology Solutions Incorporated
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NM	nautical miles
NPR	NASA Procedural Requirement
OSED	Operational Services and Environmental Definition
P_f	probability of failure
ROA	Remotely Operated Aircraft
RPA	Remotely-Piloted Aircraft
RPAS	Remotely-Piloted Aircraft System
RTCA	no longer an abbreviation, formerly Radio Technical Commission for Aeronautics
SC	Special Committee
STANAG	Standardization agreement
SUA	Special Use Airspace
sUAS	Small Unmanned Aircraft System
UA	Unmanned Aircraft
UAS	Unmanned Aircraft System
UAS-FCL	Unmanned Aircraft System - Flight Crew Licensing
UAS-OPS	Unmanned Aircraft System - Operations
UAV(s)	Unmanned Aerial Vehicle(s)
UK	United Kingdom
US	United States
USFS	United States Forest Service
UVSI	Unmanned Vehicle Systems International
VLOS	Visual Line of Sight
VMC	Visual Meteorological Conditions
VTOL	Vertical Takeoff and Landing
WG(4)	Working Group (4) of RTCA SC-203

1. Introduction

The use of unmanned aircraft in the National Airspace System (NAS) has been characterized as the next great step forward in the evolution of civil aviation [Sabatini-2006]. Although use of unmanned aircraft systems (UAS) in military and public service operations is proliferating, civil use of UAS remains limited in the United States (US) today, where operation is constrained under special airworthiness certificates in the experimental category, which does not allow operations for compensation. Despite significant progress made towards the goal of integrating UAS into the NAS [GAO-2012], numerous political, technological and regulatory challenges still remain in realizing routine and safe operation of these aircraft [DeGarmo-2004]. This report provides a preparatory discussion of one particular regulatory challenge: airworthiness standards for UAS.

Today's regulatory framework supporting civil aviation provides guidance necessary for aircraft, their operations, and those involved in those operations, to ensure the "highest possible uniform level of safety" [ICAO-328]. The regulatory challenge, generally speaking, is to incorporate comparable guidance for UAS within that framework that ensures the safety of other airspace users as well as the safety of persons or property on the ground. Under that large umbrella, the challenge with respect to airworthiness is to provide design standards that are no less demanding in the pursuit of safety than those currently applied to manned aircraft [EASA-EY013-01-2009], and also "to accommodate the diversity of UAS design, capability, and operations" [CCGW-2007]. As reported in [CPWF-2010], "much effort is being devoted to the definition of standards specific to UAS (e.g., the specification of prescriptive requirements on aspects of their design, maintenance, manufacture and operation). However, little consideration has been given to how these standards and regulations may be appropriately applied across the diversity of UAS, their operations and the mitigation strategies widely employed."

The regulatory challenge is particularly difficult because the safety argument that underlies standards for manned or conventionally piloted aircraft differs for unmanned aircraft in several fundamental aspects. First, unlike conventionally piloted aircraft, an unmanned aircraft can suffer catastrophic loss without necessarily endangering any human life. Second, existing airworthiness and operational standards for conventionally piloted aircraft presume the existence of an on-board pilot. Because the pilot is not on-board an unmanned aircraft, reliance is placed on automation to a much greater degree than in conventional aircraft—especially in unusual situations. And finally, there is a lack of hazard data on civil UAS operations to support development of airworthiness standards. All of these impact safety risks associated with UAS and their operations, and, as a result, the guidance needed to ensure an unmanned aircraft has been designed for and is in a condition for safe flight.

According to Title 14 of the Code of Federal Regulations (14CFR), every civil aircraft that operates in the US must have a valid airworthiness certificate (14CFR91.203[1]); and that certificate is issued when, among other things, the aircraft conforms to an approved type design and is in a condition for safe operation (14CFR21.183). Thus for UAS to have routine access to the NAS, aircraft design standards and airworthiness certification processes must be established that afford confidence in their reliability and safe operation comparable to conventionally piloted aircraft. Understanding existing airworthiness processes and concepts of risk management and assessment as they affect the allocation of airworthiness standards for civil use aircraft is essential to support decision-making on design and airworthiness standards for UAS. The degree to which current regulatory guidance applies to unmanned aircraft is a subject of high current interest.

[1] The notation 14CFR91.203 should be read as, "Title 14 of the Code of Federal Regulations, part 91, section 203." This notation is common in the legal profession and will be used throughout this paper when referring to specific regulations. A website with access to the Code of Federal Regulations is presented in the reference [CFR].

A key issue related to the development of airworthiness standards for civil UAS, and a primary focus of this paper, is that of aircraft *classification*. Classification, as used in civil certification, partitions aircraft with their operation into groups for the purpose of assigning regulations, requirements, standards or other guidance to the aircraft within each group. This paper catalogs different approaches, either used or proposed, across numerous organizations to classifying UAS. This report also discusses basic terminology and certification considerations pertinent to airworthiness, and a preliminary analysis and perspective on factors that may impact safety-related risk of UAS operating in the NAS. This report, however, is not intended to be a complete treatment of the subject, but to help inform discussion within the UAS community regarding those factors and their implications. This information will support the development of an effective and practical approach to UAS classification.

This report is organized as follows. Section 2 outlines the scope of discussion on UAS classification, and Section 3 defines terminology fundamental to a coherent discussion on classification of UAS for certification. Section 4 describes the role of classification in the scope of larger certification issues. Section 5 describes the current classification approach used in the US for conventionally piloted aircraft. Section 6 describes UAS classification systems, for both civil use and public use, including approaches in both the US and other countries. The specific classification approaches are presented in appendices A through D. Section 7 shares some observations about the classification systems presented in section 6, and thoughts on the implications of them.

2. Scope

The Federal Aviation Regulations that govern, among other things, the design and operation of civil aircraft within the NAS are contained in Title 14 of the Code of Federal Regulations. Among other duties, the Federal Aviation Administration (FAA) is charged with ensuring the requirements of 14CFR are satisfied. There is a strong desire within much of the civil aviation community to leverage the existing certification framework, as codified in 14CFR, for regulation of unmanned aircraft [CAP-722, DVP-2009, EASA-EY013-01-2009]. This desire is partially motivated by the recognition that the process for making substantial changes to the certification framework is complex and time-consuming. However, there are much deeper motivations: perhaps the DoD said it best, "requirements for UAS operation in civil airspace means flight over populated areas must not raise concerns based on overall levels of airworthiness; therefore, UAS standards cannot vary widely from those for manned aircraft without raising public and regulatory concern" [DOD-2009].

Certification has many different meanings and many different aspects. For example, in 14CFR, there are aspects of certification specific to aircraft, airborne and ground-based systems and equipment, to airspace and operations within different airspace classes, and to pilots and other personnel involved in operating or managing aircraft. In this paper, the primary focus is on certification aspects pertinent to airworthiness of aircraft systems and equipment. Annex 8 of the International Civil Aviation Organization (ICAO) Chicago Convention states that a purpose of airworthiness is "among other things, protection of other aircraft, third parties and property" [ICAO]. The term *airworthy*, as defined in 14CFR21.183, means, "…the aircraft conforms to its type design and is in a condition for safe operation." Furthermore, any aircraft that operates in the NAS must be in an airworthy condition (14CFR91.7).

There are three certificates relevant to airworthiness: a type certificate, a production certificate, and an airworthiness certificate. A type certificate is issued for a particular design of a civil aircraft, engine, or propeller insofar as it complies with applicable airworthiness requirements. The quality system used for the manufacture of aircraft is addressed through production certification. A production certificate is issued to confirm that a manufacturer can produce duplicate products under an FAA-approved type design. For an aircraft with a type certification, information about production and maintenance must be provided to obtain an airworthiness certificate. An airworthiness certificate indicates approval that each aircraft, as built, complies with its type design and is in a condition for safe operation. As such, airworthiness is applied on an airframe-by-airframe basis, whereas the type design applies to all aircraft of that design. However, the same airworthiness standards, such as those in 14CFR25 for transport category airplanes, underlie both certificates. This paper focuses on the technical aspects of airworthiness at the design phase (i.e., type certificate). This paper does not consider issues related to production certificates or continuing airworthiness for individual aircraft, nor does it consider the particular legal and procedural issues involved in the certification process.

Airworthiness certificates are one of two types. Most commercial operations require a *standard* airworthiness certificate. Under a standard airworthiness certificate, an aircraft typically has relatively few operating restrictions. *Special* airworthiness certificates include operational limitations such as restrictions on maneuvers, speed, number of passengers, activities undertaken, and where flights may be conducted. The classification approach provided in 14CFR maps types of aircraft into one of these types of airworthiness certificates. Certificates that allow commercial use have more stringent requirements than other types of use. Regular access of civil UAS to the NAS implies some (perhaps, most) of this use will be for commercial purposes. Therefore, in this examination of classification, certification that allows regular use for commercial purposes is of more interest than recreational or hobby use.

Lastly with respect to scope, this paper focuses on safety and safety-related risk pertinent to airworthiness standards, rather than other considerations such as security and environmental impact that have also been introduced into current aircraft regulation. Concerns raised recently about the privacy implications of UAS [GAO-2012] are, likewise, not addressed in this paper.

3. Terminology

Because the intent of this paper is to both inform and facilitate discussion on classification of unmanned aircraft for civil airworthiness standards, a few definitions and terms are essential, especially terms specific to classification and to unmanned aircraft. Dictionaries typically define the terms *class* and *category* as synonyms, meaning members of a larger group that share specific properties. However, the CFR and FAA policy distinguish between these terms. To the extent possible, this paper uses terminology consistent with 14CFR and other FAA regulation and policy as the foundation for discussion on UAS classification.

- Class (defined in 14CFR1.1): "As used with respect to the certification of aircraft [i.e., *aircraft class*], means a broad grouping of aircraft having similar characteristics of propulsion, flight, or landing. Examples include: airplane; rotorcraft; glider; balloon; landplane; and seaplane". Another definition of *class* provided in 14CFR1.1 addresses classification for airmen ratings, including single engine, multiengine, land, water, gyroplane, helicopter, airship, and free balloon. For this paper, we use the terminology in first definition.
- Category (defined in 14CFR1.1): "As used with respect to the certification of aircraft [i.e., *aircraft category*], means a grouping of aircraft based upon intended use or operating limitations. Examples include: transport, normal, utility, acrobatic, limited, restricted, and provisional." Other parts of the CFR refer to the light-sport aircraft category. Just as with the definition of class in 14CFR1.1, another definition for *category* addresses classification for airmen ratings, with regard to aircraft characteristics including airplane, rotorcraft, glider, and lighter-than-air. For this paper, we use the terminology in first definition.

In this paper, the dictionary definition for the term *classification*, "a set of classes or categories often used to organize" [Oxford-1996] is used. There is no explicit definition of *classification* given in 14CFR, although the term is used several times, referring to classification of aircraft, airworthiness certificates, air traffic control routes, etc. The use of the term in the CFR is consistent with the dictionary definition. A *classification approach* includes both the particular arrangement of groups and the method by which aircraft are assigned to the group.

Terminology specifically for unmanned aircraft is less well defined. Different terms have evolved over the years to describe unmanned aircraft, including *drone*, *unmanned aerial*[2] *vehicle* (UAV), as well as UAS, which is the term commonly used within the US today. This terminology continues to evolve: in a recent report from the ICAO, the terms *remotely piloted aircraft* (RPA) and *autonomous aircraft* are introduced as two distinct types of unmanned aircraft (UA) [ICAO-328]. As per the ICAO definitions, a UA is any aircraft intended to operate without a human pilot on-board; an RPA is an aircraft where the flying pilot is not on-board the aircraft; and, an autonomous aircraft is an unmanned aircraft that does not allow pilot intervention in the management of the flight. The term *system* is commonly appended, for example unmanned aircraft system (UAS) and remotely piloted aircraft system (RPAS), to take into account associated support equipment such as a control station, command and control links, and launch and recovery equipment.

The main body of this report uses the term UAS, and also adopts the term *conventionally piloted aircraft* (CPA) instead of manned aircraft, as recently used in other papers [ALPA-2011, CPWF-2011]. The survey of approaches to UAS classification presented in the appendices retains the terminology originally used in the referenced documents.

4. Classification in Context

"A prerequisite to the realization of a viable civil UAS industry is the definition of an appropriate airworthiness certification framework for UAS. This framework must take into consideration the unique aspects of the technology, their operations, the market drivers, and the broader socio-political issues associated with the integration of a new aviation technology into society." [CPWF-2010] Classification, which in this context is the grouping of aircraft into classes and categories for the purpose of assigning airworthiness standards, is foundational to a long-term certification framework intended to support routine access to the NAS. With respect to airworthiness, routine access implies that the approach to type design and airworthiness certification for a UAS should be similar to that for conventionally piloted aircraft today.

The primary means to certify the design of an aircraft in 14CFR could be called *standards-based certification*. The idea is that a list of minimum criteria (i.e., the standard) that must be met for certification of a product (aircraft, engine or propeller) is established well before an applicant applies for type certification. These standards typically include specific design criteria (e.g., structural load limits), required design features (e.g., existence of fire extinguishers), and performance parameters (e.g., required ratios of rotation speed to minimum control speed). Conceptually, standards-based certification is reasonably straightforward. An applicant for certification defines a product, establishes the product's regulatory requirements in collaboration with the certification authority, including agreement on deviations from the standard to account for specific design elements of their aircraft, and presents evidence that they have met the certification standard [AGF-2004, McCormick-2007]. The certification authority evaluates this evidence to see if compliance has been achieved. Benefits of standards-based certification include a priori knowledge of the expectations for certification, which facilitates planning from a design and cost perspective for certification, as well as providing a consistent and level playing field for all applicants.

For most aircraft, the standards-based approach is used (e.g., 14CFR25 for transport category airplanes). However, for aircraft that do not obviously fit into the conventional mold, certification authorities can establish appropriate criteria, as per 14CFR21.17b. A tilt rotor aircraft is an example of a novel design for which a standardized set of airworthiness criteria does not exist. The advantage of the 14CFR21.17b approach is that it can accommodate any particular type design immediately, often leveraging relevant

[2] Sometimes, *aerial* is replaced with *air*.

portions of existing standards, without waiting for the standards development process to take place. The 14CFR21.17b approach can be used for UAS today, and, in fact, is the only alternative for their certification at this time since airworthiness standards specific to civil UAS do not yet exist. The disadvantages of this approach include that it is much more labor-intensive for the certifying authority; and, since all of the criteria are not known upfront, it is more difficult for the applicant and the regulator to plan for the cost of the certification effort, with much more uncertainty in the outcome.[3]

Clearly, a standards-based approach to certification is essential to achieve routine, versus case-by-case, access to the NAS for UAS. Classification supports that approach by providing a means for grouping aircraft together with similar design attributes (e.g., rotorcraft versus fixed wing aircraft); but, less obviously and perhaps more importantly, grouping aircraft together that pose comparable safety risk and holding them to the same standards. Higher confidence certification standards, necessitating levels of redundancy and fail-safe features to meet reliability requirements, are levied on aircraft that pose a greater safety risk; whereas those that pose less safety risk are held to a lower standard (e.g., Part 23 vs. light sport aircraft). Classification recognizes those differences in aircraft and the need for different standards. Airworthiness standards reflect general consensus on minimum design and performance requirements necessary for safe flight; and are derived from engineering judgment and experience, especially lessons learned from accidents and incidents.

Classification of UAS could proceed in a similar way: since UAS differ from conventionally piloted aircraft in meaningful ways, these differences should be manifested in meaningful certification differences. For example, civil UAS will require certification standards for components such as ground control stations and communications related to aircraft control that do not exist with conventionally piloted aircraft. This concept, apparently, is not controversial. At least since 2006, the FAA has discussed certification of the whole system, not just the aircraft [Sabatini-2006]. Additionally, there are likely design differences among the wide range of UAS in existence today that would drive differences in required design criteria. For example, "sense and avoid" may be provided through an on-board system or it may be provided through a ground-based system. Although the safety objective—sense and avoid air traffic—is the same for either approach; the airworthiness standards will vary quite a bit depending on how the function is accomplished. In a similar way, a UAS that uses a beyond-line-of-sight communications system will have different certification standards than one that uses line-of-sight communications.

Classification also supports risk reduction in, at least, two additional ways. First, it uses the notion of risk reduction through *operational compensation*. Some potential aircraft operations do not provide enough economic or other benefit to justify the expense involved in a standard airworthiness certification effort. Thus, strictly for economic reasons, these operations will not be conducted. However, in cases where these operations do not derive their benefit through general access to the NAS, their operation may be restricted in a way that still retains the desired benefit, without adversely affecting the safety risk to the general public or other NAS users. The primary means provided in 14CFR to perform this risk tradeoff is through the *restricted* aircraft category, where the operation of a restricted category aircraft is limited to special purposes identified in their type certification approval. This category is used for limited special purpose operations in manned aviation today, e.g., agricultural spraying and aerial surveying. For UAS, this classification could be applied in a straightforward manner. One can imagine that an agricultural UAS could fly under operational restrictions similar to conventionally piloted agricultural aircraft. Furthermore, one may be able to develop appropriate restricted certifications for other operations that are outside of normal air traffic routes and away from populated areas (e.g., pipeline monitoring, commercial fish and other marine species tracking, etc.).

[3] In the US, the cost of regulators is not borne by the applicant. In Europe, the applicant must account for the involvement of the European certification experts.

Another way classification supports risk reduction is through the notion of *certification compensation*. Advisory Circular (AC) 23.1309 [AC23.1309, p. 5-6] describes how certification standards are lowered for avionics in some general aviation airplanes. The assessment is made that low-time general aviation pilots have made mistakes that might have been prevented with advanced avionics, and therefore the avionics certification requirements are lowered to encourage greater equipage. Essentially, regulators concluded that the risk of a low-time general aviation pilot making a mistake is greater than the risk of the avionics misbehaving. The operational risk is mitigated through acceptance of an airworthiness risk, and by this assessment overall system risk is lowered. Using this approach for lowering certification requirements is controversial for UAS. On one side of the debate, all other things being equal, UAS have no people on-board, thus their risk is inherently less. On the other side, establishing that a UAS is equal to a CPA is not trivial. For instance, the only data a ground pilot uses to build situational awareness comes from the sensors and equipment of a UAS; in a CPA, the pilot acts as a sensor. At a higher level, the certification requirements in AC23.1309 were only relaxed after detailed study, supported by years of safety data. Another consideration is that in unmanned operations, the primary safety risk is borne by other users of the airspace and the general public, not by the primary beneficiaries.

In all, the role of classification as described in this paper is to facilitate a standards-based approach to airworthiness certification of UAS, by providing a descriptive framework for grouping together UAS with similar risk characteristics that would then be held to similar airworthiness standards.

5. Classification of Aircraft for Airworthiness in 14CFR

Assuming, based on the reasoning in section 2, that routine access to the NAS will require UAS to be classified by the existing approach in 14CFR, then understanding that approach to classification is critical. As the subsections below show, the classification system encoded in 14CFR was developed over many years as new aircraft types came into the market and real-world issues—including technical, economic, and political issues—needed to be resolved. One particular aircraft physical parameter, weight[4], is a key dimension in aircraft classification. Weight can be viewed as a proxy for safety-related risk, that is, heavier aircraft pose a greater risk and therefore have more stringent airworthiness standards. However, aircraft classification for airworthiness standards includes considerations beyond aircraft weight. This section discusses some of the most relevant considerations, as they may affect the inclusion of UAS within that framework.

5.1. High Level View of Airworthiness Classification

CPA are classified in 14CFR based on both their physical characteristics of propulsion, flight, or landing (*aircraft class*) and intended use and operational characteristics (*aircraft category*). To see how aircraft class and category are used to determine applicable airworthiness standards, consider a simplification of the full classification system in 14CFR presented in Table 1. The top row of Table 1 represents two types of aircraft classes: airplanes and rotorcraft. The first column represents two types of aircraft categories. The *transport* category refers to aircraft used for regular transportation of passengers or cargo, and the *normal* category refers to most other types of normal flying[5] (non-utility, non-aerobatic, or non-commuter) operations, including general aviation, aerial photography, etc. Applicable airworthiness

[4] Historically, there has been confusion between the meaning of weight and mass. A kilogram (kg) is a unit of mass and a pound may be a measurement of weight (typically in physics and engineering) or mass (typically in commerce and law). Classification approaches, both in the US and internationally, use these terms interchangeably, for example using the kilogram as a unit of weight. The technical difference between weight and mass is largely irrelevant in the classification of UAS. Thus, this paper also uses them interchangeably, but it retains the usage of the source being quoting. When the source is unclear, *weight* is used.

[5] It is difficult to find a definitive definition for "normal flying." The 14CFR definitive describes it in terms of what it is not, rather than what it is.

standards are determined as a function of the aircraft's intended usage and the aircraft's physical characteristics. The entries in the table (Part 23, 25, 27, and 29 of [CFR]) provide the particular airworthiness standards for each class/category of aircraft.

Table 1. Simplified View of Airworthiness Classification in 14CFR

	Airplane Class	Rotorcraft Class
Normal Category	Part 23 (14CFR23)	Part 27 (14CFR27)
Transport Category	Part 25 (14CFR25)	Part 29 (14CFR29)

5.2. Aircraft Class

Regardless of the appeal of a simple classification approach as presented in section 5.1, the full classification framework in 14CFR is more complex, including additional classes and categories for a variety of aircraft types and operations. This section describes classes of aircraft in 14CFR and the next section describes categories.

14CFR1.1 lists the following examples of *aircraft classes*, based on flight, propulsion, or landing characteristics:

- Airplane, i.e., fixed wing
- Rotorcraft
- Glider
- Balloon or Manned Free Balloon
- Landplane
- Seaplane

Determining whether an aircraft is in one of these classes is fairly straightforward. For example, if an aircraft gets its aerodynamic lift from rotating blades, including gyroplanes, the aircraft is a rotorcraft. For aircraft outside of these classes, such as a tilt-rotor, certification would be handled under the special provisions of 14CFR21.17b. Presumably, if the market for tilt-rotors grows and the FAA certifies several of them, then tilt-rotor would become an aircraft class.

Most UAS designs fit well within the aircraft classes listed above. Unmanned Vehicle Systems International (UVSI) provides an annual yearbook that catalogs UAS throughout the world from many domains including law enforcement, commercial, military, research, etc. According to UVSI's 2012 yearbook [UVSI-2012], of the 1103 vehicles surveyed only 23 would not fit into one of the existing aircraft classes. Those that do not fit include novel configurations such as flapping wings or tilt body aircraft.

5.3. Aircraft Category

The *aircraft categories* in 14CFR, where the groupings are primarily based on similar use or operating limitations, are provided in Table 2. This table shows the relationship among aircraft category, type certificates, airworthiness certificates, and the possibility of performing the operation for "compensation or hire," that is to be paid for the operation.

Table 2. Aircraft Categories

Category	Type Certificate	Airworthiness Certificate	Compensation or Hire
Normal	Yes	Standard	Yes
Acrobatic	Yes	Standard	Yes
Utility	Yes	Standard	Yes
Commuter	Yes	Standard	Yes
Transport	Yes	Standard	Yes
Restricted	Yes	Special	Yes[6]
Primary	Yes	Special	No
Limited	See note[7]	Special	No
Light-sport	No[8]	Special	No
Experimental	No	Special	No[9]
Provisional[10]	Yes	Special	No

As seen in Table 2, most commercial operations require a standard airworthiness certificate. Under a standard airworthiness certificate, an aircraft typically has few operating restrictions, beyond the flight rules captured in 14CFR91, 14CFR121, 14CFR125, and 14CFR135. Special airworthiness certificates include operational limitations such as restrictions on maneuvers, speed, number of passengers, activities undertaken, and where flights may be conducted. As per 14CFR21.183, standard airworthiness certificates might also be issued to aircraft that are not in a category, specifically manned free balloons (14CFR31), or aircraft designated as special classes of aircraft (gliders, airships, etc.).

The next step in understanding aircraft classification under 14CFR is to examine how the aircraft categories themselves are defined. As was mentioned previously, the focus of this paper is civil operations, including flights for "compensation or hire." Thus, we will restrict our discussion categories that operate under a standard airworthiness, and the restricted category for special purpose operations. Table 3 relates aircraft categories to the primary 14CFR Part containing applicable airworthiness standards per aircraft class that would typically serve as the type certification basis under a standard airworthiness certificate or special airworthiness certificate-restricted category. This is not intended to include everything in a typical certification basis, such as noise regulations or other regulations specific to equipage for operational capabilities. The third column presents the expected starting point for type design criteria.

6 Only some operations are allowed for compensation, such as for agriculture or aerial surveying (14CFR21.25)

7 A short list of World War II era aircraft have limited category type certificates [FAA-8130.2G]

8 Light Sport Aircraft are not type certificated. Instead a statement of conformance to industry consensus standards (see [ASTM-F2245-12c]) must be provided to the FAA.

9 Operations for "compensation or hire" are not allowed under an experimental certificate. However, some very limited commercial operations are allowed including sales demonstration, market survey, and pilot training (14CFR21.191).

10 The provisional category is used during the development of an aircraft in some other category, but the vehicle in question has not met all the requirements for a full type and/or airworthiness certificate.

Table 3. Current Aircraft Category and Regulatory Basis Supporting Type Certification

Aircraft Category	Aircraft Use and Notable Limitations	Applicable Airworthiness Standards for Type Design
Acrobatic	Use: acrobatics Notable limitations: weight ≤ 12,500 lbs. seats ≤ 9, excluding pilot seats, (14CFR23.3)	Part 23, with regulations specific to acrobatic category airplanes No acrobatic rotorcraft
Normal	Use: Normal flying (nonutility, nonaerobatic, or noncommuter operations) Notable limitations: weight ≤ 12,500 lbs. (airplanes) ≤ 7000 lbs. (rotorcraft) seats ≤ 9, excluding pilot seats (14CFR23.3)	Part 23 for airplanes Part 27 for rotorcraft
Utility	Use: Normal + limited acrobatics allowed; e.g., spins (14 CFR 23.3) Notable limitations: weight ≤ 12,500 lbs. seats ≤ 9, excluding pilot seats	Part 23 for airplanes No utility rotorcraft
Commuter	Use: commuter operations (scheduled operation with at least 5 round trips/week on at least one route between two or more points according to the published flight schedules (14 CFR 110.2) Notable limitations: weight ≤ 19,000 lbs. seats ≤ 19, excluding pilot seats (14 CFR 23.3)	Part 23 for airplanes No commuter rotorcraft
Transport	Use: multi-engine aircraft intended for the regular public transport of passengers and/or cargo for hire or reward Notable limitations: weight: > 19,000 lbs. (jets & props), 7,000 lbs. (rotorcraft) seats ≥ 10 (jets), seats > 19 (props and rotorcraft)	Part 25 for airplanes Part 29 for rotorcraft
Restricted	Use: special purpose operations (as defined in 14CFR21.25, including agriculture and aerial surveying) Notable limitations: no operation over densely populated areas, in a congested airway, or near a busy airport (14CFR91.313)	Requirements of some other category or an aircraft meeting the requirements and accepted for use by the US military with exemptions and operating limitations specific to the special purpose (14CFR21.25)

As shown in this table, categories are defined in terms of aircraft weight, but also other factors such as number of seats, maneuverability (acrobatic maneuvers), number of engines, frequency of flights, and public transport of passengers or cargo. It is not difficult to recognize how each of these factors affects risk to the people on-board those aircraft.

Unlike aircraft class described in section 5.2, the direct applicability to UAS of the aircraft categories and the factors used to distinguish them is debatable. For example, the intended uses for UAS do not necessarily align as well with the existing set of aircraft categories. Although one can imagine transport category UAS for cargo, notions of normal, acrobatic, and utility category UAS are not so clear. Little, if any, data exists to show how factors such as maneuverability, number of engines, and number of scheduled operations affect risk for UAS. This observation points to a conclusion that additional aircraft categories and perhaps even additional factors may be needed to support UAS.

5.4. System Certification in Part 23

The classification approach in 14CFR does not end with a discussion of class and category. One particular requirement, 14CFR23.1309, regulates equipment, systems, and installations on-board normal, acrobatic, utility, and commuter category airplanes. The accompanying advisory circular (AC23.1309-1E), *System Safety Analysis and Assessment for Part 23 Airplanes* [AC23.1309], which describes a means to meet the regulation, describes four "certification classes of airplanes" within Part 23:

- Class I from 23.1309:
    - Categories: normal, utility, acrobatic
    - Weight ≤ 6000 lbs.
    - Single reciprocating engine
- Class II from 23.1309:
    - Categories: normal, utility, acrobatic
    - Weight ≤ 6000 lbs.
    - Either multiple reciprocating engine or a turbine engine
- Class III from 23.1309
    - Categories: normal, utility, acrobatic
    - Weight > 6000 lbs.
    - Either a multiple reciprocating engine or a turbine engine
- Class IV from 23.1309:
    - Category: commuter, typically
    - Weight ≤ 19,000 lbs.
    - 19 or fewer seats

This use of the term *class* has no relationship to the term described in section 5.2. Although *class* is an overloaded term, the fact that further subgroups of normal, utility, and acrobatic category aircraft are called out is significant. AC23.1309-1E gives specific reliability and design assurance requirements, which affect system development cost. Table 4 relates the 23.1309 class to specific requirements for probability of failure (P_f) and design assurance levels (DAL) at the indicated severity of failure as given in AC23.1309-1E.

Table 4. Relationship among 23.1309 class, severity, reliability, and DAL

23.1309 Class	Reliability & Design Assurance Requirements			
	Minor	**Major**	**Hazardous**	**Catastrophic**
23.1309 Class I	$P_f < 10^{-3}$ DAL = D	$P_f < 10^{-4}$ DAL = C/D	$P_f < 10^{-5}$ DAL = C/D	$P_f < 10^{-6}$ DAL = C
23.1309 Class II	$P_f < 10^{-3}$ DAL = D	$P_f < 10^{-5}$ DAL = C/D	$P_f < 10^{-6}$ DAL = C	$P_f < 10^{-7}$ DAL = C
23.1309 Class III	$P_f < 10^{-3}$ DAL = D	$P_f < 10^{-5}$ DAL = C	$P_f < 10^{-7}$ DAL = C	$P_f < 10^{-8}$ DAL = B
23.1309 Class IV	$P_f < 10^{-3}$ DAL = D	$P_f < 10^{-5}$ DAL = C	$P_f < 10^{-7}$ DAL = B	$P_f < 10^{-9}$ DAL = A

It is important to recognize that the classes specified in this table are particular to only one regulation: 14CFR23.1309. That is, Classes I-IV do not apply outside of Part 23 airplanes, nor do they apply to any other regulations within Part 23. However, the important point with respect to UAS classification is that both airplane weight and type of engines are factors that ultimately affect type design criteria. Moreover, requirements for reliability and design assurance levels will likely be a significant cost driver for UAS.

The classification approach in 14CFR is not static. There is an Aviation Rulemaking Committee (ARC) [ARC-Part23-2011] working to reconsider the classes given in [AC23.1309]. The purpose of that ARC is to consider reorganization of Part 23 based on airplane performance and complexity instead of the current basis on weight and propulsion.

5.5. Civil Use and Public Use

As was mentioned several times, this paper focuses on civil operations with a special emphasis on commercial operations. However, understanding precisely what civil operations are, including alternatives to civil use, is helpful in fully appreciating the regulatory framework. Under 14CFR, aircraft are classified based on use at a very high level; that is, civil use and public use. *Civil use* refers to aircraft operation by a private individual or company, such as for recreational or commercial purposes. *Public use* refers aircraft that are operated for governmental purposes, such as military operations, border patrol, law enforcement, or scientific research.

Even though this paper is concerned with airworthiness standards for civil use of UAS, learning from airworthiness-related experiences of UAS in public service is important. Indeed, the bulk of the information that exists on safety-related hazards and design criteria for UAS comes largely from public use.

Civil Use

Under Title 49 of the US Code (section 44704(d)), the FAA is responsible for ensuring that aircraft for civil use are airworthy. UAS can be authorized by the FAA to operate in the NAS today through the issuance of a special airworthiness certificate-experimental category (14CFR21.191) [FAA-7210.766]. Operating limitations and airworthiness standards are developed for the specific UAS to ensure the safety of other airspace users and persons and property on the ground. Any aircraft operating under an experimental airworthiness certificate cannot be used to conduct operations for compensation or hire; however they may be used for commercial applications including research and development, market survey, or crew training.

Model aircraft also fall under the umbrella of civil use, and are operated under the guidelines of [AC91-57]. These guidelines do not restrict the aircraft (size, weight, etc.) or contain requirements regarding airworthiness. Instead, these guidelines restrict model aircraft operations to visual line of sight (VLOS), altitudes below 400 feet above ground level (AGL), day/visual meteorological conditions (VMC), away from noise sensitive areas, and away from airports and other air traffic. Furthermore, these operations are restricted to recreational use only (i.e., operations of model aircraft for commercial purposes are not allowed).

Precisely what constitutes an operation for “compensation or hire” is, apparently, a legal gray area. But, it appears that general commercial use of UAS is not permitted today.

Public Use

The government agency that is conducting a public use operation must provide its own assurance that its aircraft is airworthy, which is sometimes referred to as self-certification. UAS for public use may be operated in the NAS under a Certificate of Authorization or Waiver (COA) issued by the FAA [FAA-7210.766]. The public operator is required to follow the particular operating procedures delineated in the COA, which is written for a particular operation. By 14CFR1.1, public aircraft cannot conduct commercial operations; thus, UAS operations for compensation or hire are not permitted under a COA.

UAS may operate in the NAS without COAs when the activity is contained totally within active warning and restricted areas, typically for military operations. Only aircraft involved in the operation, including UAS, are allowed in these areas due to the inherent danger involved.

The rules that govern in-theater use of military UAS are the responsibility of the military. These rules may change under the dynamics of the battlefield environment. Due to the vastly different risk environment, such operations are not considered in this paper.

6. Classification Approaches for Unmanned Aircraft

Much work has been done in the past few years relevant to UAS classification. Work has been done both nationally and internationally, for both public and civil use. In line with that, the UAS classification approaches identified to date in this report have been organized by whether that approach is applied to US civil UAS (Appendix A), international civil UAS (Appendix B), public use in the US UAS (Appendix C), or international public use UAS (Appendix D), as shown in Table 5.

Table 5. UAS Classification Organization

	Civil Use	**Public Use**
US	Appendix A	Appendix C
International	Appendix B	Appendix D

The classification approaches listed in Table 6 are proposed or used in assigning regulations, requirements, standards or other guidance for UAS to operate in civil and public use environments. Some organizations have classification approaches specific to airworthiness (that is, grouping together different UAS for the purpose of assigning airworthiness requirements), while other organizations have only specified operational limitations or other criteria. Still others propose some combination of the two. As such, there are a variety of factors used for classifying UAS in those contexts. Differences regarding actual risk, perceived risk, and safety objectives may mean some classification approaches are less relevant to a discussion on UAS civil airworthiness certification.

The summary of each classification approach given in the appendices provides a short description including a characterization of the organization (e.g., government, industry) that developed the approach. Also included is a general description of how UAS are divided into categories and classes, as well as their purpose with respect to classification, e.g., airworthiness certification, operational constraints, etc. Classification approaches related to operational limitations could be relevant to airworthiness, since the limitations may be related to airworthiness concerns.

It should be noted that different organizations use different terminology (for example, definitions of *class* and *category*). Every attempt has been made to be consistent with both the terminology used in this paper and the spirit of the proposed system, although inconsistencies may have been inadvertently introduced. Due to the changing nature of this subject, portions of this paper can easily become obsolete as new or modified approaches are introduced or developed. To indicate currency, the last date this information was accessed is noted in the references, when possible. Finally, not every organization provided a comprehensive classification approach. For instance, some organizations evaluate the airworthiness of each aircraft and its operation on a case-by-case basis. These organizations are listed to indicate that they have been considered in the research, but the words “no approach” are added to the section heading to indicate that a comprehensive classification approach is not included; for example, section C.3, “United States Customs and Border Protection – No approach.”

Table 6. Classification Approaches

Type	Appendix	Included Approaches
US Civil Use	A	Small Unmanned Aircraft System Aviation Rulemaking Committee, Operational Services and Environmental Definition for UAS, RTCA SC-203, Safety Working Group, ASTM F38, Unmanned Aircraft Systems Committee, Weibel and Hansman.
International Civil Use	B	Canada, Australian Civil Aviation Safety Authority, Australian Research Community, United Kingdom – Civil Aviation Authority (CAA), European Aviation Safety Agency, Civil Aviation Authority of Israel, Directorate General for Civil Aviation – France, Japan, Sweden, Malaysia, New Zealand, Belgium, Germany (LBA), Germany (UAV DACH) – No approach, Germany (IABG), Switzerland, Joint Authorities for Rulemaking on Unmanned Systems (JARUS), EUROCAE Working Group 73 UAV Systems
US Public Use	C	National Aeronautics and Space Administration, United States Forest Service, United States Customs and Border Protection – No approach, US Department of Defense – Joint Unmanned Aircraft Systems
International Public Use	D	North Atlantic Treaty Organization, United Kingdom Ministry of Defence – No Approach, Israeli Ministry of Defense – No approach

7. Observations About UAS Classification

As described in section 4, classification of aircraft for the purpose of assigning airworthiness standards should account for risk, in addition to accounting for substantive differences in design features. Ideally, if risks inherent in different types of UAS and their operations could be identified, then UAS classification could be fashioned around these identified risks. Although this is conceptually appealing, comprehensive risk identification across the spectrum of UAS has proven difficult. From a high-level perspective, DeGarmo made one of the best attempts [DeGarmo-2004].

Instead of attempting to identify all risks across all types of UAS, the research approach described in this paper involves gathering UAS airworthiness classification approaches from a broad spectrum of organizations, and then identifying the various classification bases (i.e., a set of classification factors) from these approaches. Presumably, each organization develops a classification basis to address the risks that they deem most relevant to safety. Thus, by identifying the classification bases, one can infer the classification factors that point out the risks deemed most important to safety from a broad section of the UAS community. An analysis of this type includes high uncertainty, thus it should be used to draw preliminary observations, rather than precise conclusions. As additional hazard data is collected through increased operation of UAS, safety issues and risks can be better characterized and managed through appropriate classification.

For each classification scheme given in Appendices A-D, all of the factors explicitly used in either structuring the classification or used to influence the requirements that might apply were identified. For example, in the classification proposed by the small Unmanned Aircraft System Aviation Rulemaking Committee (see A.1), gross takeoff weight of the aircraft and aircraft speed were the factors used to group small UAS together for assigning specific sets of operational limitations and recommended system standards.

Table 7 shows the different classification bases, which are composed of classification factors, from the UAS classifications given in Appendices A-D, regardless of whether those bases were used to classify all UAS or a particular subset of UAS. As shown in the table, some organizations only use one factor, namely aircraft weight, whereas other organizations use two or three different aircraft or operational characteristics to distinguish different groups of UAS. Some classifications are based on calculations of kinetic energy, which is a function of aircraft weight and speed. Other classifications specify weight and speed as separate factors. In Table 7, kinetic energy is considered a single driver. As is clear from this table, aircraft weight, either directly or through kinetic energy, is a consistent driver for grouping UAS in all but one of the classifications.

Table 7. Bases and Factors in UAS Classification

Number of Factors	Classification Bases from Appendices A-D
One	Aircraft weight
	Avionics complexity
	Aircraft configuration (number and type of engines, etc.)
Two	Aircraft weight, and Aircraft speed
	Aircraft weight, and Application (e.g., aerial work)
	Aircraft weight, and Operational range[11]
	Airspace (segregated, non-segregated), and Overflown area
	Kinetic energy, and Overflown area
	Kinetic energy, and Operational range[11]
	Kinetic energy, and Operational failure consequence
Three	Aircraft weight, Altitude, and Operational range[11]
	Aircraft weight, Kinetic energy, and Operational range[11]
	Aircraft weight, Altitude, and Application
	Aircraft weight, Altitude, and Aircraft speed

Although there are a number of different combinations of factors listed in Table 7, two observations are apparent. First, aircraft weight is considered to be a predominant factor influencing risk to safety in UAS operations. This is not surprising. Second, operational aspects are also considered an important driver for risk in many of the classifications. These operational aspects are different from those shown in Table 3. For example, operational factors that affect risk include if the operation is conducted within visual range or if the operation is over a populated area. This particular observation is important because such operational aspects are not always a factor in the existing classification for CPA. Aircraft weight is the dominant factor affecting risk for CPA operating under a standard airworthiness certificate. For those aircraft, where the aircraft operates is inconsequential from a risk perspective compared with the number of people on-board. That is reflected in the fact that normal, acrobatic, utility, commuter, and transport aircraft are not distinguished by where they fly, but largely by weight. Generally speaking, heavier aircraft allow more people to be carried, and thus must meet more stringent reliability requirements. Under a special airworthiness certificate-restricted category, where the aircraft operates is an important factor. Because operation of those aircraft is in a limited operational area, operational restrictions can compensate for not meeting all airworthiness standards expected under a standard certificate. The fact

[11] Operational range refers to the maximum distance between the pilot and the vehicle. Operational range is typically designated as Line-of-Sight (LOS) or Beyond Line-of-Sight (BLOS). [ICAO-328] distinguishes between visual line-of-sight and radio line-of-sight. This distinction points to two distinct hazards: visual line-of-sight operations allow a human to continue to provide "see and avoid" capability and radio line-of-sight recognizes a UA may lose radio contact and potentially becoming uncontrolled by any human. Further analysis is needed regarding this factor to provide salient differences between these uses.

that many of the proposed UAS classification approaches include operational dimensions may suggest that further exploration of operation under a restricted category is warranted.

Modern Technologies Solutions, Inc. (MTSI) and Embry-Riddle Aeronautical University (ERAU) both conducted independent research[12] on the topic of UAS classification. MTSI's study [MTSI-2012] consisted of an extensive evaluation of proposed UAS classification approaches (similar to the survey reported in Appendices A-D), supplemented by interviews with subject matter experts, to identify criteria important to grouping UAS for airworthiness certification. The MTSI study identified weight/mass, airframe type, and complexity as important classification factors, and concluded that any civil UAS classification scheme should be similar to that given in 14CFR, although some modification would likely be necessary.

ERAU approached the problem from a different direction. In their study [SRRC-2011], ERAU derived parameters for possible UAS classification based on UAS system design and desired operational characteristics. Then, a House of Quality methodology [HOQ- 2012] was applied to determine which parameters might have the greatest potential impact on safety, and therefore greatest importance in classification. In contrast to MTSI's approach, the ERAU study concluded that operational parameters, such as the population density in the operational area, airspace classification, and contingency planning rank higher with respect to impact on safety than most system parameters such as weight.

Though the two research studies reach different conclusions, both studies confirm that identification of factors important to UAS classification is not clear-cut. Those studies also support the general view that there are factors that indicate risk associated with UAS beyond those that define the current aircraft class/category structure in 14CFR, and those factors should be considered in deliberations about UAS classification.

8. Summary

In the pursuit of enabling UAS to routinely access the NAS, much attention is being devoted worldwide to challenges of developing certification processes, regulation, and standards for UAS, including those related to airworthiness. Many organizations have developed or are currently debating classification approaches for UAS airworthiness standards. Most notably, though, there is an absence of consensus on what those airworthiness standards should be and how they might apply across the diverse spectrum of UAS types. This paper is not intended to propose answers to those questions, but instead to facilitate ongoing deliberations by providing insight into some of the relevant factors underlying classification of CPA, and observations based on current approaches about the applicability of the current aircraft classification system and corresponding airworthiness standards to UAS.

In particular, this paper calls attention to several considerations that are relevant in the discussion of classification. Today, classification is used to support a standards-based approach to CPA certification, through airworthiness standards specifically tailored to the physical characteristics (class) and operational characteristics (category) of the aircraft; e.g., Part 25 for transport airplanes, and Part 27 for normal rotorcraft. This function of aircraft class and category neatly captures risk associated with design attributes of a particular type of aircraft, but also risk associated with intended use and operational limitations. Classification also supports risk reduction through operational compensation or through certification compensations such as those done for different classes of Part 23 airplanes. Altogether, the classification approach codified in 14CFR and other regulatory policy represents a sensible and successful approach to mitigating airworthiness hazards in CPA.

[12] Funded under NASA Research Announcement (NRA), "Research Opportunities in Aeronautics – 2010 (ROA-2010)," NNH10ZEA001N, Appendix D-3 (UASNAS1) of Amendment No 5, Released June 2, 2010.

An important question is whether that classification approach can accommodate the broad range of UAS and their desired civil operations. Examination of many UAS classification approaches from around the world suggests that classification of UAS for airworthiness is more complicated than it may appear. Aircraft weight and a parameter that includes weight, namely kinetic energy, are commonly used in classification. Another observation is that classification approaches rarely exclusively use weight. Importantly, most classification systems also include operational dimensions to their classification system, such as the intended operational area. These operational dimensions are not necessarily different in intent from those used to partition different CPA categories today; but there is a subtle difference. Under a standard airworthiness certificate that allows relatively unrestricted access to the NAS, intended operational area is not a factor in distinguishing categories; weight is, since that is the primary indicator for risk in CPA. Operation under a special airworthiness certificate-restricted category is different, with distinctions in intended use and operational area becoming dominant risk factors. Attention focused on classification particular to potential UAS operations amenable to a special airworthiness certificate-restricted category may facilitate small incremental steps into the NAS.

These observations may seem trivial. Their contribution, though, is in supporting an emerging realization that the historical separation of airworthiness issues and operational issues may not apply neatly to UAS [Allouche]. One implication is that, while the general class and category framework in 14CFR seems suitable for UAS, the particulars of the existing aircraft categories may not be a good fit for UAS. For example, there may be no normal, acrobatic, or utility category of UAS. Further analysis of factors sufficient to characterize the risk associated with UAS and their intended operations is necessary to define appropriate categories of UAS that support a standards-based approach to assignment of airworthiness requirements.

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A. US Classification Approaches for Civil Certification

The following subsections provide information on UAS classification from a civil use perspective from organizations within the United States.

A.1. Small Unmanned Aircraft System Aviation Rulemaking Committee

In April 2008, the FAA established a small UAS ARC to provide recommendations for integration of small UAS into the NAS ([FAA-1110.150]. There are no specific airworthiness requirements recommended for small UAS in the final recommendations from that ARC [SUAS-ARC-2009], except for inspection and maintenance requirements and compliance with yet-to-be-developed consensus standards. However, the report does include 17 recommended "system standards" which would provide a guide to the development of the consensus system standards, most of which are airworthiness related. The report provides recommendations for operational limitations and required capabilities for five different groups of small UAS, as per the following table (see Table 8).

This report is only a recommendation to the FAA and may or may not be similar to the final FAA rulemaking for small UAS. The FAA is expected to release a rule for small UAS in 2013.

Table 8. UAS Groups Recommended by small UAS ARC

Group	Group characteristics: Gross Takeoff Weight (GTOW), w (lbs.) Speed, s (kts)	Operational Limitations	Recommended System Standards
I	$w \leq 4.4$ $s \leq 30$ Frangible	Generally include: • Limitations on how high they can fly, within certain distances from airports; e.g., Operate ≤ 400 AGL in Class C, D, E, and G airspace • Requirements on the pilot in control and visual line of sight • Proximity to airports Requirements become more stringent as weight increases. See Section 9.2 for Group I See Section 10.2 for Group II See Section 11.2 for Group III See Section 12.2 for Group IV See Section 13 for Group V	7 of the 17 recommended standards apply to Group 1
II	$w \leq 4.4$ $s \leq 60$		17 of 17 recommended standards apply to Groups II-V. These include standards for: • Structural integrity • Fire protection • Control Station synchronization • Powerplant fail safe • Weight and balance • Fuel/power markings • materials
III	$w \leq 19.8$ $s \leq 87$		
IV	$w \leq 55$ $s \leq 87$		
V	Lighter-than-air small UAS	Reserved – no recommendations for this group	

A.2. RTCA, Operational Services and Environmental Definition for UAS

The RTCA organizes committees of government and industry representatives to develop consensus standards for aviation and air navigation systems. RTCA Special Committee (SC) 203 was established in

2004 to define Minimum Aviation System Performance Standards (MASPS) for the UAS, for sense and avoid technology, and for command and control technology [RTCA-SC203].

The SC-203 committee published the *Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems* [DO-320] in June of 2010. The OSED offers a comprehensive approach to UAS classification geared to the assessments specified in [DO-264]. These assessments are aimed at addressing issues related to airspace integration, not airworthiness. Table 9 presents the classification approach. First the vehicles are divided along basic vehicle characteristics (i.e., fixed wing, rotary wing, etc.). Next vehicles are subdivided based on attributes unique to UAS: conversion of a CPA to a UAS; high altitude long endurance (HALE), meaning an altitude greater than 60,000 ft.; or low visual signature, which is termed "small." The airspace information presented in Table 9 was derived from representative scenarios in [DO-320].

Table 9. DO-320 Classification Approach

Class[13]	Subclass	Typical Airspace	Potential Example
Turbojet fixed-wing	Standard	A, C, D	Global Hawk, X-47B
	Non-standard small		
	Non-Standard HALE		
	Conversion	A, C, D	Gulfstream G550
Turboprop fixed-wing	Standard		
	Non-standard small		
	Non-Standard HALE	A, C, D, E, G	Predator B
	Conversion	A, C, D, E, G	King Air 200, Cessna Caravan
Reciprocating/ electric fixed-wing	Standard	D, E, G	Shadow 200
	Non-standard small	E, G	ScanEagle, Raven
	Non-Standard HALE	A, C, D, E, G	Predator A, Global Observer
	Conversion	C, D, E, G	Cessna 182
Vertical take-off and landing (VTOL)	Standard	D, E, G	Firescout, RMAX Type II
	Non-standard small	E, G	T-Hawk
	Non-Standard HALE	A, C, D, E, G	Hummingbird
	Conversion	C, D, E, G	Bell 206
Airship	Standard	E, G	SA-60 LAA
	Non-standard small		
	Non-Standard HALE	E, G	WDL 1B
	Conversion		

[13] DO-320 uses the term *category*, however this factor's definition is closer to *class*, as described in section 3.

A.3. RTCA SC-203, Safety Working Group

In a separate effort from the OSED (section A.2), the Safety Working Group (WG4) of RTCA SC-203 has proposed using a simple two-part approach as a basis for conducting an operational safety assessment to help derive requirements in the absence of a UAS classification system [RTCA-SC203-WG4]. The regulations in Part 23 would apply to propulsion, mechanical systems, and structures for all UAS. The two-part approach applies to systems and equipment (i.e., avionics) as follows:

Table 10. UAS Representative Class from SC-203 Safety Working Group

Class	Class Characteristics	Applicable Airworthiness Requirements
1	non-complex UAS systems, regardless of whether they perform critical functions	Class I from [AC23.1309]
2	complex UAS systems	Class III from [AC23.1309]

[AC23.1309] identifies a "complex system" as one whose operation, failure modes, or failure effects are difficult to comprehend without the aid of analytical methods or structured assessment methods.

The WG4 position paper provides a summary of different approaches that were considered and the rationale for the two-part approach described above. The rationale for this approach is that for some systems, airworthiness standards given in Part 23 for propulsion, mechanical systems, and structures are sufficient, may be reduced, or eliminated (e.g., lower loads for wings, unneeded seat belts and oxygen systems). But more complicated avionics complexity may require higher standards to compensate for the removal of the pilot. WG4 also observes that operational considerations such as UAS loitering over urban areas for several hours may also require a higher level of design assurance.

WG4 is currently reevaluating this proposed approach. A new position paper for consideration by WG4 and the full committee is expected to follow. The new approach is still likely to be based on UAS complexity.

A.4. ASTM F38, Unmanned Aircraft Systems Committee

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), is an international voluntary consensus standards organization. ASTM Technical Committee F38, Unmanned Aircraft Systems, is developing standards for airworthiness, operations, and pilot and maintenance qualifications. This committee has produced a document [ASTM-F2505-07], which proposes a modification to 14CFR21 (Certification Procedures for Products and Parts) to incorporate certification procedures for UAS. To fully understand this document ASTM has also produced a terminology document [ASTM-F2397-07]. The document [ASTM-F2505-07] refers to UAS as an aircraft category (see section 4.7) in the same sense as normal, utility, acrobatic, commuter, and transport categories. Section 1.1 mentions four UAS classes: micro (no definition specified by ASTM F2396-07), mini (≤ 55 lbs. maximum gross takeoff weight (MGTOW)), light (≤ 1320 lbs. MGTOW) and Remotely Operated Aircraft (ROA), but considers Part 21 to only be applicable to light UAS and ROA. Airworthiness certification is suggested as unnecessary for unmanned aircraft in the micro and mini classes. Requirements for a special airworthiness certificate for light UAS are given in a new section (10.13) proposed for Part 21, comparable to the requirements for a special airworthiness certification for a light sport category aircraft.

A.5. Weibel and Hansman

The FAA and NASA funded Roland Weibel and John Hansman of the Massachusetts Institute of Technology (MIT) to investigate the safety issues of integrating UAS into the NAS. Their research report, titled “Safety Considerations for Operation of Unmanned Aerial Vehicles in the National Airspace System,” [WeibelHansman-2005] describes a UAS classification approach as follows:

Table 11. UAS Classification From MIT Research Report

Class	**Mass[4], m (lbs.)**	**Operating Area**	**Operating Altitude, h (ft,FL)**
Micro	$m < 2$	Local	< 500
Mini	$2 \le m \le 30$	Local	$100 \le h \le 10,000$
Tactical	$30 \le m \le 1000$	Regional	$1500 \le h \le 18,000$
Medium Altitude	$1000 \le m \le 30,000$	Regional/National	$18,000 \le h \le$ FL 600
High Altitude		Regional/National/International	$h >$ FL 600
Heavy	$m > 30,000$	National/International	$18,000 \le h \le$ FL 450

The report contains extensive analysis of the risk from ground impact for aircraft in each class considering population density and kinetic energy, and also considers risk of mid-air collision based on air traffic density over the continental US. The report stops short of proposing specific airworthiness requirements or operational criteria for the different classes.

B. Non-US Classification Approaches for Civil Certification

The following subsections provide information on UAS classification from a civil use perspective from organizations outside of the United States.

B.1. Canada

In December of 2006, the General Aviation branch of Transport Canada assembled the Unmanned Air Vehicle Working Group to address the integration of UAS into the Canadian national airspace [TC-2006]. The Working Group recommended the adoption of a classification approach based on maximum takeoff weight (MTOW) to provide some harmonization with existing Civil Aviation Regulations (CARs) as well as European Aviation Safety Agency (EASA) and North Atlantic Treaty Organization (NATO) criteria. Note that the Working Group's recommendations for classification also introduce some coupling with operational conditions for UAS up to 35 kg.

Table 12 shows the classification approaches proposed by the Working Group. For MTOWs up to 35 kg, classification type is further segmented into LOS and BLOS operation, where LOS operations would make use of existing CARs for model aircraft and BLOS operations would call for new regulations. The Working Group adopts the weight breakpoints of UAS at 35 kg and 150 kg to be consistent with EASA and NATO criteria. Transport Canada recognizes that the possibility of future modifications to the MTOW used for classification dependent upon any Standard and Recommended Practice developments by the ICAO.

Table 12. Classification approaches proposed by Canada's Unmanned Air Vehicle Working Group

Category	Characteristics of Category: Weight[4], w (kg) Operation (LOS / BLOS)	Airworthiness requirements
I	$w \leq 35$, LOS	equivalent to CARs for model aircraft
II	$w \leq 35$, BLOS	more rigorous standards than model aircraft
III	$35 \leq w \leq 150$	airworthiness standards, internationally harmonized
IV	$w > 150$	full type certification, internationally harmonized

B.2. Australian Civil Aviation Safety Authority

Australia's Civil Aviation Safety Authority (CASA) is responsible for regulating civil use of UAS. The Civil Aviation Safety Regulations (CASRs) are Australia's equivalent of 14CFR in the US. In 2002, CASA introduced civil UAS regulations, making CASA the first civil regulatory agency to do so [Coyne-2011]. These regulations, however, require Certificates of Airworthiness (CofAs) to be issued under experimental or restricted categories, and therefore only solve part of the UAS integration challenge. Australia also has an active research community (see section B.3) working to propose a more-permanent framework for regulation. A common theme between CASA and the research community for the existing and proposed regulatory framework is the perceived risk posed by UAS operations [DVP-2009]. Thus, the recommended airworthiness certification criteria are closely coupled with operational considerations.

Currently, CASR Part 101 (Unmanned Aircraft and Rocket Operations) [CASR-101] contains regulations for the operation of Unmanned Aerial Vehicles (UAVs). Part 101 separates model aircraft from UAVs, then divides UAVs into three categories: micro, small, and large (see Table 13). Part 101 requires all large UAVs to have a special certificate of airworthiness in the restricted category or an experimental certificate. In addition, any UAV that operates in a populous area at a height lower than necessary to clear the area in case of a failure must have a certificate.

The advisory circular for CASR 101 [CASR-AC-101] partitions guidance for operational approval and for airworthiness into two categories: small UAVs and large UAVs. An airworthiness certificate is not required for small UAVs. However, small UAVs may apply for a CofA through a process similar to that for large UAVs, and thereby gain access to a broader scope of operations, dependent upon conditions in the CofA (AC 101-1(0).12.2.3).

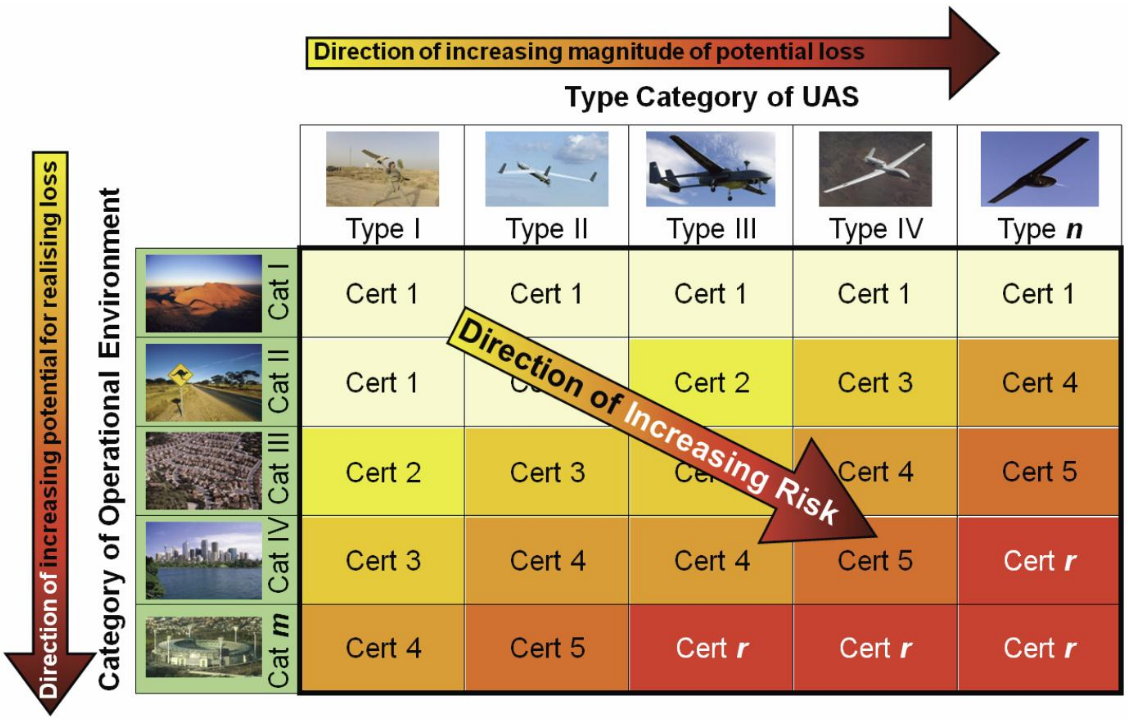
Table 13. Australia's UAV Categories

Categories	Category Characteristics: Gross Weight[4], w (kg)	Airworthiness Requirements	Operational Requirements
Micro UAV	$w \leq 0.1$	None	Unspecified in CASR 101.F
Small UAV	a UAV that neither a large UAV nor a micro UAV Weight, w (kg) $0.1 \leq w \leq 150$	None, if operated over unpopulated areas, can follow large UAV process for relief of this restriction	None for operation < 400 ft. AGL over unpopulated areas For operations ≥ 400 AGL, requirements include: maximum altitude, communication requirements, operating times, operating area limitations, and UAV equipment
Large UAV	$w > 150$ (airplanes) $w > 100$ (rotorcraft) There are other specifications for airships, parachutes and lift devices	Must use experimental or restricted category airworthiness certificate, comparable to requirements under manned standards	Must have an operating certificate

B.3. Australian Research Community

Researchers from the Australian Research Centre for Aerospace Automation, Defence Science and Technology Organisation, and Commonwealth Scientific and Industrial Research Organisation have written a number of papers related to UAS classification for the purpose of airworthiness regulation. One particular paper of interest, *Definition of an Airworthiness Certification Framework for Civil Unmanned Aircraft Systems* [CPWF-2010 and CPWF-2011], introduces an approach to UAS classification that is notably different from most others. The authors propose a quantified risk matrix as a framework for guiding the structuring of airworthiness regulations for UAS, which is reproduced in Table 14. This approach defines an airworthiness certification framework that matches the UAS type to its operational environment. The UAS type represents a group of UAS where the magnitude of damage is similar given the occurrence of an unrecoverable, flight-critical failure and independent of any particular area over-flown. The operational environment represents a grouping of operational areas where the potential for realizing loss is of a similar magnitude, but does not include the loss of the UAS itself. The corresponding risk of a catastrophic event occurring increases with the aircraft's potential for causing damage and the density of the operational environment. Certification categories are then assigned to each scenario (cell) based on the assessed levels of risk.

Table 14. Australian Research Classification



B.4. United Kingdom – Civil Aviation Authority (CAA)

The Civil Aviation Authority (CAA) is responsible for regulating civil UAS operations in the United Kingdom (UK). The CAA's Directorate of Airspace Policy (DAP) provides guidance under Civil Aviation Publication (CAP) 722: *Unmanned Aircraft System Operations in UK Airspace* [CAP-722] for a path to UAS certification. CAP 722 classifies UAV according to which authority regulates civil UAV in Europe (see Table 15). As the table shows, large UAV are under the regulatory purview of EASA.

Table 15. UK CAP 722 UAV Groups

Weight Classification Group	Civil Category	Mass, m (kg)	Civil Regulation
1	Small Unmanned Aircraft	$m \leq 20$	national
2	Light UAV	$20 < m \leq 150$	national
3	UAV	$m > 150$	EASA

More specific guidance is provided in the Civil Operations section (Section 3) of [CAP-722]. Section 3, Chapter 1 states that "all civil aircraft [shall] fly subject to the legislation of the Air Navigation Order

2009 (ANO) and the associated Rules of the Air Regulations 2007." However, in accordance with its powers under Article 242 of the ANO, the CAA may exempt UAV operators from the provisions of the ANO and the Rules of the Air, depending on the unmanned aircraft's potential to inflict damage and injury. Small, unmanned aircraft are exempted from most of the provisions of the ANO and Rules of the Air Regulations by the provisions of Article 253.

Table 16 summarizes the CAA policy with respect to operational constraints and airworthiness standards for unmanned aircraft flying in UK airspace.

Table 16. UK Operational Constraints and Airworthiness Standards for UAS

Civil Category	Aircraft Weight[4], w (kg)	Application	Operational Permission	Airworthiness Requirements / standards
Small UAV	$w \le 20$	Other	No	• No airworthiness standards
		Commercial use (aerial work), congested areas, or close to people or property	Yes	
Light UAV	$20 < w \le 150$	Commercial use (aerial work)	Yes	• Airworthiness recommendation from accredited body
UAV	$w > 150$	Commercial use (aerial work)	By existing national operating rules	• EASA airworthiness standards

B.5. European Aviation Safety Agency

The European Aviation Safety Agency (EASA) was created in July 2002 by the European Union to provide a common regulatory framework for its member states. EASA's responsibilities include type certification of aircraft and components. EASA Policy Statement [EASA-EY013-01-2009], *Airworthiness Certification of Unmanned Aircraft Systems (UAS)*, establishes general principles for type certification (including environmental protection) of UAS. In particular, the policy provides guidance for type certificates and restricted type certificates as per regulations in Part 21. The policy does not apply to military or public use UAS, experimental UAS, or UAS less than 150 kg. Appendix 1 of the policy statement describes an approach for selecting the applicable airworthiness code(s), based on kinetic energy principles and equivalence with conventionally piloted aircraft.

Two energy calculations are made: one for an "unpremeditated descent" and one for a "loss of control". The standards applied are on a per design feature basis. For features whose failure would affect the ability to maintain altitude, the "unpremeditated descent" standard is used. For features whose failure would affect the ability to maintain control, the "loss of control" standard is used. Table 17 summarizes this classification approach. EASA has a preference to maintain the existing classes/categories for CS-23, CS-25, etc. (equivalent to 14 CFR Part 23, Part 25, etc.)

Table 17. EASA classification

Failure Consequence	If the Kinetic Energy, KE (GJ), of the aircraft is…	Fixed Wing Airplanes would apply the airworthiness requirements from	Rotorcraft would apply the airworthiness requirements from
Unpremeditated Descent	$0 \le KE \le 0.0015$	Microlight (similar to ultralight)	
	$0 \le KE \le 0.003$	CS-Very Light Airplanes (similar to light sport aircraft)	
	$0.0015 \le KE \le 0.02$	CS-23 single engine	CS-27
	$0.01 \le KE \le 0.1$	CS-23 dual engine	CS-29
	$KE \ge 0.06$	CS-25	
Loss of Control	$0 \le KE \le 0.01$	Microlight (similar to ultralight)	
	$0 \le KE \le 0.025$	CS-Very Light Airplanes (similar to light sport aircraft)	
	$0.01 \le KE \le 0.2$	CS-23 single engine	CS-27
	$0.1 \le KE \le 2$	CS-23 dual engine	CS-29
	$KE \ge 0.3$	CS-25	

The ranges for kinetic energy in the table are approximate and based on visual interpretation of values on a graph. Some of the categories overlap, indicating that a combined standard from both categories may be needed, at the discretion of the certification authority. In addition, the certification authority may require different probabilities of equipment failure and design assurance level then those based on [AC23.1309].

EASA's policy statement [EASA-EY013-01-2009] indicates that airworthiness is primarily targeted at the protection of people and property on the ground. Avoiding other airspace users is part of the operational regulations, not airworthiness requirements. EASA acknowledges that for a system to implement "see and avoid", it will rely on a verification of proper system functioning and hence bring in airworthiness issues.

B.6. Civil Aviation Authority of Israel

The Civil Aviation Authority of Israel (CAAI) is the regulator for the civil aviation sector, as part of Israel's Ministry of Transportation. The paper *CAAI UAV Systems Airworthiness Regulations*[14] [CAAI] describes CAAI interim policy for approval of civil or non-military UAV operations in the State of Israel, as defined in the applicability conditions section. This document contains regulations on airworthiness, continued airworthiness, and manufacturer organization.
Section 4 of [CAAI] defines three "top level" categories that should constitute the driving factor in defining the extent and level of requirements to be applied when granting approval to conduct UAV operations:

- Category I: UAV operations that do not belong to either of the other two categories, i.e., conducted within confined airspace portions and above confined area (usually unpopulated).
- Category II: UAV operations may be allowed with some operational restrictions (e.g., in terms of airspace segregation or overflown areas), with two practical subdivisions.
  - Category IIa: Airspace restrictions but no specific restrictions in term of overflown areas.
  - Category IIb: Airspace restrictions and flight above sparsely populated areas only.

[14] The authority of the "CAAI UAV Systems Airworthiness Regulations" paper is unknown. It was found on the Israeli CAA website.

- Category III: UAV operations may be allowed with no specific operational restrictions (i.e., in non-segregated airspace and over populated areas).

Table 18 provides high-level guidance for airworthiness and operational approval.

Table 18. Airworthiness and Operational Requirements for UAS in Israel

Category	Category characteristics	Airworthiness approval (requirements)	Operational Approval / Airspace Requirements
I	UAV operations that do not belong to either of the other two categories, (i.e., conducted within confined airspace portions and above confined area usually unpopulated)	Basic evidence of flight safety to show that applied limitations may be complied with	Segregated airspace, limits on overflown areas
II	UAV operations may be allowed with some operational restrictions (e.g., in terms of airspace segregation or over flown areas), with two practical subdivisions • Cat IIa – Airspace restrictions but no specific restrictions in terms of overflown areas • Cat IIb – Airspace restrictions and flight above sparsely populated areas only	Cat IIa: may be identical to Cat III Cat IIb: may be tailored to the level of over flown areas limitations	Only partial compliance, tailored to the level of airspace restrictions applied
III	UAV operations may be allowed with no specific operational restrictions (i.e., in non-segregated airspace and over populated areas)	Full certification required	Compliance with operational rules, including collision avoidance requirements

B.7. Directorate General for Civil Aviation – France

The French Directorate General for Civil Aviation (DGAC) is part of France's Ministry of Ecology, Sustainable Development, Transport and Housing, and is responsible for regulating the French airspace, among other activities [DGAC-2011]. In April 2012, the DGAC issued regulations concerning the design, use, and operators of UAS in France, which include a UAS classification approach that is related to airworthiness [DGAC-2012]. In the regulations, UAS are primarily separated between model aircraft and RPA, and they are then further subdivided by weight, operation, and in the case of model aircraft, by propulsion system [DGAC-2012]. The DGAC defines model aircraft to include the requirement that it remain "permanently within direct visual range of the remote pilot" [DGAC-2012]. Since model aircraft are not the focus of this paper, they were omitted from the summary of the DGAC system (categories A-C), as shown in Table 19. Table 19 includes information on the design and operational requirements in addition to the airworthiness requirements related to classification. It should also be noted that the regulations pertain only to specific operations of UAS, which are shown in Table 21. Finally, France is also a member of EASA, and aircraft greater than 150 kg fall under the purview of EASA.

Table 19. DGAC UAS Categories

Category	Maximum Takeoff Weight[4], w (kg)	Operational Constraints	Airworthiness Requirements
D	$w < 2$	1) May not operate while aboard another moving aircraft without obtaining permission 2) LOS or remote viewing if 2nd pilot can take command 3) may operate only in specified scenarios (S-1,S-2,S-3,S-4, see Table 20)	Exempt
E	$2 \leq w < 4$	1) May not operate while aboard another moving aircraft without obtaining permission 2) LOS or remote viewing if 2nd pilot can take command 3) may operate only in specified scenarios (S-1, S-2, or S-3, see Table 20)	Exempt
	$4 \leq w < 25$	1) May not operate while aboard another moving aircraft without obtaining permission 2) LOS or remote viewing if 2nd pilot can take command 3) may operate only in specified scenarios (S-1 or S-2, see Table 20)	
F	$25 \leq w < 150$	1) May not operate while aboard another moving aircraft without obtaining permission 2) LOS or remote viewing if 2nd pilot can take command	Required (issued by DGAC, not EASA)
G	$w \geq 150$	1) May not operate while aboard another moving aircraft without obtaining permission 2) LOS unless certified to be operated BLOS	Required. Issued by EASA.

Table 20. DGAC UAS Scenarios

Number	Description
S-1	An operation conducted within direct visual range of the remote pilot, away from any populated areas, at a maximum horizontal distance of 100 m from the remote pilot.
S-2	An operation conducted away from any populated area, in a volume with a maximum horizontal radius of 1 km and a height of less than 50 m above the ground and artificial obstacles, with no one on the ground in this operating area. Note: requires specific authorization unless the RPA is type-certificated (see 3.2.3.3 of [DGAC-2012])
S-3	An operation conducted in a built-up area or in the vicinity of people or animals, within direct visual range of and at a maximum horizontal distance of 100 m from the remote pilot. Note: requires specific authorization unless the RPA is type-certificated (see 3.2.3.3 of [DGAC-2012])
S-4	A specific activity involving aerial surveying, photography, observation and surveillance conducted away from any populated area, but not meeting the criteria for scenario S-2, the flight height being less than 150 m above the ground and artificial obstacles. Note: requires specific authorization unless the RPA is type-certificated (see 3.2.3.3 of [DGAC-2012])

Table 21. DGAC UAS Operations

Applicable UAS Operations[15]
1. Agricultural, phytosanitary or health and safety treatments, and any other operations involving spreading on the ground or dispersal in the atmosphere
2. Airdrops of any kind
3. The towing of banners or any form of advertising
4. Aerial surveying, photography, observation and surveillance; this activity shall include participation in fire-fighting activities
5. Any other specific activity requiring a derogation from the general air traffic rules
6. Training for any of the aforementioned activities

B.8. Japan

Use of UAS for civil applications is governed by two different organizations in Japan: the Japan Agricultural Aviation Association (JAAA) and the Japan UAV Association (JUAV). The JAAA, which is part of the Ministry of Agriculture, Forestry and Fisheries, addresses the safe construction and operation of UAS for agricultural applications. JAAA is part of the ministry of agriculture, since the bulk of UAS operations in Japan are for agricultural purposes, which entail flying over uninhabited fields with

[15] "Anyone wishing to deploy an RPA for any other activity shall contact the Minister responsible for civil aviation, in order to be notified of the conditions applicable to this new activity" [DGAC-2012].

line-of-site operations. The JUAV Association is a private industry consortium of sixteen companies that reports to the Ministry of Economy, Trade and Industry. This group was set up to expand Japan's UAS industry and to develop standards for the safe use of UAS in non-agricultural applications. The Japanese Civil Aviation Bureau (Japan's equivalent of the FAA), which is a part of the Ministry of Land, Infrastructure, Transport and Tourism, does not address UAS issues [Sato-RMAX-2003].

In 1991, JAAA issued a "Safety Standard for Unmanned Helicopters of Agricultural Use" [Hosoda-2010]. This document is only available in Japanese and was not translated for the purposes of this paper. However, JUAV has proposed a classification system (see Table 22) [Sato-2003]. Since many Japanese policy documents are not available in English, it is not clear whether this system has legal force.

Table 22. Japanese UAS Safety Standards

	Rotary Wing	**Fixed Wing**	**Hobby-level**
Airspace shared with manned aircraft	To be formulated	To be formulated	Not applicable
Flying over inhabited areas	To be formulated	To be formulated	Not applicable
Out of visual range, uninhabited	[JUAV-Rotary-2005]	[JUAV-Fixed-2007]	Not applicable
Within visual range, uninhabited	[JUAV-Rotary-2005]	[JUAV-Fixed-2007]	
Agricultural spraying, uninhabited	Existing JAAA standards		Not applicable

B.9. Sweden

According to the Swedish Transport Agency's statute 2009:88 [Sweden-2009], a UAS classification approach has been put into place based on physical properties (MTOW and KE)[16] as well as the type of operation (visual LOS or beyond visual LOS) as shown in Table 23. It is assumed that for cases of ambiguity (e.g., UAS less than 7 kg but with kinetic energies greater than 1000 J) that the applicable category would be the highest applicable category (i.e., Category 2 for the example case). According to the statue, the regulations "shall apply to design, manufacture, modification, maintenance and activities with civil unmanned aircraft systems within Sweden which are not covered by regulation number 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency [EASA]." This statement indicates that for aircraft under the purview of EASA (i.e., aircraft above 150 kg) the EASA standards should be used.

Table 23. Swedish Transport Agency UAS classification approach

Category	**Maximum Takeoff Weight[4], w (kg)**	**Kinetic Energy, KE (J)**	**Operational Restriction**
1A	$w \leq 1.5$	$KE \leq 150$	LOS
1B	$1.5 < w \leq 7$	$KE \leq 1000$	LOS
2	$w > 7$	N/A	LOS
3	N/A	N/A	BLOS

[16] Since weight is a significant part of kinetic energy, no explanation is given why kinetic energy is specified instead of speed.

B.10. Malaysia

The Malaysian Department of Civil Aviation (DCA) issued an Aeronautical Information Circular (AIC) titled, “Unmanned Aerial Vehicle Operations in Malaysian Airspace,” to provide guidance to civil-use UAS operators in the form of Civil Aviation Regulations [Malaysia-2008]. In particular, this AIC version states that civil-use UAS above 20 kg shall be required to have a certificate of airworthiness. However, the document focuses primarily along operational dimensions and does not provide details of the airworthiness certification process for UAS, nor does it provide details of UAS classification approaches beyond introducing the 20 kg benchmark. Section 2.1 of the AIC provides some evidence that the DCA has considered classification approaches that relate UAS to manned aircraft but, at the time of this paper, it is not clear what criteria are being considered as necessary for establishing equivalence, nor is the characterization of the equivalence clear. Table 24 shows a framework of the classification approach, as it has been interpreted from the DCA AIC.

Table 24. Conceptualization of the Malaysian Department of Civil Aviation’s UAS classification approach

Weight[4], w (kg)	Airworthiness Certification Basis
$w < 20$	No CofA necessary
$w \geq 20$	“manned aircraft equivalent class or category”

B.11. New Zealand

The Civil Aviation Authority (CAA) of New Zealand released their “UAV Issues Paper” in January of 2007 [NZ-2007]. The paper presents the relevant UAS regulatory and operational issues identified by the CAA, defense, and industry at a seminar held in late 2006. A portion of the paper is devoted to discussion of a proposed UAS classification approach (see **Table 25**). The approach is similar to others discussed throughout this paper in its use of kinetic energy as a means of classification as well as the inclusion of operator and operational dimensions as further considerations for classification. Although the approach outlined in **Table 25** was prepared without explicit consideration of any existing international regulatory efforts, the CAA recommended in their issues paper that a survey of global UAS regulation be conducted in the interest of harmonization.

Table 25. New Zealand proposed UAS classification approach

<table>
<tr><th>Class</th><th>Kinetic Energy, KE (J)</th><th>Operation</th><th colspan="2">Operator Requirement</th><th>Airworthiness Certification Requirements</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">KE ≤ 10,000</td><td>LOS</td><td colspan="2">Must be regulated by certificated UAV association</td><td rowspan="2">None</td></tr>
<tr><td>BLOS or controlled airspace</td><td>Commercial Pilot License (CPL) required</td><td>Must be regulated by certificated UAV association</td></tr>
<tr><td>2</td><td>10,000 J ≤ KE ≤ 1,000,000</td><td>N/A</td><td colspan="2">Certificated by CAA, CPL required, type rating required, and if RPA or IFR[17] must hold a current instrument rating</td><td>Annual inspection required, UAV flight permit required (similar to microlight aircraft)</td></tr>
<tr><td>3</td><td>KE > 1,000,000</td><td>N/A</td><td colspan="2">Certificated by CAA, CPL required, type rating required, and if RPA or IFR must hold a current instrument rating</td><td>Type certificate, airworthiness certificate, maintenance release, and continuing airworthiness as for manned type certificated aircraft</td></tr>
</table>

B.12. Belgium – No Approach

The Belgian Civil Aviation Authority, which is part of Belgium's Federal Public Service Mobility and Transport and responsible for preparing and implementing transportation policies, produced the *Belgian Certification Specification for UAV Systems* in January 2007 [Belgium-2007]. This document is a set of certification specifications mostly based on EASA CS 23 requirements. The document lists the individual CS 23 requirements as they may apply to fixed-wing, single, or multi-engine UAS. This paper does not propose any type of UAS classification, except in the sense that there is a single class for UAS that are fixed wing UAS. No guidance or other information is given for UAS that are not of this type.

Because Belgium is a member of EASA, classification of UAS for the purpose of specifying airworthiness requirements will presumably follow guidance from EASA; EASA requirements will be used for aircraft above 150 kg.

[17] Instrument Flight Rules

B.13. Germany (LBA)

Luftfahrt-Bundesamt (LBA) is the national civil aviation authority of Germany. The LBA is responsible for developing and maintaining aviation safety standards among other responsibilities. No English-language LBA documentation regarding UAS airworthiness was found. The most relevant information was found in a January 2012 news report, where *Deutsche Welle* (*DW*) reported [Bolinger-2012] that the German parliament was considering a bill that would approve "unmanned aeronautical systems" for operation in the national airspace system. According to the report, The German Ministry of Transport, Building, and Urban Development (BMVBS) was seeking to create the UAS category and establish a procedure of approval. More recently, DW reported [Lichtenberg-2012] that the BMVBS had approved most of the 500 applications to use drones in the German airspace. The applications had been submitted over the past two years up to the time of the report, May 2012. Most notably, the article states that, "according to current regulations, drones cannot be heavier than 25 kilograms and must not fly out of their controller's sight." Thus, it appears the present classification approach includes a single category with a maximum weight restriction of 25 kg and LOS operation.

B.14. Germany (UAV DACH) – No approach

The German-language UAS association known as UAV DACH represents the German, Austrian, Swiss, and Dutch RPAS industry and research organizations [UAV-DACH-2010]. UAV DACH is a legal non-profit German association that "contributes to the German legislative process by supplying opinions and position papers to the German authorities, which will help to standardize the necessary safety standards for the national and pan-European use of civil unmanned aircraft systems." This group has not publicly proposed a UAS classification approach.

B.15. Germany (IABG)

This description of IABG comes from the report [MTSI-2012]. *Industrieanlagen-Betriebsgesellschaft* mbH (IABG) was founded as a central analysis and testing organization for the aeronautics industry and the Ministry of Defense in 1961 as part of an initiative by the German government. Today, it is a leading European technology and science service provider.

In December 2001, IABG developed a preliminary study in response to a 2001 EUROCONTROL research proposal examining innovation in air traffic management (ATM) research. The IABG study [IABG-2001] identifies a UAS classification scheme based on weight, range, radius, and typical maximum altitude (see Table 26). This classification scheme was developed to support UAS certification.

Table 26. Germany (IABG) UAV Classification

UAV Class	**Maximum Takeoff Weight[4], w (kg)**	**Range Category**	**Typical Radius, r (NM)**	**Typical Max Altitude (ft)**
Class 0	$w < 25$	Close Range	$r < 10$	1000
Class 1	$25 \le w \le 500$	Short Range	$10 \le r \le 100$	15,000
Class 2	$501 \le w \le 2000$	Medium Range	$101 \le r \le 500$	30,000
Class 3	$w > 2000$	Long Range	$r > 500$	30,000

B.16. Switzerland

Switzerland integrated its civil and military airspace in 2001 [Skyguide-web]. The Swiss regulatory efforts on UAS appear to largely involve a few key organizations, both private and public. The most prominent organizations include the Swiss Federal Office of Civil Aviation (FOCA), Skyguide, and Aerosuisse.

FOCA, part of the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC), is Switzerland's regulatory and supervisory authority for aviation. Currently, the Swiss regulations address UAS operational certification on a weight basis, with a 30 kg breakpoint. In particular, UAS above 30 kg must seek specific approval for operation in the Swiss national airspace, and UAS below 30 kg do not require authorization to operate, provided they are operated as outlined in **Table 27** [FOCA].

Skyguide is a company that provides air traffic management services and is charged with the responsibility for ensuring the efficient and shared use of the Swiss airspace by commercial, general aviation, and military air traffic [Skyguide-web, Skyguide]. Skyguide has planned for a "fully unsegregated" Swiss airspace to exist sometime in 2012, which plans to include UAS operations as well [Skyguide]. As of July 2012, however, clear evidence of integration beyond that provided in **Table 27** was not identified.

Table 27. Swiss UAS Classification Approach

Class[18]	Mass, m (kg)	Operational Condition	Authorization Requirements[19]	Operational Restrictions
1	$m \leq 30$	VLOS	None	A. No aerial photography of military installations or in cases that violate privacy laws. B. Must operate at least 5 km from airport runways
2		VLOS with Binoculars	FOCA approval	A and B
3		BLOS	"The video glasses and similar devices shall be permitted if a second operator monitors the flight and was able to resume control at any time of the device. The operator must then be at the same place as the driver."	A and B
4	$m > 30$	FOCA approval	FOCA approval	FOCA determination.

B.17. Joint Authorities for Rulemaking on Unmanned Systems (JARUS) – No Approach

Joint Authorities for Rulemaking on Unmanned Systems (JARUS) is a consortium of civil aviation authorities from 19 countries whose goal is to draft harmonized technical and operational requirements

[18] These classes are unofficial, author-named classes, and not officially defined by FOCA.

[19] Any UAS above 500 g requires insurance of at least one million francs.

for the certification and airspace access of light UAS [JARUS]. These draft requirements will be submitted to European Organization for Civil Aviation Equipment Working Group 73 (EUROCAE WG73), RTCA SC203 and NATO Flight In Non-Segregated Air Space (FINAS) for consultation. To that end, JARUS has created three subgroups: Certification Specification for Light Unmanned Rotorcraft Systems (CS-LURS), System Safety (i.e., the "1309 group"), and Ops and Licensing [Leijgraff-2011-2, Leijgraff-2011-2].

CS-LURS has submitted a draft for light unmanned rotorcraft systems to EUROCAE WG73 for consultation which is based on the Certification Specification for Very Light (conventionally piloted) Rotorcraft (less than 600 kg). The "1309 group" will draft system safety requirements and advisory material, and their analysis will establish systems integrity standards. They have also submitted a draft proposal to EUROCAE WG73. Additionally, Ops and Licensing has drafted a UAS-Flight Crew Licensing (UAS-FCL) regulation and provided it to EUROCAE WG73. Their next activity will be to draft a UAS-Operations (UAS-OPS) regulation.

B.18. EUROCAE Working Group 73 UAV Systems – No approach

The European Organisation for Civil Aviation Equipment (EUROCAE) is an industry consensus body that develops technical standards for aviation equipment. This organization is comparable to RTCA in the US and EUROCAE Working Group (WG) 73 is comparable to RTCA Special Committee 203 (see section A.2). The WG 73 charter includes analysis of the key issues related to UAV operations in the context of European ATM and UAV terminology and definitions as required. WG 73 includes four sub-groups:

- SG1 UAS Operations
- SG2 UAS Airworthiness
- SG3 Command, Control, Communications, Spectrum and Security
- SG4 UAV under 150 kg

WG 73 produced a report "A Concept for UAS Airworthiness Certification and Operational Approval" in November 2010 [EUROCAE-ER-004] that provides an overview of EASA-related general regulations and guidance, and summarizes the EASA policy approach, including UAS airworthiness categorization and overall EASA certification specification-tailoring considerations. This document bases its classification approach on EASA guidance (see section B.5).

C. Classification of US Public Use UAS

The following subsections provide information on UAS classification from a public use perspective from organizations within the United States.

C.1. National Aeronautics and Space Administration

The National Aeronautics and Space Administration (NASA) operates unmanned aircraft for a variety of research applications, including numerous science missions. NASA Procedural Requirement (NPR) 7900.3C, Aircraft Operations Management [NASA-NPR], groups UAS into three categories for specifying requirements for the following: (1) Airworthiness and Flight Safety Review, (2) Maintenance, (3) Range Operations, (4) Mishap Reporting, and (5) Flight Termination System. **Table 28** gives the characteristics for the three UAS categories and the statement for airworthiness requirements for flying in special use airspace. The NPR allows very capable aircraft to be designated as small UAS. In this NPR, small UAS are defined as model or sub-scale aircraft designed and built to operate with an onboard flight management system, may carry a variety of payloads, and be operated using either licensed or unlicensed frequency bands for command and control. Small UAS can be operated by a manual control, by an onboard flight management system (still under human control), or autonomously.

Table 28. NASA Classification Approach

Category	Characteristics of Category: Weight, w (lbs.), Airspeed, s (kts)	Airworthiness requirements For operations in Special Use Airspace
I Model or small UAS	$w \leq 55$ $s \leq 70$	Commercial off-the-shelf models and small UAS (sUAS) receive flight approval via NASA Center airworthiness and flight safety review process. All NASA and NASA hosted aircraft must have an airworthiness statement and flight release
II Small UAS	$55 \leq w \leq 330$ $s \leq 200$	
III UAS	$w > 330$ $s > 200$	NASA Center airworthiness and flight safety review and a flight readiness review are required. Subsequent system modifications require the same reviews and a technical review in accordance with Center requirements. All NASA and NASA hosted aircraft must have an airworthiness certificate and flight release.

C.2. United States Forest Service

The US Forest Service (USFS) is an agency of the Department of Agriculture that manages the national forests and grasslands. Their use of aircraft, including unmanned aircraft, is integrally linked with their role in fighting wildland fires. Other agency use of aircraft includes insect and disease surveys, aerial photography, and aerial applications related to forest health. The forest service, like the Department of Defense, only uses one set of policy documents for both conventionally piloted aircraft and UAS [USFS-Airworthiness].

Consistent with 14CFR1, the USFS distinguishes between two types of aircraft: public and civil. When the USFS use their aircraft for civil operations, the FAA regulates compliance with the airworthiness requirements. The USFS self-certifies the airworthiness of public aircraft. Furthermore, the USFS operates UAS as public aircraft, and only public aircraft are used for firefighting missions. The airworthiness requirements for these firefighting missions are based on a safety assessment of the particular aircraft and its particular operation.

The USFS is just beginning to develop the policy documents for UAS. Their document "National Aviation Safety and Management Plan" [USFS-NASMP] is released every year, and the 2012 version was the first version to discuss UAS operations.

C.3. United States Customs and Border Protection – No approach

The Customs and Border Protection (CBP) service is a law-enforcement organization within the Department of Homeland Security. The mission of the border security part of CBP is to monitor the borders of the United States to prevent illegal entry into the country and the smuggling of drugs, weapons, and other contraband. This agency flies five MQ-9 Predator-B UAS along the northern and southern borders of the country. In addition, the agency is acquiring a variant of the MQ-9 called a Guardian UAS that is specialized for marine applications.

Despite investigation, no information was found about CBP UAS airworthiness classification or standards [CBP].

C.4. US Department of Defense – Joint Unmanned Aircraft Systems

The Joint Unmanned Aircraft Systems (JUAS) Center of Excellence (COE) was a multi-service unit based at Creech Air Force Base in Indian Springs, Nevada that was disestablished in 2011. The COE was designed to improve UAS interoperability and use, and it examined the use of sensors and intelligence collection assets to meet joint operational requirements of U.S. forces in any combat environment. The COE was an operationally focused organization concentrating on UAS systems technology, joint concepts, training, tactics, and procedural solutions to the warfighters' needs. The center had representatives from the Army, Navy, Air Force, and Marine Corps, as well as other Department of Defense (DoD) and non-DoD agencies.

Table 29 is often given in descriptions of UAS classification within the military [JUAS-2011]. There seems to be some movement to use this classification approach for the purpose of specifying certification requirements of any type. The DoD military handbook (MIL-HNBK) on airworthiness [MIL-HNBK-516B] covers all aircraft certification criteria (for both conventionally piloted and unmanned aircraft) and does not offer a classification system. However, there is recognition that the standards must be modified for particular aircraft, especially unmanned ones.

Table 29. Department of Defense—Joint UAS Center of Excellence

UAS Group	Maximum Gross Takeoff Weight (MGTOW), w (lbs.)	Normal Operating Altitude, h (ft.)	Speed, s (kts)	Representative UAS
Group 1	$0 \leq w \leq 20$	h < 1200 AGL	100	Raven (RQ-11), WASP
Group 2	$21 \leq w \leq 55$	h < 3500 AGL	s < 250	ScanEagle
Group 3	w < 1320	h < FL 180	s < 250	Shadow (RQ-7B), Tier II / STUAS
Group 4	w > 1320	h < FL 180	Any	Fire Scout (MQ-8B, RQ-8B), Predator (MQ-1A/B), Sky Warrior ERMP (MQ-1C)
Group 5	w > 1320	h > FL180	Any	Reaper (MQ-9A), Global Hawk (RQ-4), BAMS (RQ-4N)

D. Classification of International Public Use UAS

The following subsections provide information on UAS classification from a public use perspective from organizations outside of the United States.

D.1. North Atlantic Treaty Organization

The North Atlantic Treaty Organization (NATO) is a military alliance of nations. Among other roles, this organization provides standards for interoperability between military systems, including airworthiness standards. The NATO airworthiness document "Unmanned Aerial Vehicles Systems Airworthiness Requirements" [STANAG-4671] does not have a formal classification approach, but does address the airworthiness requirements for UAS that are fixed-wing, require a human pilot, or weigh between 150 and 20,000 kg. Some topics included in this document are flight, structure, design, construction, powerplant, equipment, command and control, and control station. It also issues a disclaimer that the listed requirements may not be sufficient for unconventional, novel, or extremely complex UAS, nor any other UAS with a design that is significantly different than that of a general aviation aircraft.

NATO has established the Joint Air Power Competence Centre (JAPCC) as a NATO Centre of Excellence (COE). JAPCC has proposed [JAPCC-2010] the classification approach (see **Table 30**) for "[military] services to organize, train, equip, and standardize UAS for optimum employment." It is unclear if this classification system is used to assign or develop airworthiness requirements.

Table 30. NATO Classification

Class & Weight, w (kg)	Category & Weight[4], w (kg)	Normal Employment	Normal Operating Altitude, h (ft)	Normal Mission Radius (km)	Example Platform
Class I w < 150	Small w > 20 kg	Tactical Unit (employs launch system)	h ≤ 5000 AGL	50 (LOS)	Luna, Hermes 90
	Mini 2 ≤ w ≤ 20 kg	Tactical Unit (manual launch)	h ≤ 3000 AGL	25 (LOS)	ScanEagle, Skylark, Raven, DH3, Aladin, Strix
	Micro w < 2	Tactical Patrol/section, Individual (single operator)	h ≤ 200 AGL	5 (LOS)	Black Widow
Class II 150 ≤w ≤ 600	Tactical	Tactical Formation	h ≤ 10,000 AGL	200 (LOS)	Sperwer, Iview 250, Hermes 450, Aerostar, Ranger
Class III w > 600	Strike/ Combat	Strategic/ National	h ≤ 65,000	Unlimited (BLOS)	
	HALE	Strategic/ National	h ≤ 65,000	Unlimited (BLOS)	Global Hawk
	MALE[20]	Operational/ Theater	h ≤ 45,000 MSL[21]	Unlimited (BLOS)	Predator A, Predator B, Heron, Heron TP, Hermes 900

D.2. United Kingdom Ministry of Defence – No Approach

The UK ministry of Defence provides [DefStan-970] a policy document that describes acceptable means to show airworthiness, meaning who should approve that a requirement has been met. The specific technical requirements of airworthiness are captured in the NATO document [STANAG-4671].

D.3. Israeli Ministry of Defense – No approach

Israel uses UAS as part of their air force. UAS in use include Israeli-developed aircraft such as the Israel Aerospace Industries' (IAI) Eitan, IAI Heron, and the Elbit Hermes. No information was found on classification systems or airworthiness standards.

[20] Medium Altitude Long Endurance
[21] Mean Sea Level

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

The use of unmanned aircraft in the National Airspace System (NAS) has been characterized as the next great step forward in the evolution of civil aviation. Although use of unmanned aircraft systems (UAS) in military and public service operations is proliferating, civil use of UAS remains limited in the United States today. This report focuses on one particular regulatory challenge: classifying UAS to assign airworthiness standards. This paper provides observations related to how the current regulations for classifying manned aircraft could apply to UAS.

15. SUBJECT TERMS

Aircraft; Airworthiness; Certification; Classification; Remotely Operated; Unmanned

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