PROPOSED AIRWORTHINESS CERTIFICATION REQUIREMENTS FOR UNMANNED AERIAL VEHICLES / SYSTEMS (UAV / UAS)

ABSTRACT

Proposes Airworthiness requirements for Un-manned Aerial Systems (UAS) which do not carry passengers or cargo, weigh less than 12,500 pounds, fly less than 500 ktas, and carry less than 5,000 pounds of fuel. This class would include most proposed military and civilian UAS designs and is similar to General Aviation\(^1\) manned vehicles. Recommendations include required equipment, reliability requirements based on expected vehicle loss rate with associated hazard to personnel, and operational restrictions along with an explanation of their derivation.

BACKGROUND

A combination of technological maturity and operational expediency is driving heightened interest in developing and deploying UAS. Authorities have not yet defined Airworthiness certification requirements for civilian or military UAS. Various groups and committees\(^2\) are looking into the issues, but no clear consensus is evident. This paper proposes concepts for consideration in defining UAS / UAV Airworthiness Certification requirements for US military and general aviation UAS which do not carry passengers or cargo, weigh less than 12,500 pounds, fly less than 500 ktas, and carry less than 5,000 pounds of fuel.

Airworthiness certification for US military vehicles is described in MIL-HDBK-516 which defines UAV as: Unmanned aerial vehicle (UAV) - A remotely piloted, semi-autonomous, or autonomous air vehicle and its operating system. This does not include air vehicles designed for one-time use as a weapon (e.g., cruise missile). The operating system can be built into the vehicle or be part of the control station for remotely piloted vehicles. This “system” includes the control station, data links, flight control system, communications systems/links, etc., as well as the air vehicle. It is becoming common to refer to the entire system (UAV, ground system, support equipment, etc.) as an Un-manned Aerial System [Remotely Operated Aircraft (ROA) is the FAA equivalent].

Airworthiness is “The property of a particular air system configuration to safely attain, sustain, and terminate flight in accordance with the approved usage and limits”\(^3\), safely meaning it does not pose hazard to persons or property. It is important to note Airworthiness standards are intended to define the MINIMUM performance required for SAFE operation; there may be instances where other factors (financial investment, mission value, security risk, logistics costs, etc.) dictate a more stringent design requirement. This should continue to be reflected in contractual design requirements for the air system, not Airworthiness standards.

MIL-HDBK-516 often refers to “adequate”, “acceptable”, and “proper levels” for aircraft functions and verifications, but does not define what these mean. Some guidance is provided by the Joint Service Specification Guide JSSG-2008 for manned vehicles and there is historical precedent as well for manned vehicles. There is little or no guidance on the appropriate application for UAS.

There are three categories of Airworthiness safety hazards: risk to the air vehicle and its occupants, risk to people and property on the ground, and risk to other air traffic. Hazard levels increase with the people and the property value at risk (amount and intensity of potential death

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1 FAA Title 14 Code of Federal Regulations Part 23 (except Commuter)
2 RTCA Special Committee 203, (SC-203), OSD-FAA Unmanned Aerial Vehicle Airspace Integration Initiative, DoD Policy Board on Federal Aviation (PBFA), Air Force Flight Standards Agency (AFFSA)
3 MIL-HDBK-516B w/Change1
and/or damage). A combination of vehicle design, operation, and maintenance standards are used to mitigate these hazards.

HISTORICAL SAFETY RESULTS

US DOD claims an overall aircraft loss mishap rate of 1.3 / 100,000 flight hours (2005), but rotary-wing aircraft had a mishap loss rate of 3.3 / 100,000 flight hours (2005). These statistics include accidental losses during military campaigns in foreign locales, but do not include losses due to combat damage. While not all aircraft losses result in fatalities, data from 1990 through 1996 shows 741 aircraft losses resulted in 777 fatalities; over that same span aircraft mishap losses averaged 1.83 aircraft and 1.97 lives per 100,000 flight hours and cost more than $1.2 billion each year. JSSC-2008 reports field safety experience data for unspecified aircraft mishap losses as: 3.103 /100,000 flights (bomber), 1.870 /100,000 flights (cargo), 0.578 /100,000 flights (cargo), and 8.210/100,000 flights (fighter). It is reasonable to assume an average flight was 1 hour, although transports and bombers could fly considerably longer.

US general aviation averages about 1.3x 10^-5 fatal accidents and 2.4x 10^-5 fatalities per flight hour. Between 1995 and 2004, 99% of all fatalities were aircraft occupants; the rest were onboard other aircraft or on the ground. If aircraft occupants are excluded (UAS operations), it would have required 97.5 times as many flight hours (25.5B) between 1995 and 2004 to result in the same number of fatalities (6,179). The most common accident causes are: personnel (78%), aircraft (19%), and environment (3%) - 2004 data normalized to 100%.

US Commercial aircraft have the best Aviation Safety record in the world. US part 121 aircraft average about 1.1x 10^-7 fatal accidents and 2.4x 10^-6 per flight hour because accidents average more than 40 fatalities for this class of aircraft. US part 135 aircraft average about 6.1x 10^-6 fatal accidents and 1.7x 10^-5 per flight hour. The most common accident cause or factor is personnel, including pilots, others aboard, and others not aboard. Also, Africa and South America part 121 operation fatal accident rates are 10 times higher than US.

| Average Fatalities Per 100,000 Flight Hours |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| US Military     | 1.97            | General Aviation| 2.38            | Commercial Part 35|
| Commercial Part 135 | 1.70        | Commercial Part 121| 0.47           | UAS (proposed) 2.00 |

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4 Defense Science Board Task Force On Future Need for VTOL/STOVL Aircraft, July 2007
ANALYSIS OF AIRCRAFT OPERATIONAL SAFETY

Historical US data shows that currently around 2 fatalities result from 100,000 hours of aircraft operation. If we assume UAS operations present a General Aviation type hazard to ground and other aircraft personnel (due to their size, speed, etc.) and subtract the 99% of general aviation fatalities to vehicle occupants (no UAS occupants), then 110 UAS vehicle losses results in 2 fatalities. This implies a UAS loss rate of $1.1 \times 10^{-3}$ per flight hour for an Equivalent Level of Safety (ELOS) as historical US aviation.

![Fatalities per Vehicle Loss (estimated)](image1)

![Vehicles Lost per Fatality (estimated)](image2)

Part 121 and UAS are substantially different than other aviation and inversely related to each other. This is due to Part 121 aircraft having many occupants and UAS having none.

The threat presented by UAS operation over population concentrations has not been assessed. If these operations are substantially more frequent and/or lengthy, occur at lower altitudes, etc. than general aviation experience, the risk from a mishap may also be significantly different. Most of the UAS contemplated for low altitude flight over population centers are also very small and slow,
which reduces their damage potential. This unique risk should be addressed with operational restrictions.

**UAS CHARACTERISTICS RELATED TO SAFETY**

Size and Construction - Most UAS are less massive, fly as slow or slower, and carry equal or lesser quantities of fuel than General Aviation aircraft. Therefore their potential to cause death and destruction is expected to be less than general aviation aircraft. Some UAS fly at higher altitudes, but terminal velocity would not be any greater because they are made from the same or less dense materials. UAS may have very long flight times, but accident rates are based on flight hours. Generally, UAS should present the same or lesser hazard rate to ground personnel as General Aviation aircraft. Different standards may be needed for UAS which are over 12,500 pounds, fly faster than 500 ktas, or carry more than 5,000 pounds of fuel. Weaponized UAS present a similar hazard as legacy Military aircraft and need similar restrictions on their operation.

No Passengers - UAS present unique Safety opportunities. Since there are no lives on board to protect, a UAS in difficulty may be commanded to crash in a manner that minimizes risk to ground personnel (assuming control is still possible). Military practice is to direct aircraft away from populated areas before ejection; UAS do not need to level off for safe ejection and might be controlled all the way to the ground. A very steep ground impact angle may reduce the hazard area up to 90%\(^8\). Alternatively, an initiated self-destruct could dissipate the vehicle’s destructive potential before it reaches the ground.

**AIRWORTHINESS RELIABILITY STANDARDS (MANNED VEHICLES)**

United States Airworthiness requirements are different for different types of manned air vehicles based partly on hazard level, partly on trade-offs required to increase safety (weight/performance penalties, cost), and partly on mishap probability (exposure time, operation, environment, etc.). The most stringent requirements are assessed against large commercial aircraft carrying passengers and operating in all conditions. The least stringent requirements are assessed against small, experimental aircraft operating in Visual Flight Rule (VFR) conditions during the day. Extending these principles would further reduce Airworthiness requirements for UAS because no occupants are at risk.

Military Airworthiness requirements and their verification are described in MIL-HDBK-516, but the actual threshold values are tailored for aircraft type and mission by contract requirements unique to each Program. Large transports generally have more stringent requirements than small fighters. Similarly, Short Take Off and Landing (STOVL) aircraft often accept a higher failure rate to allow design space to meet performance requirements. JSSC-2008 guidance (for Vehicle Control and Management Systems) is that maximum Probability Loss of Control (PLOC) should be between \(1 \times 10^{-5}\) and \(1 \times 10^{-7}\) per flight hour. Legacy Flight Control systems (F-16, F-15, C-17) have allocated failure rates of \(1 \times 10^{-5}\), which suggests their overall Probability of Loss of Aircraft (PLOA) was around \(1 \times 10^{-4}\) per flight hour (current Military rate is about 7 times better overall).

General Aviation aircraft\(^9\) have a maximum capacity of 9 passengers and a maximum weight of 12,500 pounds. These aircraft are designed to “minimize hazards to the airplane in the event of a probable malfunction or failure”\(^10\); though certain systems may have more stringent requirements. A hazard is a failure condition which results in large reductions in safety margins or functional capabilities, stresses the flight crew such that they cannot be relied upon to perform their tasks accurately or completely, and/or serious or fatal injury to an occupant\(^11\). Hazard also includes Catastrophic failures which prevent continued safe flight and landing. This Airworthiness standard

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\(^8\) European Aviation Safety Agency (EASA)

\(^9\) FAA Title 14 Code of Federal Regulations Part 23 (except Commuter)

\(^10\) Federal Aviation Regulation 23.1309

\(^11\) FAA Advisory Circular No: 23.1309-1D
requires mitigation of hazards more probable than $1 \times 10^{-5}$ ($1/100,000$) failures per flight hour. While the goal is to eliminate hazards or reduce their probability below $1 \times 10^{-5}$ per flight hour, practical issues (both technical and cost) are considered in determining whether the hazard has been “minimized”.

Commercial (Transport Category) Airworthiness requirements\textsuperscript{12} incorporate the concept of fail-safe design as explained in FAA Advisory Circular No: 25.1309-1A. This generally requires vehicle systems designed such that no single failure prevents continued safe flight and landing. Additionally, no combination of failures which are not extremely improbable may prevent continued safe flight and landing. “No single failure” means flight critical parts must have a backup. “Extremely improbable” means the overall systems must have a critical failure rate less than $1 \times 10^{-8}$ ($1/1,000,000,000$) failures per flight hour. This failure rate may require triple or even quadruple redundancy to achieve, although exposure time may be taken into account. These aircraft also require a backup pilot (no single failure), but there is no similar requirement for pilot reliability (one critical failure in a billion flight hours).

<table>
<thead>
<tr>
<th>Critical Failures per Flight Hour</th>
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<tbody>
<tr>
<td>US Military</td>
</tr>
<tr>
<td>General Aviation</td>
</tr>
<tr>
<td>Commercial Part 135</td>
</tr>
<tr>
<td>Commercial Part 121</td>
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<tr>
<td>UAS (proposed)</td>
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</tbody>
</table>

Note 1: This is an inverse logarithmic scale where each increment is a 10x decrease
Note 2: Part 135 operations utilize Part 23 non-Commuter aircraft.
Note 2: Part 121 operations utilize Part 23 Commuter or Part 25 aircraft.

**UAS RELIABILITY RECOMMENDATIONS**

For UAS with no occupants on board, a vehicle loss probability of $1.1 \times 10^{-3}$ per flight hour will provide an equivalent level of safety (ELOS) as current US aviation. We may expect UAS vehicle loss causes to follow General Aviation trends which average 78% for personnel, 19% for vehicle systems, and 3% due to weather. This would be allocated as $8.6 \times 10^{-4}$ critical pilot errors and $2.1 \times 10^{-4}$ critical aircraft failures per flight hour. Alternatively, we might expect the pilot error and weather mishap causes to remain at General Aviation levels ($1 \times 10^{-5}$ per flight hour), allowing aircraft failures to be $10 \times 10^{-4}$ per flight hour without exceeding 11 vehicle losses every 10,000 flight hours. Considering that a single pilot may simultaneously control several UAS, the author believes the more conservative number of $2.1 \times 10^{-4}$ critical aircraft failures per flight hour should be required. To the extent the piloting function is replaced by aircraft automation, aircraft failure allocation may be increased up to $10 \times 10^{-4}$ critical aircraft failures per flight hour for a fully autonomous UAS (self contained pilot functions).

\textsuperscript{12} FAA Title 14 Code of Federal Regulations Part 25 and Part 23 Commuter
An Airworthiness requirement of $2.1 \times 10^{-4}$ critical aircraft failures per flight hour can probably be met with robust, non-redundant vehicle systems which are economical even for low cost UAS designs. While this proposed UAS reliability requirement is $1/20^\text{th}$ as stringent as General Aviation, the hazard from a UAS mishap is $1/97^\text{th}$ as great. It may also be useful to consider that Part 25 aircraft have reliability requirements 10,000 times more stringent than General Aviation (as well as a backup pilot), yet have 1% the fatal mishaps and 20% the fatalities per flight hour.

High value UAS do not require more stringent Airworthiness standards; economics will result in these vehicles being designed to better accommodate failures (the expense of a redundant Flight Control computer is easier to justify on a $100$ million vehicle). A balanced design will be achieved with sound Engineering judgment and well-reasoned contract requirements including attrition in life cycle cost calculations.

As noted, UAS may allow operational changes which significantly improve Safety when there is failure warning (such as controlled crashes or self-destruct). If these benefits could be adequately quantified, such techniques/devices might justify a higher acceptable vehicle loss rate (and lesser reliability) on an Exception basis. It is more likely these considerations will simply improve safety (above ELOS) or offset riskier UAS operations over concentrated populations.

**SENSE-AND-AVOID VS OPERATING RESTRICTIONS**

UAS present no hazard to occupants since there are no occupants. The hazard to ground personnel is addressed throughout this paper. The remaining hazard is to other aircraft.

Federal Aviation Regulation 91.113 requires aircraft operators to see-and-avoid other aircraft and yield right-of-way appropriately. ELOS would require an equivalent UAS ability to sense and avoid other aircraft. It is extremely difficult to provide a UAS with the ability to sense and avoid other traffic equivalent to VFR piloted vehicles. Several programs are in various stages of development, but this capability is not currently practical except for the most sophisticated UAS.

Consider the Airspace Integration Plan for Unmanned Aviation\(^\text{13}\) (excerpt included in Reference). This plan envisions three categories of UAS (noted ROA in the document):

- **CAT 1** – similar to a Radio-Controlled (RC) model aircraft
- **CAT 2** – does not fully comply with airspace equipage requirements and not used similarly to RC model aircraft
- **CAT 3** – capable of fully complying with applicable parts of FAA Title 14 Code of Federal Regulations Part 91

CAT 1 UAS should be treated like RC models for similar operations. RC model aircraft historical experience shows they do not present a significant danger to other aircraft and FAA Advisory Circular 91-57 provides only operational guidance (no Airworthiness standards). UAS characteristics to qualify for this class need to be clearly defined (propose less than 330 pounds and less than 100 knots in order to limit damage from a mishap to less than a typical automobile accident). Operation is expected to be within line of sight (VFR) from ground controllers and Class G airspace (within 1200 feet of the ground). The limited hazard potential and RC model historical record supports a minimum-regulation approach.

CAT 3 UAS would possess a sense and avoid capability as well as all other required equipment to make them fully compliant with current regulations. Current or future versions of Predator and Global Hawk are examples of this type. These aircraft should perform indistinguishably from manned aircraft and be allowed the same access to airspace. UAS that regularly operate in Class

\(^{13}\) Airspace Integration Plan for Unmanned Aviation, November 2004 from the Office of the Secretary of Defense
A airspace (18,000 to 60,000 feet above mean sea level) should be CAT 3. It may be advisable to reserve special transponder codes to differentiate UAS from other vehicles.

CAT 2 UAS do not completely comply with equipment requirements and therefore need to be operationally restricted. These UAS cover a broad spectrum of vehicles designed for different purposes; the design purpose should have bearing on the imposed restrictions. The most likely equipment shortfall is a sense-and-avoid capability (due to its inherent difficulty).

High Altitude Long Endurance (HALE) vehicles may spend days or even years observing a particular location. They don’t need to change altitude or position quickly or often and can be slow and clumsy. Endurance requires they only carry mission essential equipment. A HALE vehicle with a maximum speed less than 100 ktas should be allowed to operate above 60,000 feet (Class E airspace) without sense-and-avoid capability. From the perspective of other air traffic, the HALE vehicle presents a similar hazard to an observation balloon. As long as the HALE vehicle has a mode S (or mode 5) transponder, anti-collision lights, and navigation lights, other aircraft can easily avoid it. The HALE’s transponder could be coded to signal other aircraft it has the right of way. The UAS controller can adjust vehicle position to maintain 10,000 feet (suggested) minimum separation from other HALE aircraft tracked by Air Traffic Control (ATC). Flight below 60,000 feet should be restricted as noted below. Higher speed UAS probably need sense and avoid capability even above 60,000 feet.

Low Altitude UAS should be able to operate in class G airspace (within 1200 feet of the ground) without an onboard sense-and-avoid capability by means of ground-based observers (VFR conditions). While these operational restrictions are similar to CAT 1 UAS, CAT 2 UAS would also be subject to Airworthiness standards including a reliability requirement. The more stringent requirements are due to the greater potential for mishap damage from the much larger (up to 12,500 pound) vehicle.

Special Use (or Restricted) Airspace (test ranges, training ranges, war zones) is largely reserved for and controlled by the military. Aircraft allowed to use this airspace (military or civilian) are subject to restrictions which might, for example, yield right-of-way to UAS. Alternatively, UAS may be segregated from manned aircraft in this airspace by operational location and/or altitude.

Class A, B, and C airspace are controlled by ATC. The large amount of traffic in these areas should require sense and avoid capability (most likely a CAT 3 UAS) or significant operational restrictions (such as chase planes or special times/areas for operation).

Class E airspace also includes the altitudes between class G and class A (between 1200 feet above ground level and 18,000 feet above mean sea level). There are many general aviation aircraft flying in this airspace without transponders (commercial aircraft require transponders). Such “non-cooperative” aircraft require active detection from other aircraft (see and avoid). CAT 2 UAS operations need to be restricted in this airspace to avoid hazard to other aircraft.

Equipment failures on a UAS may not result in the same risks as have been the historical norm. For example, failure of sense and avoid equipment (which does not exist on manned aircraft) would necessitate declaring an emergency on a CAT 3 UAS.

Since UAS do not board passengers, they generally will not need to use commercial airports. The congestion at many of these airports should discourage UAS operation as well. Therefore, unless a compelling case is made for the need to operate there, CAT 1 and 2 UAS should be banned from these facilities. If operation is allowed, detailed procedures must be developed to maintain safety for other traffic.
Intense UAS operations over densely populated areas should be subjected to special requirements. The European Aviation Safety Agency (EASA) has developed algorithms to compute the risk to ground personnel from aircraft operation. Such analysis will allow formulation of regulations to provide an equivalent level of safety as historical aviation operation. Perhaps only CAT 1 UAS should be allowed to operate within 500 feet of structures (for example). An alternative might be a special class of UAS which has higher reliability to offset the additional risk.

EQUIPMENT RECOMMENDATIONS

All UAS need anti-collision lights. UAS operating at night also need navigation lights. UAS operating more than 1,600 feet above ground (1600 AGL) should include functioning pressure altimeters, GPS, communications, and mode S (or mode 5) transponders. UAS operating with ground observers (below 1,600 feet) should have a means of determining height above ground such as a laser rangefinder. The UAS or its ground station needs two-way communication with ATC. Additional equipment may be required to maintain continued safe flight during GPS and/or radio outages such as back up navigation or radios. This equipment is in addition to any equipment required to maintain normal safe flight (such as Air Data, Flight Control Computers, etc.), depending on the vehicle design.

REFERENCE INFORMATION

MIL-HDBK-516B w/Change 1 (excerpts):

1. Airworthiness - The property of a particular air system configuration to safely attain, sustain, and terminate flight in accordance with the approved usage and limits.
2. Airworthiness certification - A repeatable process implemented to verify that a specific air vehicle system can be, or has been, safely maintained and operated within its described flight envelope. The two necessary conditions for issuance and maintenance of an airworthiness certificate are 1) the aircraft must conform to its type design as documented on its type certificate, and 2) the aircraft must be in a condition for safe operation.
3. Certification basis - The tailored, complete (necessary and sufficient), documented set of MIL-HDBK-516 airworthiness criteria utilized to assess the safety of a specific system design.
4. Flight critical - A term applied to any condition, event, operation, process, or item whose proper recognition, control, performance, or tolerance is essential to achieving or maintaining controlled flight of an aircraft.
5. Mission critical - A term applied to any condition, event, operation, process or item, the failure of which may result in the inability to achieve successful mission completion or to maintain combat capability.
6. Remotely operated aircraft (ROA) - A remotely operated, semi-autonomous, or autonomous aircraft and its operating system. This does not include air vehicles designed for one-time use as a weapon (e.g., cruise missile). The operating system can be built into the aircraft or be part of the control station for remotely operated vehicles. This "system" includes the control station, data links, flight control system, communications systems/links, etc., as well as the aircraft. [Ref: FAA Order 7610.4K and AFI 202 V3]
7. Safety-of-flight (SOF) - The property of a particular air system configuration to safely attain, sustain, and terminate flight within prescribed and accepted limits for injury/death to personnel and damage to equipment, property, and/or environment. The intent of safety-of-flight clearance is to show that appropriate risk management has been completed and the level of risk (hazards to system, personnel, property, equipment, and environment) has been appropriately identified and accepted by the managing activity prior to flight of the air system.
8. Type certification - A repeatable process implemented to verify that an air vehicle design conforms to it’s type design. It does not verify that the system has been properly
maintained or operated in accordance with its technical data. (See airworthiness certification.)

9. Type design - The type design consists of
   a. The drawings and specifications, and a listing of those drawings and
      specifications, necessary to define the configuration and the design features of
      the air system shown to comply with the airworthiness criteria applicable to the
      air system;
   b. Information on dimensions, materials, materiel properties, and processes necessary to
      define the structural strength of the product;
   c. Any airworthiness limitations required for safe operation and maintenance; and
   d. Any other data necessary to allow, by comparison, the determination of the
      airworthiness, noise characteristics, fuel venting, and exhaust emissions (where
      applicable) of later products of the same type.

10. Unmanned aerial vehicle (UAV) - A remotely piloted, semi-autonomous, or autonomous
    air vehicle and its operating system. This does not include air vehicles designed for one-
    time use as a weapon (e.g., cruise missile). The operating system can be built into the
    vehicle or be part of the control station for remotely piloted vehicles. This "system"
    includes the control station, data links, flight control system, communications
    systems/links, etc., as well as the air vehicle. [Ref: NAVAIRINST 13034.2]

11. Vehicle control functions (VCFs) - VCFs include all functions and their associated
    components used to transmit flight control commands from the pilot and/or other sources
    to appropriate force and moment producers. Flight control commands may result in
    control of aircraft flight path, attitude, airspeed, aerodynamic configuration, ride, and
    structural modes. Integrated VCFs are a combination of flight controls and any other air
    vehicle functions or subsystems that cause, augment, or replace pilot initiated commands
    or provide basic, necessary data/information for the flight control subsystem to function
    and ensure safety of flight.

Verify that the integrated VCF architecture safely implements the proper levels of
 redundancy, fault tolerance, physical/functional separation of flight/safety-critical
 functions/components and other aspects.

Verify the autonomy of each function integrated in or by the VCF design to be safe.

Verify that no single, like dual, second, or single combination failure points in any VCF
 function result in an unacceptable probability of loss of function.

Verify that all single point failures are identified with the associated probability of
 failure(s) and that they demonstrate an acceptable flight safety risk.

Verify that the design is free from unacceptable mishap risk.

Verify that no single-point failure unacceptably affects the safety of the system.

Verify that the flight-essential configurations are identified and proper levels of
 redundancy (hardware and software) exist at the system level to preclude loss of critical
 processing capabilities.

Office of the Secretary of Defense Airspace Integration Plan for Unmanned Aviation,
November 2004 (excerpts):
Airspace

There are six defined classes of airspace in the U.S. that are controlled in various degrees by the air traffic control (ATC) infrastructure. Because these classes are referenced throughout this document, a brief discussion is useful.

- **Class A** airspace exists from Flight Level (FL) 180 (18,000 feet Mean Sea Level (MSL)) to FL600 (60,000 feet MSL). Flights within Class A airspace must be under Instrument Flight Rules (IFR) and under the control of ATC at all times.

- **Class B** airspace surrounds several major airports (generally up to 10,000 feet MSL) to reduce mid-air collision potential by requiring ATC control of IFR and VFR (Visual Flight Rules) flights in that airspace.

- **Class C** airspace surrounds busy airports (generally up to 4,000 feet Above Ground Level (AGL)) that do not need Class B airspace protection, and requires flights to establish and maintain two-way communications with ATC while in that airspace. ATC provides radar separation service to flights in Class C airspace.

- **Class D** airspace surrounds airports (generally up to 2,500 feet AGL) that have an operating control tower. Flights in Class D airspace must establish and maintain communications with ATC, but VFR flights do not receive separation service.

- **Class E** airspace is all other airspace in which IFR and VFR flights are allowed. Although Class E airspace can extend to the surface, it generally begins at 1200 feet AGL, or 14,500 MSL, and extends upward until it meets a higher class of airspace (A-D). It is also above FL600.

- **Class G** airspace (there is no Class F airspace in the U.S.) is also called uncontrolled airspace because ATC does not control aircraft there. Class G airspace can extend to 14,499 feet MSL, but generally exists below 1200 feet AGL, and below Class E airspace.

Accordingly, Classes B, C, and D relate to airspace surrounding airports where increased mid-air collision potential exists; Classes A, E, and G primarily relate to altitude, and the nature of flight operations that commonly occur at those altitudes. ATC provides separation services to all flights in Classes A, B, and C. They provide it to some flights in Class E, and do not provide service in Class G. Regardless of the class of airspace, or whether ATC provides separation services, pilots are required to “see and avoid other aircraft” whenever weather permits.

**ROA in the National Airspace**

The migration of the NAS from ground based traffic control to airborne traffic management, scheduled to occur over the next decade, will have significant implications for ROA. Sense-and-avoid will become an integrated, automated part of routine position reporting and navigation functions by relying on a combination of Automatic Dependent Surveillance-Broadcast (ADS-B) and Global Positioning System (GPS). In effect, it will create a virtual bubble of airspace around each aircraft so that when bubbles contact, avoidance is initiated. All aircraft will be required to be equipped to the same level, making the unmanned or manned status of an aircraft transparent to both flyers and to the FAA.

With respect to regulations, Table 6-1 summarizes the current FAA regulations that could be applied to ROA to allow more routine access to the NAS, as discussed in section 3.1.
Table 6-1: Alignment of ROA Categories with FAA Regulations

<table>
<thead>
<tr>
<th></th>
<th>Certified Aircraft / Cat III ROA(^{14})</th>
<th>Non-Standard Aircraft / Cat II ROA</th>
<th>RC Model Aircraft / Cat I ROA</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAA Regulation</td>
<td>14 CFR 91</td>
<td>14 CFR 91, 101, and 103</td>
<td>None (AC 91-57)</td>
</tr>
<tr>
<td>Airspace Usage</td>
<td>All</td>
<td>Class E, G, &amp; non-joint-use Class D</td>
<td>Class G (&lt;1200 ft AGL)</td>
</tr>
<tr>
<td>Airspeed Limit, KIAS</td>
<td>None</td>
<td>NTE 250 (proposed)</td>
<td>100 (proposed)</td>
</tr>
<tr>
<td>Example Types</td>
<td>Manned</td>
<td>Airliners</td>
<td>Light-Sport</td>
</tr>
<tr>
<td></td>
<td>Unmanned</td>
<td>Predator, Global Hawk</td>
<td>Pioneer, Shadow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dragon Eye, Raven</td>
</tr>
</tbody>
</table>

The terms within Table 6-1 are further defined below.

- **ROA – Cat III**: capable of flying throughout all categories of airspace and conforms to Part 91, etc. (i.e., all the things a regulated manned aircraft must do including the ability to “sense-and-avoid”). Airworthiness and operator certification are required. ROA are generally built for beyond line-of-sight operations.
  
  Examples: Global Hawk, Predator

- **ROA – Cat II**: non-standard aircraft that perform special purpose operations. Operators must provide evidence of airworthiness and operator qualification. Cat II ROA may perform routine operations within a specific set of restrictions.
  
  Examples: Pioneer, Shadow

- **ROA – Cat I**: analogous to RC models as covered in AC 91-57. Operators must provide evidence of airworthiness and operator qualification. Small UAVs are generally limited to visual line-of-sight operations.
  
  Examples: Pointer, Dragon Eye

\(^{14}\) Some Cat III ROA may only be certified to operate under VFR.