SPECIAL FEATURE

Office of the Secretary of Defense

UAS AIRSPACE INTEGRATION

The following is an extract of the first edition of the integrated Unmanned Systems Roadmap (2007-2032) published by the Office of the Secretary of Defense in December 2007.

Overview

The OSD vision is to have "File and Fly" access for appropriately equipped UAS by the end of 2012 while maintaining an equivalent level of safety (ELOS) to aircraft with a pilot onboard.
For military operations, UASs will operate with manned aircraft in civil airspace, including inand around airfields, using concepts of operation that make on- or off-board distinctionstransparent to ATC authorities and airspace regulators. The operations tempo at mixed airfieldswill not be diminished by the integration of unmanned aviation.
In the past, UAS were predominately operated by the DoD for combat operations in militarycontrolled airspace; however, there is a growing desire to employ UAS in support of homeland defense and civil authorities, e.g., DHS. To be effective, UAS will need routine access to the NAS outside of restricted and warning areas, both over land and over water.

Background

Because the current UAS do not have the same capabilities as manned aircraft to safely and efficiently integrate into the NAS, military UAS requirements to operate outside of restricted and warning areas are accommodated on a case-by-case basis. A process used to gain NAS access was jointly developed and agreed to by the DoD and FAA in 1999. Military operators of UAS are required to obtain a COA from the FAA. The process can take up to 60 days and, because UAS do not have an S&A capability, may require such additional and costly measures as providing chase planes and/or primary radar coverage. COAs are typically issued for a specific UAS, limited to specific routes or areas, and are valid for no more than one year. Exceptions are the National COA that was issued to the Air Force for Global Hawk operations in the NAS and the Disaster Relief COA that was issued to NORTHCOM's Joint Force Air Component Commander for the Predator UAS.
With a COA, the UAS is accommodated into the system when mission needs dictate; however, because the UAS lacks the ability to meet the same regulator requirements as a manned aircraft, it is frequently segregated from manned aviation rather than integrated with it, an exception being the integration of UASs flying on Instrument Flight Rules (IFR) flight plans. As the DoD CONOPS for UAS matures and as we ensure the airworthiness of our UAS, we will look toward developing new procedures to gain access to the NAS. Toward that end, the DoD is working with the FAA to refine and/or replace the COA process to enable more ready access to the NAS for qualified UAS.
From the DoD perspective, three critical issues must be addressed in order to supplant the COA process: UAS reliability, FAA regulations, and an S&A capability. Each is discussed here. OSD and FAA, working through the DoD Policy Board on Federal Aviation (PBFA), are engaged in establishing the air traffic regulatory infrastructure for integrating military UAS into the NAS. By limiting this effort's focus to traffic management of domestic flight operations by military UAS, the hope is to establish a solid precedent that can be extended to other public and civil UASs domestically and to civil and military flights in international and non-U.S. airspace.
As depicted in Figure 1, this initiative (shown by the lower-left block in the figure) is intended to serve as the first brick in the larger, interwoven wall of regulations governing worldwide aviation. Precepts include the following:

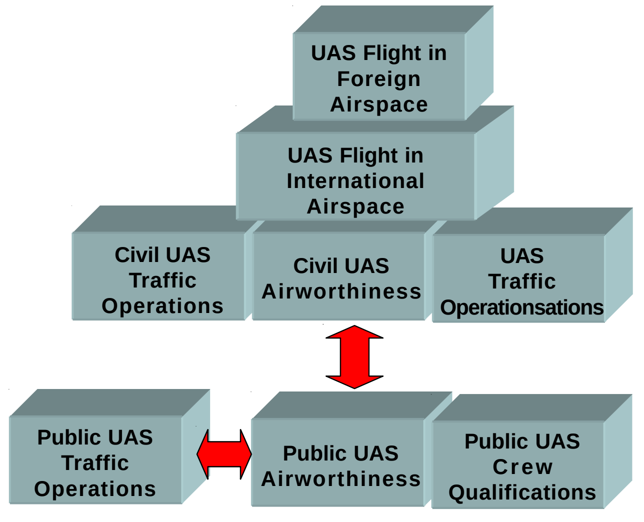

Figure 1 Joint FAA/OSD Approach to Regulating UAS

- Do no harm
  Avoid new initiatives, e.g., enacting regulations for the military user that would adversely impact the Military Departments' right to self-certify aircraft and aircrews, ATC practices or procedures, or manned aviation CONOPS or TTPs or that would unnecessarily restrict civilian or commercial flights. Where feasible, leave "hooks" in place to facilitate the adaptation of these regulations for civil use. This also applies to recognizing that "one size does NOT fit all" when it comes to establishing regulations for the wide range in size and performance of DoD UAS.
- Conform rather than create
  Apply the existing Title 14 Code of Federal Regulations (CFR) (formerly known as Federal Aviation Regulations, or FARs) to also cover unmanned aviation and avoid the creation of dedicated UAS regulations *as much as possible*. The goal is to achieve transparent flight operations in the NAS.
- Establish the precedent
  Although focused on domestic use, any regulations enacted will likely lead, or certainly have to conform to, similar regulations governing UAS flight in International Civil Aviation Organization (ICAO) and foreign domestic (specific countries') airspace.

Before the vision of "file and fly" can occur, significant work must be accomplished in the mutually dependent areas of UAS reliability, regulation, and an S&A capability.

Reliability

UAS reliability is the first hurdle in airspace considerations because it underlies UAS acceptance into civil airspace—whether domestic, international, or foreign. Historically, UAS have suffered mishaps at one to two orders of magnitude greater than the rate (per 100,000 hours) incurred by manned military aircraft. In recent years, however, flight experience and improved technologies have enabled UAS to continue to track the reliability of early manned military aircraft with their reliability approaching an equivalent level of reliability to their manned military counterparts (see Figure 2). Further improvements in reliability will be seen as airworthiness teams develop rigorous standards, and greater redundancy is designed into the systems, e.g., the MQ-1C Sky Warrior and MQ-9A Reaper flight management systems.

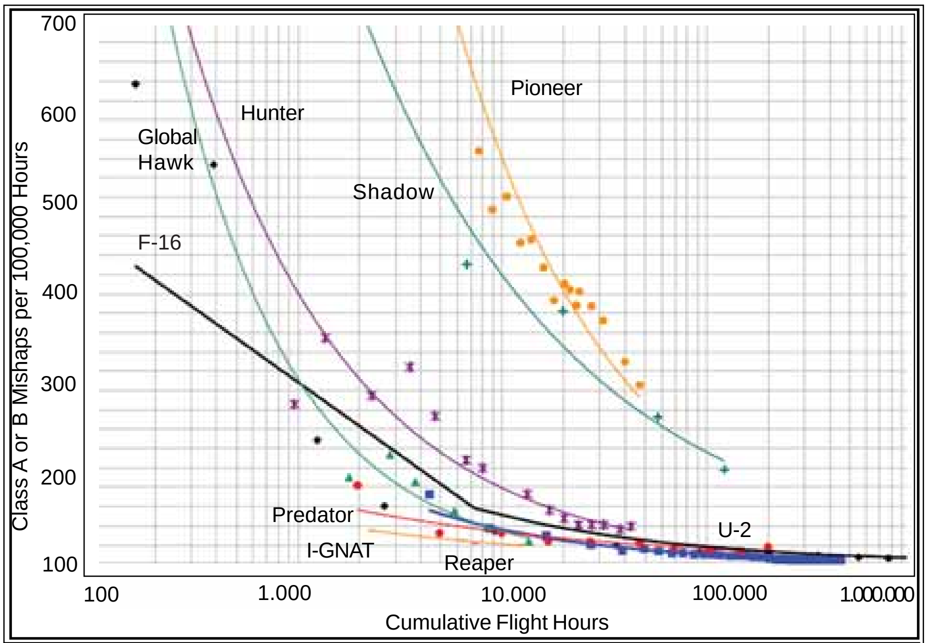

Figure 2: U.S. Military Aircraft & UAS Class A Mishap Tates (Lifetime), 1986-2006

Regulation

Air Traffic Operations

The FAA's air traffic regulations are meant to ensure the multitude of aircraft flown in the NAS are operated safely and pose a minimal hazard to people or property on the ground or in the air. FAA's air traffic management focus is on the day-to-day operation of the system and the safe, expeditious movement of air traffic. Aircraft are separated by time, altitude, and lateral distance.

Additionally, classes of airspace are established that include specific requirements for aircraft equipage, pilot qualifications, and flight plan filing. Regardless of the class of airspace in which aircraft are operating, pilots are required to S&A other air traffic. This requirement exists even when ground controllers provide traffic advisories or when an onboard collision avoidance system, such as the Traffic Alert and Collision Avoidance System (TCAS), is required. S&A is a key issue in allowing UAS into civil airspace and is discussed in detail hereinafter.

Six classes of airspace are defined in the United States, each requiring varying levels of user performance (aircrew/aircraft). Aircraft are controlled to varying degrees by the ATC infrastructure in the different classes of airspace. Because these classes are referenced throughout this discussion, a brief description is useful.

- Class A airspace exists from Flight Level (FL) 180 (18,000 feet MSL) to FL600 (60,000 feet MSL). Flights within Class A airspace must be under IFR and under the control of ATC at all times.
- Class B airspace generally surrounds major airports (generally up to 10,000 feet MSL) to reduce mid-air collision potential by requiring ATC control of IFR and Visual Flight Rules (VFR) flights in that airspace.
- Class C airspace surrounds busy airports (generally up to 4000 feet 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 2500 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 feet 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 United States) is also called "uncontrolled airspace" because ATC does not control aircraft there. (ATC will provide advisories upon request, workload dependent.) 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 (terminal airspace) 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 (en route airspace). ATC provides separation services and/or advisories 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 S&A other aircraft during all conditions. Figure 3 depicts this airspace with representative UAS and their anticipated operating altitude.

It is clear that some taxonomy for UAS is needed to define their operating privileges, airworthiness standards, operator training and certification requirements, and place in the right of- way rules. Although public (e.g., U.S. military) aircraft are to some degree exempt from a number of FAA regulations such as airworthiness and pilot certification, certain responsibilities still exist.

- Meeting equivalent airworthiness and operator qualification standards to operate in the NAS,
- Conforming to FAA traffic regulations (S&A, lighting, yielding right-of-way) when operating outside of restricted

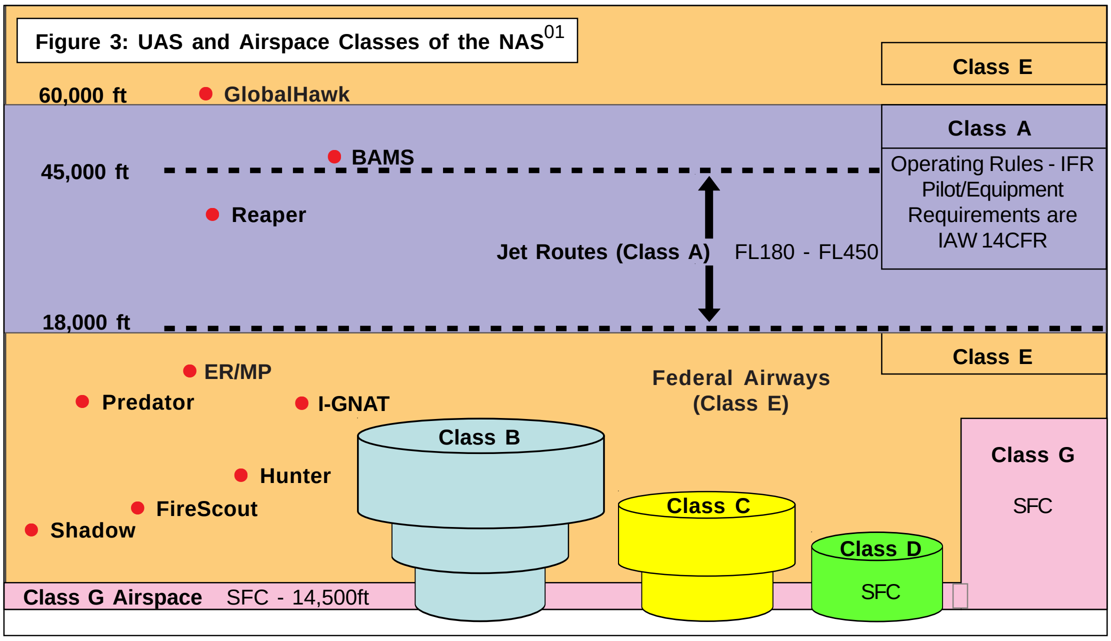

Figure 3: UAS and Airspace Classes of the NAS[01]

airspace, and

- Complying with international (oceanic and foreign domestic) regulations when transiting that airspace, regulations which often take those of the FAA as precedents.

Military UAS with a need to routinely operate outside of restricted airspace or in international airspace must, therefore, make themselves transparent to air traffic management authorities. In large part, this means *conforming by waiver* to 14 CFR 91 for the larger UASs, such as the Air Force's Global Hawk and Predator. This plan calls for these UAS (Cat III) to be treated similarly to manned aircraft.

The FAA has approved a Light Sport Aircraft (LSA) category in the regulations and does not require either airworthiness or pilot certification (similar to Part 103 aircraft) for certain uses and limited operations. These aircraft achieve an equivalent level of safety to certificated aircraft with a slightly lower level of reliability. There are also many restricted category aircraft that perform special purpose operations. A number of U.S. military UAS (e.g., Army's RQ-7 Shadow and MQ-5 Hunter) share similar characteristics and performance. This plan calls for these UAS (Cat II) to be treated similarly to ultralights, LSA, or restricted category aircraft.

As a final case with application to UAS, the FAA has chosen not to explicitly regulate certain other aircraft, such as model rockets, fireworks, and radio-controlled (RC) model aircraft. 14 CFR 101 specifically exempts smaller balloons, rockets, and kites from the regulation; and AC 91-57 addresses RC model airplanes, but is advisory only. These systems are omitted from the regulations. All three military departments currently employ UAS in the same size, weight, and performance regimes as those of RC models (e.g., Raven for the Army, Air Force, and Marine Corps). This plan calls for small UAS similar to RC model aircraft (and operated similarly) [UAS (Cat I)] to be treated similarly to RC model aircraft. This discussion provides divisions, based on the existing regulatory FAA infrastructure, into which all current military UAS can be placed and is depicted with example UAS types in Table 1.

The terms within Table 1 are further defined below.

- UAS (Cat III)
  Capable of flying throughout all categories of airspace and conforms to Part 91 (i.e., all the things a regulated manned aircraft must do including the ability to S&A). Airworthiness certification and operator qualification are required. UAS are generally built for beyond LOS operations. Examples: Global Hawk, Predator
- UAS (Cat II)
  Nonstandard aircraft that perform special purpose operations. Operators must provide evidence of airworthiness and operator qualification. Cat II UAS may perform routine operations within a specific set of restrictions. Example: Shadow.

		Certified A/C UAS (Cat III)	Non-Standard A/C UAS (Cat II)	RC Model A/C UAS (Cat I)
FAA Regulation		14 CFR 91	14CFR 91, 101, & 103	None (AC91-57)
Airspace Usage		All	Class E,G & non-joint-sue Class D	Class G (<1200ft AGL)
Airspeed Limit, KIAS		None	NTE 250 (proposed)	100 (proposed
Example Types	Manned	Airliners	Light-Sport	None
	Unmanned	Predator,	Shadow Global Hawk	DragonEye Raven

Table 1: Alignment of UAS Categories with FAA Regulations

- UAS (Cat I)
  Analogous to RC models as covered in AC 91-57. Operators must provide evidence of airworthiness and operator qualification. Small UAS are generally limited to visual LOS operations. Examples: Raven, Dragon Eye.

The JUAS COE has since further divided these three categories into six categories, as shown in Figure 4.

It is important to note that the FAA uses the term "category" in two different ways (14 CFR 1).

As used with respect to the certification, ratings, privileges, and limitations of airmen, the term "category" means a broad classification of aircraft. Examples include airplane, rotorcraft, glider, and lighter-than-air. As used with respect to the certification of aircraft, the term "category" means a grouping of aircraft based upon intended use or operating limitations. Examples include transport, normal, utility, acrobatic, limited, restricted, and provisional. When discussing right-of-way rules in 14 CFR 91.113, however, the FAA uses nonmutually exclusive categories such as balloon, glider, airship, airplane, rotorcraft, and engine-driven aircraft for determining which flight has the right of way. 14 CFR 103 requires ultralights to yield the right of way to all other manned aircraft. Similarly, the FAA provides

[01] The FAA is moving toward a two-class structure for the NAS, "terminal" and "en route." Terminal will subsume Class B, C, and D airspace, and en route will include Class A, E, and G airspace.

JUAS Categories	Operational Altitude (ft)	Typical Payload	Launch Method	Weight (lbs)	Airspeed (kts)	Endurance (hours)	Radius (nm)	Current Systems (Projected by 2014)
T1-Tactical 1 Special Operations Forces Team Small Unit Company & below	≤ 1,000	Primarily EO/IR or Comms Relay	Hand-launched	≤ 20	≤ 60	< 4	< 10	Hornet, BATCOM Raven, DragonEye FPASS, Pointer Wasp, Buster (rail-launched), MAV
T2-Tactical 2 Battalion/ Brigade Regiment SOF Group/ Flight	≤ 5,000	Primarily EO/IR or Comms Relay	Mobile launched	20-450	≤ 100	< 24	< 100	Neptune, Tern, Mako OAV-II, Shadow 200 SilverFox ScanEagle Aerosonde
T3-Tactical 3 Division./Corps MEF/Squadron/ Strike Group	≤ 10,000	Above, plus SAR, SIGINT, Moving Target Indicator	Conventional or vertical take-off & landing (VTOL)	450-5000	≤ 250	< 36	< 2000	Maverick, Pioneer Hunter, SnowGoose I-GNAT ER, ER/MP Dragonfly, EagleEye FireScout, BAMS Hummingbird, Onyx
0-Operational JTF	≤ 40,000	(MTI), or WPNS	Conventional	≤ 15000	≤ 250	< 36	< 2000	Predator, N-UCAS Reaper
S-Strategic National	≥ 40,000	Above, plus Radar	Conventional	>15000	> 250	< 36	Theater wide	GlobalHawk

Note: This chart is meant to be evolutionary in nature. It reflects current capability/technology and is likely to evolve. As an example, although not a separate JUAS category, airships are recognized as having capabilities and attributes similar to other UAS. As their utility becomes more operational, they will be included in appropriate JUAS categories. The data presented represents typical parameters for the systems that fall in each category. There are several exceptions.

- Operational Altitude: The normal altitude range for systems based on payload capabilities, airspace management requirements, & aircraft capabilities
- Endurance: Includes the time from launch to recovery, based on single aircraft capability without refueling.
- Radius: The radial distance from a launch site to the operating area, limited by C2 linkage and/or endurance and desired time on station.
- Exceptions: Aerosonde endurance - 30 hrs; radius - 1,000 nm; Silver Fox airspeed - 105 kts; Predator airspeed - 118 kts; N-UCAS weight - 46,000 lbs.
- UA operating within an operational theater must comply with existing ACO / SPINS.
- Airspeed: 250 kts is the upper airspeed limit for operations below 10,000 ft MSL.
- Weight: 1,320 lbs is the upper MGTOW limit for FAA light sport aircraft, 12,500 is the upper limit for normal, utility, and acrobatic aircraft.
- Altitude: - 1,200 ft AGL is upper altitude limit for Class G uncontrolled airspace.
  - 3,000 ft AGL is the lower limit for VFR en-route altitudes.
  - 18,000 ft MSL is the lower alt. limit of Class A airspace, (Predator is an exception as it operates above 18,000 ft.)
- Design: FAA standards also vary for winged aircraft, rotorcraft, and airships.

Figure 4: JUAS COE's Categories for UAS

avoidance (right-of-way) advice for RC model aircraft in an Advisory Circular.

It is envisioned, then, that UAS could be assigned their own category in order to facilitate the development of regulations for air operations, airworthiness, operator certification, and right-of-way rules. The UAS category may be exclusive of certain UAS in the same way that model airplanes are omitted from current regulations; and some UASs may be regulated separately, as ultralights, light-sport, or restricted category aircraft are currently.

In addition to regulatory changes necessary for routine operation of military UAS in civil airspace, changes to several other documents, such as Advisory Circulars and FAA Joint Order 7610.4M (Special Operations), will be required.

Airworthiness Certification

The FAA's airworthiness regulations are meant to ensure that aircraft are built and maintained to minimize their hazard to aircrew, passengers, and people and property on the ground.

Airworthiness is concerned with the material and construction integrity of the individual aircraft and the prevention of the aircraft's coming apart in mid-air and/or causing damage to persons or property on the ground. Over the 19-year period from 1982 to 2000, an annual average of 2.2 percent of all aviation fatalities involved people being hit by parts falling off aircraft. A UAS that must be available for unrestricted operations worldwide (e.g., Global Hawk) in most classes of airspace compels serious consideration for the safety of people on the ground. The operational 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.

FAA regulations do not require "public aircraft" (government-owned or -operated) to be certified airworthy to FAA standards. Most nonmilitary public aircraft are versions of aircraft previously certified for commercial or private use; however, the only public aircraft not related to FAA

Domestic Use UAS Levels	Current System Attributes				
	Airspeed (kts)	Weight (lbs)	Operating Altitude (ft)	Current Systems (Projected by 2014)	Description
Level 0	≤ 250	≤ 2	≤ 1200	Hornet, BATCAM, Wasp	Systems under 2 lbs within LOS control, operating in unregulated airspace
Level 1	≤ 250	2-20	≤ 3,000	Raven, DragonEye FPASS, Pointer Buster, MAV	Systems under 20 lbs, operating below VFR airspace
Level 2	≤ 250	21-1,320	< 18,000	SilverFox, Finder Aerosonde, Marts ScanEagle, Neptune OAV-II, Tern, Mako Shadow 200, Pioneer REAP, RAID TARS, JLENS KillerBee	Systems under 1,320 lbs fall under light sport aircraft standards
Level 3	≤ 250	1,321-12,500	< 18,000	Maverick SnowGoose Dragonfly, Hunter A Hunter B, Onyx I-GNAT ER EagleEye, ER/MP FireScout, BAMS Hummingbird Predator	Systems over 1,320 lbs operating below Class A airspace
Level 4	≥ 250	≤ 12,500	< 18,000	Currently no DoD UAS fall in this category. Example is KillerBee concept UAS	Systems operating below 10,000 ft MSL with max speeds that exceed the limit of 250 lbs
Level 5	Any	> 12,500	> 18,000	Reaper, GlobalHawk N-UCAS HAA, NSMV	Systems operating at or above 18,000 ft

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- Altitude:
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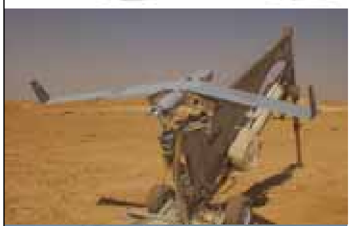
- Design: FAA standards also vary for winged aircraft, rotorcraft, and airships.

Figure 4: JUAS COE's Categories for UAS (cont'd)










certification standards in some way are almost always military aircraft. These aircraft are certified through the military's internal airworthiness certification/flight release process. A Tri-Service memorandum of agreement describes the responsibilities and actions associated with mutual acceptance of airworthiness certifications for manned aircraft and UAS within the same certified design configuration, envelope, parameters, and usage limits certified by the originating Military Department.

Similarly to manned military aircraft, unmanned military aircraft will also be subject to the airworthiness certification/ flight release process. The Global Hawk has completed this process and has been granted an airworthiness certificate.

Crew Qualifications

The FAA's qualification standards (14 CFR 61, 63, 65, and 67) are meant to ensure the competency of aircrew and aircraft maintainers. As in the case of airworthiness certification, these CFR parts do not pertain to military personnel who are certified in a similar, parallel process. DoD and FAA have signed a memorandum of agreement through which DoD agrees to meet or exceed civil training standards, and the FAA agrees to accept military-rated pilots into the NAS. These factors indicate that a certain minimum knowledge standard is required of all pilots-in-command in order to operate aircraft in the NAS. In order to meet the intent of "do no harm," training for Cat III aircraft would include, but not be limited to, regulations, airspace clearances and restrictions, aircraft flight rules, air traffic communications, aircraft sequencing and prioritization, takeoff and landing procedures for combined manned and unmanned operations, go-around and abort procedures, flight planning and filing (including in-flight filing), flight and communications procedures for lost link, weather reporting and avoidance, ground operations for combined manned and unmanned operations, flight speed and altitude restrictions, and, when applicable, weapons carriage procedures (including hung ordinance flight restrictions).

Under the international doctrine for public aircraft, the FAA does not have to agree with DoD training or accept military ratings; the Military Departments are entitled to make these judgments independently. Each Military Department identifies what and how it will operate and create the training programs necessary to safely accomplish its missions. Some of the UAS-related training is a fundamental shift away from the skills needed to fly a manned aircraft (e.g., ground-based visual landing). These differences can relate to the means of landing: visual remote, aided visual, or fully autonomous. They may also relate to different interface designs for the UAS functions or the level of control needed to exercise authority over an aircraft based on its autonomous capability. As a result, the Military Departments will have minimum standards for knowledge skills required of UAS operators operating in the NAS; this minimum standard may differ for given classes of UAS. UAS operators[02] will be expected to conform to these requirements.

"Sense and Avoid" (S&A) Principle

A key requirement for routine access to the NAS is UAS compliance with 14 CFR 91.113, "Right-of-Way Rules: Except Water Operations." This section contains the phrase "sense and avoid" and is the primary restriction to normal operations of UAS. The intent of "sense and avoid" is for pilots to use their sensors (eyes) and other tools to find and maintain situational awareness of other traffic and to yield the right-of-way, in accordance with the rules, when there is a traffic conflict. Since the purpose of this regulation is to avoid mid-air collisions, this should be the focus of technological efforts to address the issue as it relates to UAS rather than trying to mimic and/or duplicate human vision. In June 2003, USAF's Air Combat Command (ACC) sponsored a joint working group to establish and quantify an S&A system capability for submission to the FAA. Their white paper, "See and Avoid Requirement for Remotely Operated Aircraft," was released in June 2004.

Relying simply on human vision results in mid-air collisions accounting for an average of 0.8 percent of all mishaps and 2.4 percent of all aviation fatalities incurring annually (based on the 3-year average from 1998 to 2000).[04]

Meaningful S&A performance must alert the UAS operator to local air traffic at ranges sufficient for reaction time and avoidance actions by safe margins. Furthermore, UAS operations BLOS may require an automated S&A system due to potential communications latencies or failures.

The FAA does not provide a quantitative definition of S&A, largely due to the number of combinations of pilot vision, collision vectors, sky background, and aircraft paint schemes involved in seeing oncoming traffic. Having a sufficient field of regard for a UAS S&A system, however, is fundamental to meeting the goal of assured air traffic separation.

Although an elusive issue, one fact is apparent. The challenge with the S&A issue is both a capability constraint and a regulatory one. Given the discussions in this and other analyses, a possible definition for S&A systems emerges:

S&A is the onboard, self-contained ability to:

- Detect traffic that may be a conflict;
- Evaluate flight paths;
- Determine traffic right of way; and
- Maneuver well clear according to the rules in Part 91.113.

The key to providing the "equivalent level of safety" required by FAA Order 7610.4M, "Special Operations," Chapter 12, Section 9, "UAS Operations in the NAS," is the provision of some comparable means of S&A to that provided by pilots on board manned aircraft. The purpose of S&A is to avoid mid-air collisions, and this should be the focus of technological efforts to automate this capability, rather than trying to mechanize human vision.

From a technical perspective, the S&A capability can be divided into the detection of oncoming traffic and the execution of a maneuver to avoid a mid-air collision. The detection aspect can be further subdivided into passive or active techniques applicable in cooperative or noncooperative traffic environments.

The *active cooperative* scenario involves an interrogator monitoring a sector ahead of the UAS to detect oncoming traffic by interrogating the transponder on the other aircraft. Its advantages are that it provides both range and bearing to the traffic and can function in both visual and instrument meteorological conditions (VMC & IMC). Its disadvantages are its relative cost.

Current systems available in this category include the various TCASs.

The *active noncooperative* scenario relies on a radar- or laser-like sensor scanning a sector ahead of the UAS to detect all traffic, whether transponder-equipped or not. The

[02] *NOTE:* UAS operators may, or may not, be "rated pilots." For the OSD Airspace Integration Plan, "operator" is the generic term to describe the individual with the appropriate training and Service certification for the type of UAS being operated and, as such, is responsible for the aircraft's operations and safety.
[03] National Transportation Safety Board aviation statistics.

returned signal provides range, bearing, and closure rate and allows prioritization of oncoming traffic for avoidance, in either VMC or IMC. Its potential drawbacks are its relative cost, the bandwidth requirement to route its imagery (for nonautonomous systems), and its weight. An example of an active, noncooperative system that is currently available is a combined microwave radar and infrared sensor originally developed to enable helicopters to avoid power lines.

The *passive cooperative* scenario, like the active cooperative one, relies on everyone having a transponder, but with everyone's transponder broadcasting position, altitude, and velocity data.

Its advantages are its lower relative cost (no onboard interrogator required to activate transponders) and its ability to provide S&A information in both VMC and IMC. Its disadvantage is its dependence on all traffic carrying and continuously operating transponders. In this scenario, UASs should have the capability to change transponder settings while in flight.

The *passive noncooperative* scenario is the most demanding one. It is also the most analogous to the human eye. An S&A system in this scenario relies on a sensor to detect and provide azimuth and elevation to the oncoming traffic. Its advantages are its moderate relative cost and ability to detect non-transponder-equipped traffic. Its disadvantages are its lack of direct range or closure rate information, potentially high bandwidth requirement (if not autonomous), and its probable inability to penetrate weather. The gimbaled EO/IR sensors currently carried by reconnaissance UAS are examples of such systems; however, if they are looking at the ground for reconnaissance, then they are not available to perform S&A. An emerging approach that would negate the high bandwidth requirement of any active system is optical flow technology, which reports only when it detects an object showing a lack of movement against the sky, instead of sending a continuous video stream to the ground controller. Imagery from one or more inexpensive optical sensors on the UAS is continuously compared to the last image by an onboard processor to detect minute changes in pixels, indicating traffic of potential interest.

Only when such objects are detected is their bearing relayed to the ground.

Once the "detect and sense" portion of S&A is satisfied, the UAS must use this information to execute an avoidance maneuver. The latency between seeing and avoiding for the pilot of a manned aircraft ranges from 10 to 12.5 seconds according to FAA and DoD studies.[04] If relying on a ground operator to S&A, the UAS incurs the same human latency, but adds the latency of the data link bringing the image to the ground for a decision and the avoidance command back to the UAS. This added latency can range from less than a second for LOS links to more time for satellite links.

An alternative is to empower the UAS to autonomously decide whether and which way to react to avoid a collision once it detects oncoming traffic, thereby removing the latency imposed by data links. This approach has been considered for implementation on TCAS II-equipped manned aircraft since TCAS II already recommends a vertical direction to the pilot, but simulations have found the automated maneuver worsens the situation in a fraction of the scenarios. For this reason, the FAA has not certified *automated collision avoidance* algorithms based on TCAS resolution advisories; doing so would set a significant precedent for UAS S&A capabilities.

The long-term FAA plan is "to move away from infrastructure-based systems towards a more autonomous, aircraft-based system" for collision avoidance.[05] Installation of TCAS is increasing across the aviation community, and TCAS functionality supports increased operator autonomy. Research and testing of Automatic Dependent Surveillance-Broadcast (ADS-B) may afford an even greater capability and affirms the intent of the aviation community to support and continue down this path. Such equipment complements basic S&A, adds to the situational awareness, and helps provide separation from close traffic in all meteorological conditions.

Command, Control, Communications

Data Link Security

In general, there are two main areas of concern when considering link security: inadvertent or hostile interference of the uplink and downlink. The forward ("up") link controls the activities of the platform itself and the payload hardware. This command and control link requires a sufficient degree of security to ensure that only authorized agents have access to the control mechanisms of the platform. The return ("down") link transmits critical data from the platform payload to the warfighter or analyst on the ground or in the air. System health and status information must also be delivered to the GCS or UAS operator without compromise. Effective frequency spectrum allocation and management are key to reducing inadvertent interference of the data links.

Redundant/Independent Navigation

The air navigation environment is changing, in part, because of the demands of increased traffic flow. Allowances for deviation from intended flight paths are being reduced. This provides another means for increasing air traffic capacity as airways and standard departures and approaches can be constructed with less separation. As tolerances for navigational deviation decrease, the need to precisely maintain course grows. All aircraft must ensure they have robust navigational means. Historically, this robustness has been achieved by installation of redundant navigational systems. The need for dependable, precise navigation reinforces the redundancy requirements.

While navigation accuracy and reliability pertain to military operations and traffic management, current systems are achieving the necessary standard without redundancy and without reliance on ground-based navigation aids. The *Federal Radionavigation Plan*, signed January 2006, establishes the following national policies:

- Properly certified GPS is approved as a supplemental system for domestic en route and terminal navigation, and for nonprecision approach and landing operations.
- The FAA's phase-down plan for ground-based navigation aid systems (NAVAIDS) retains at least a minimum operational network of ground-based NAVAIDS for the foreseeable future.
- Sufficient ground-based NAVAIDS will be maintained to provide the FAA and the airspace users with a safe recovery and sustained operations capability in the event of a disruption in satellite navigation service.

These policies apply, as a minimum, to all aircraft flying in civil airspace. With GPS, the prospect for relief of some redundancy requirements in manned aviation may be an option in the future. However, UAS have a diminished

[04] Tyndall Air Force Base Mid-Air Collision Avoidance Study; FAA P-5740-51; see also Krause, *Avoiding Mid-Air Collisions*, p. 13.
[06] *2001 Federal Radionavigation Systems Plan.*

prospect for relief since, unlike manned aircraft, a UAS without communication links cannot readily fall back on dead reckoning, contact navigation, and map reading in the same sense that a manned aircraft can.

Autonomy

Advances in computer and communications technologies have enabled the development of autonomous unmanned systems. With the increase in computational power available, developmental UAS are able to achieve much more sophisticated subsystem, guidance, navigation and control, sensor, and communications autonomy than previous systems. For example, Global Hawk's airborne systems are designed to identify, isolate, and compensate for a wide range of possible system/subsystem failures and autonomously take actions to ensure system safety. Preprogrammed decision trees are built to address each possible failure during each part of the mission.

One of the most difficult aspects of high levels of autonomy is ensuring that all elements remain synchronized. Verifying that:

1) all messages are received;
2) all aircraft have correctly interpreted the messages; and
3) the entire squadron has a single set of mission plans to execute will be a key accomplishment.

Lost Link

In the event of lost C2 links, military UAS are typically programmed to climb to a predefined altitude to attempt to reestablish contact; this "lost link profile" may not be appropriate for operations in the NAS. If contact is not reestablished in a given time, the UAS can be preprogrammed to retrace its outbound route home, fly direct to home, or continue its mission.

With an irreversible loss of the C2 data link, however, there is usually no procedure for a communications-out recovery. (Global Hawk does have this capability using differential GPS and pre-programmed divert airfields.) Examination of a lost C2 link scenario illustrates that this communications issue can become a critical UAS failure mode.

No Radio (NORDO) requirements are well documented in 14 CFR 91.185. Remarkably, most lost C2 link situations bear a striking resemblance to NORDO, and UASs would enhance their predictability by autonomously following the guidance. The one exception to this case is the Visual Flight Rules (VFR) conditions clause. UAS, even with an autonomous S&A system, would enhance overall safety by continuing to fly IFR. Should normal ATC-voice communications fail, the FAA also has the capability to patch airspace users through to the controlling ATC authority by phone at any time.

Future Environment

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 UAS. S&A will become an integrated, automated part of routine position reporting and navigation functions by relying on a combination of ADS-B and 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.

Finally, the pejorative perception that UAS are by nature more dangerous than manned aircraft needs to be countered by recognizing that UAS can provide an equivalent level of safety to that of manned aircraft and possess the following inherent attributes that contribute to flying safety:

- Many manned aircraft mishaps occur during the takeoff and landing phases of flight, when human decisions and control inputs are substantial factors. Robotic aircraft are not programmed to take chances; either preprogrammed conditions are met or the system goes around. This will likely reduce the incidence of mishaps during these phases of flight.
- Since human support systems are not carried, mishaps from failed life support systems (e.g., Payne Stewart, Helios Airways 522) will not occur.
- An automated takeoff and landing capability reduces the need for pattern work and results in reduced exposure to mishaps, particularly in the area surrounding main operating bases.
- UAS control stations can access resources not available in the traditional cockpit and thus increase the operator's situational awareness.
- A greater percentage of UAS operator training can be performed through simulation given the nature of GCSs. Using simulations reduces the need to actually fly the aircraft and the related exposure to mishaps.

DoD Organizations with Roles in UAS Airspace Integration

As discussed, access to the NAS is currently attained primarily through the COA process, which relies on a combination of procedures and observers to provide the ELOS for UAS. Both regulatory and technical issues need to be addressed to attain UAS integration. The organizations within the DoD that are addressing these issues and are related to current and future operations include OSD Oversight and Policy, the Joint Staff chartered organizations, and the military departments' chartered organizations.

OSD Oversight and Policy

The OUSD(AT&L) established the UAS PTF in October 2001 to address the need for an integrated Defense-wide initiative for UAS planning and execution. The UAS PTF provides oversight on all DoD UAS acquisition programs. DoDD 5030.19[06] directs the Assistant Secretary of Defense (Networks and Information Integration) (ASD(NII)) to chair the DoD Policy Board on Federal Aviation (PBFA). The PBFA shall advise and assist the ASD(NII) on ATC, airspace management, NAS matters, joint systems acquisition, and aviation-related international affairs. Supporting the PBFA are the PBFA Working Group and the UAS Subgroup.

The Assistant Secretary of Defense (Homeland Defense) (ASD(HD)) is the Department's interface with DHS. It has been directed to develop a comprehensive policy document on domestic use of UAS.

Joint Staff Chartered Organizations

The JROC chartered two organizations to improve UAS interoperability and operational effectiveness of UAS:

- The former JUAS Material Review Board (MRB), to provide an UAS forum to identify or resolve requirements

[06] DoDD 5030.19, DoD Responsibilities on Federal Aviation and National Airspace System Matters.

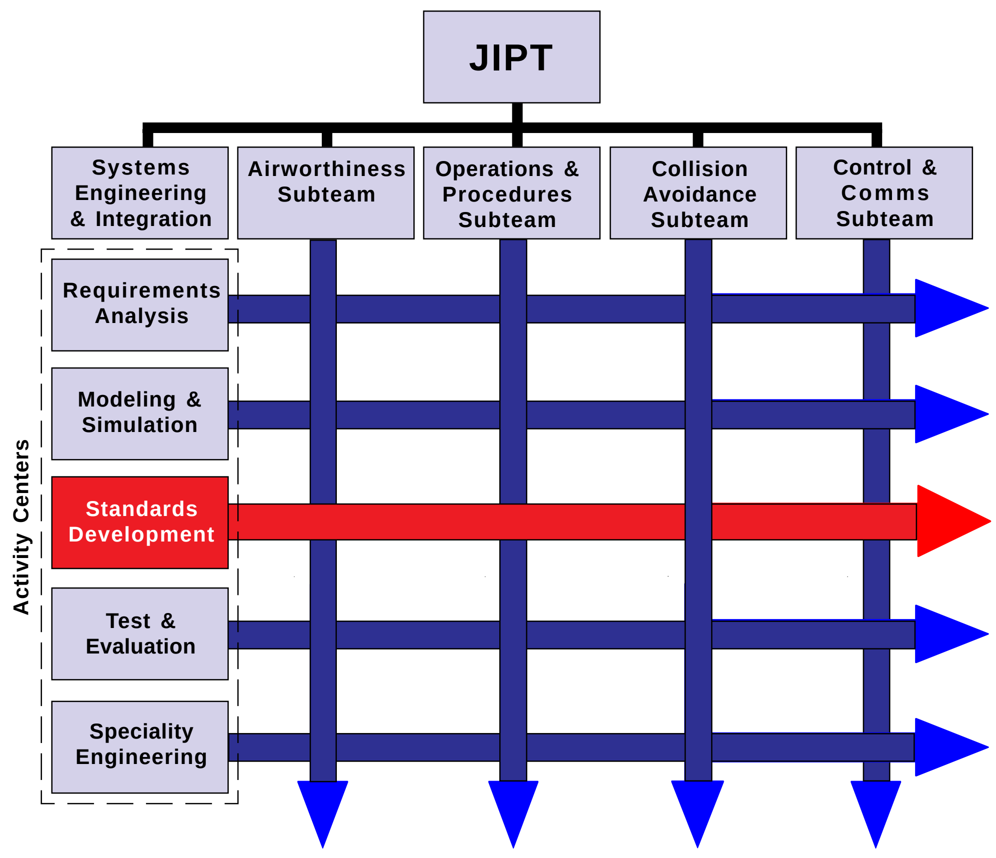


Figure 5: JIPT Functional Organization

and corresponding materiel issues (July 5, 2005), and

- The JUAS Center of Excellence (COE), to pursue solutions to optimize UAS capabilities and utilization (including concepts of operation).

The JUAS MRB was tasked to determine if the current DoD organizations working the UAS airspace integration issue were adequately resourced, both in funding and personnel. The JUAS COE has published a Joint UAS CONOPS, which includes a CONOPS for UAS providing domestic support to civil authorities.

Military Departments' Chartered Organizations

Each of the military departments has a UAS program office responsible for the development and acquisition of UAS capabilities that meet JROC-validated COCOM needs. Many of DoD UAS in development require access to the NAS and foreign domestic airspace. To coordinate related technology and standards development, the Air Force, Army, and Navy UAS acquisition program managers chartered the Tri-Service UAS Airspace Integration Joint Integrated Product Team (JIPT) in December 2005. After conducting a comprehensive assessment of the challenges associated with gaining access to civil airspace to meet operational and training requirements, the acquisition managers concluded that a coordinating body was needed to focus and align resources towards a common set of goals and objectives. The JIPT is organized into issuefocused subteams and support-focused activity centers, one of which is a standards development activity center. The subteams are responsible for identifying standards gaps and conducting the necessary activities to modify or develop the standards necessary to integrate DoD UAS into the NAS. The activity centers, through the Systems Engineering and Integration Team (SEIT) provide critical requirements analysis, M&S, test and evaluation integration, and standards validation support functions to the subteams. Figure 5 shows the JIPT's functional organization.

The JIPT is the primary DoD organization working on developing standards for the testing and operation of UAS in the NAS. A summary of the JIPT's mission, scope, and two-track strategy for integrating UASs into the NAS follows.

JIPT Mission

The JIPT will develop the standards, policy, and enabling technology necessary to (1) integrate UAS operations with manned aircraft operations in nonsegregated airspace, (2) integrate resources and activities with industry and airspace regulatory authorities to achieve greater alignment with DoD goals and objectives, (3) ensure compatibility and interoperability of global access enabling technology and ATC procedures, and (4) provide the necessary documentation to affect changes in the global ATC systems to meet the near-, mid-, and long-term airspace access needs of the DoD UAS user community. To assist in this, the JIPT will integrate work activities with the FAA, civil SDOs, the DoD PBFA, and Military Department-related airspace organizations (where deemed appropriate) to optimize resource allocation; influence standards, procedures, and policy adoption schedules; and promote convergence of technical and procedural solutions to ensure system interoperability.

JIPT Scope

The JIPT will contribute to the development of the standards, procedures, policy, and enabling technology necessary to safely integrate UAS operations with manned aircraft operations in non-segregated airspace, on a timeline that is in alignment with the acquisition schedules of major DoD UAS PORs and the allocated funding for this work. It will also facilitate near- and midterm expansion of DoD UAS use of the NAS through a modified COA process to meet existing operational requirements.

JIPT Two-Track Strategy

In order to accommodate these near-, mid-, and long-term needs, the JIPT intends to use a twotrack strategy in which each track will proceed in parallel with the other. The first track, which is focused on resolving near-term operational issues, is an incremental approach that will systematically work with the Military Departments and the FAA to expand access to the NAS beyond the existing COA restrictions for specific (CONOP/UAS) combinations. Initially, one of each Military Department's UAS operational bases will be focused upon to address, through concentrated effort, the near-term challenges of

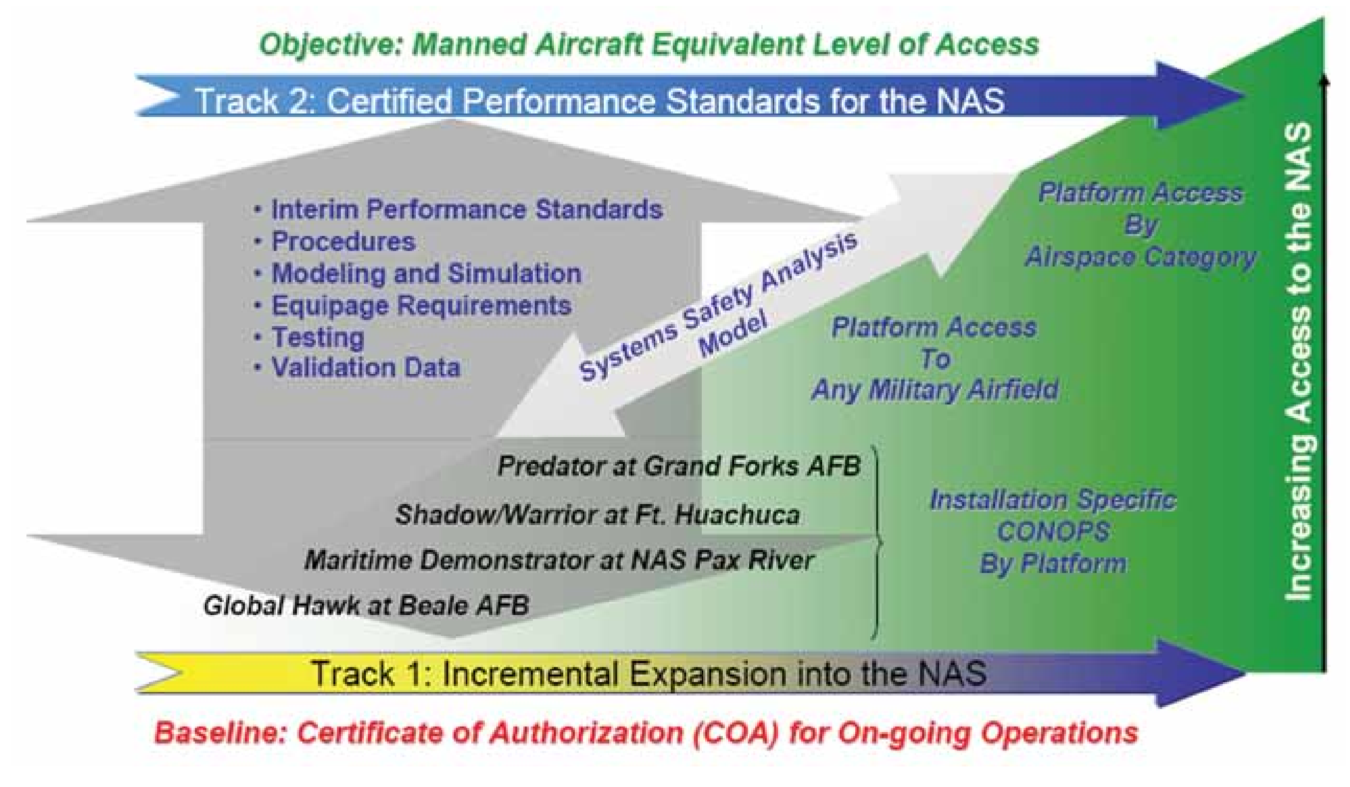


Figure 6: Track 1 and Track 2 Strategies

UAS operations in the NAS. Once an approach for reducing the restrictions on UAS has been proven to work at these locations, this approach will be standardized and then applied to various other base locations to address the Military Departments' near- and mid-term needs. Track 1 success hinges on development and standardization of a unified safety analysis framework that the FAA and DoD may agree to in principle and in fact.

The second track will build upon the approach used in Track 1 by using a disciplined systems engineering approach to generate performance standards for UAS enabling technologies, as well as the operational procedures, that will provide UAS with an appropriate level of safety for the airspace in which they will operate. Track 2 should address the long-term needs that each of the Military Departments has by ensuring that the necessary standards and procedures are in place and that there is a clear path defined for development of the enabling

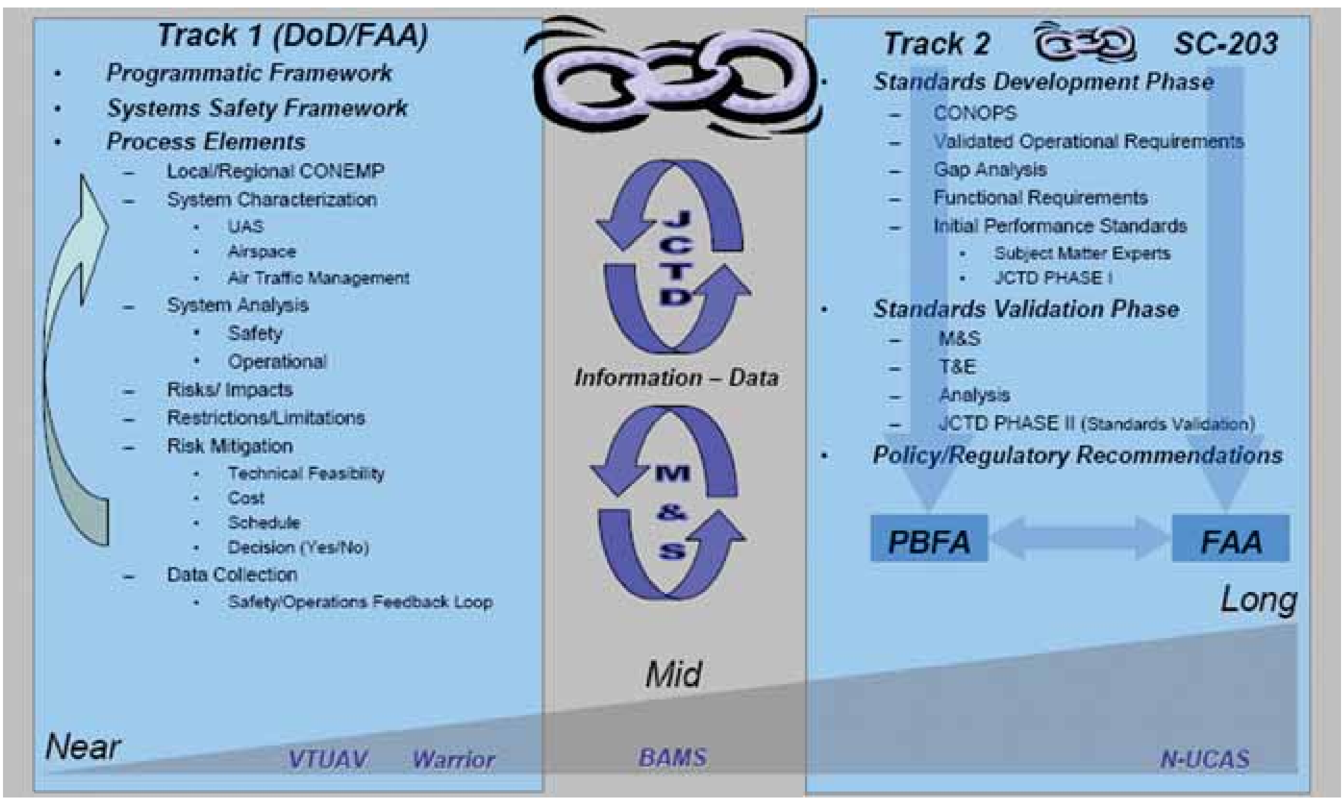


Figure 7: Track 1, Track 2, and RTCA SC203

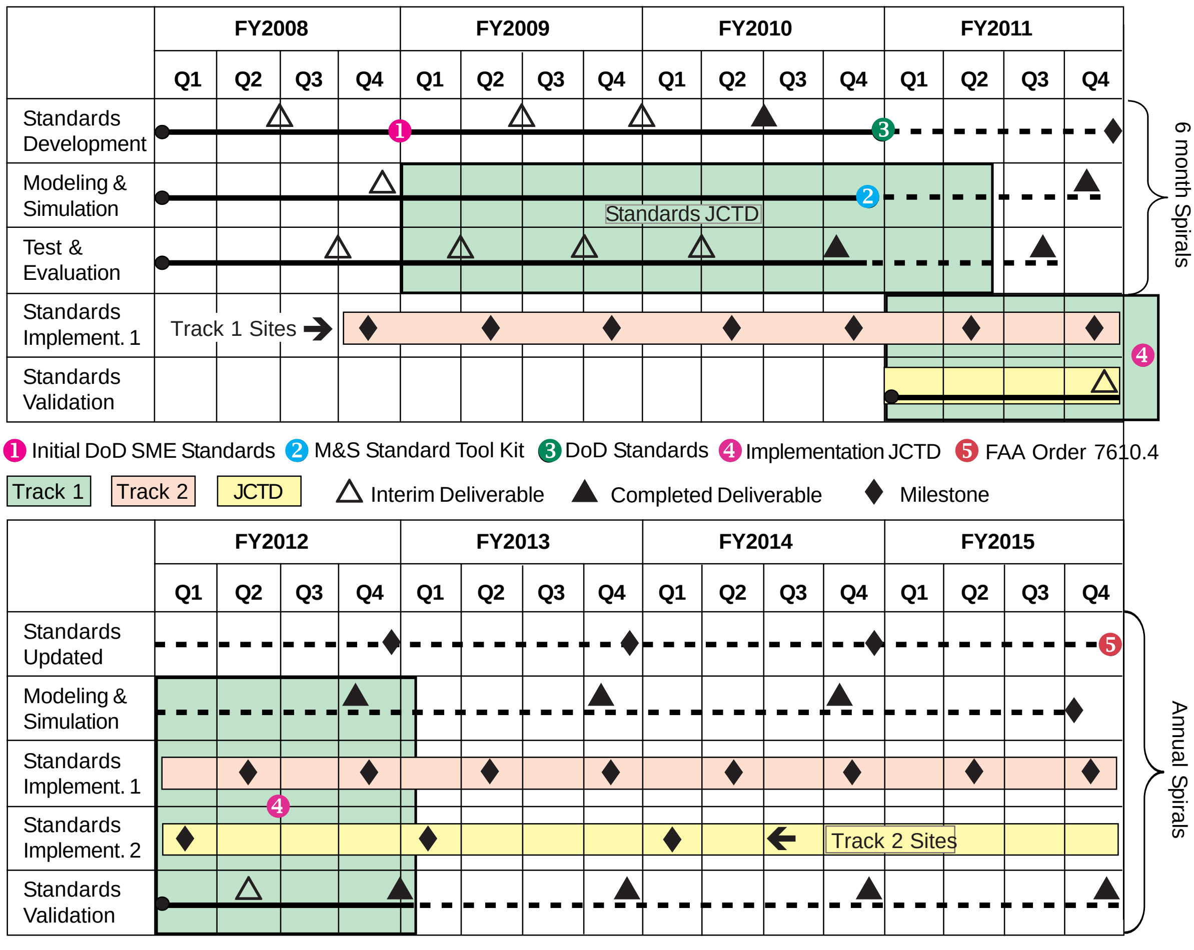


Figure 8: Proposed UAS Airspace Integration Roadmap

technologies needed to ensure safe UAS operations in civil airspace. Figure 6 depicts this two-track approach.

Recognizing the criticality of gaining FAA and industry consensus on the approach and rigor for developing and validating an integrated materiel/nonmateriel solution, including standards needed to operate safely in the NAS, the JIPT has closely aligned its activities with those of RTCA Special Committee (SC) 203 (see Figure 7). The SC-203 is chartered by the FAA to develop *civil* Minimum Aviation Safety Performance Standards (MASPS) and Minimum Operating Performance Standards (MOPS) for UASs, S&A, and communications and control.

The JIPT ensures subject matter experts are engaged in the work activities of SC-203 and conducts critical planning activities with SC-203 leadership to ensure synergy of effort. It is the intent of the JIPT to conduct, or otherwise influence, necessary studies, analysis, and technology development activities within the DoD to fill critical knowledge gaps within SC-203 that could not be met by other means. This close coupling with a key civil UAS Airspace Integration SDO that is recognized and supported by the FAA should increase the probability that the DoD will achieve its goals and objectives and should reduce the risk that the DoD standards will be on a divergent path from those of the civil community. However, the current SC-203 schedule does not meet the timelines of many DoD UAS programs.

Track 1 Definition

The objective of Track 1 is to incrementally expand UAS access to the NAS in the near- to mid-term to meet current and/or emerging operational requirements. Track 1 will focus on installation-specific CONOP by UAS platform. This track will not seek to change national level policy. The priority for working each installation-specific UAS CONOP will be determined by the individual Military Departments and must comply with the UAS-related standards including system hardware and operators' qualifications/currency requirements. One of the key activities within Track 1 will be to perform a standardized safety analysis that will seek access to regional airspace through an expanded COA. Track 1 will focus on providing cost-effective, operationally useful expansion of UAS access to the NAS that is targeted to specific operational needs of the Military Departments. The JIPT will employ both procedural and/or technical solutions to mitigate risk and to accomplish this objective.

To facilitate a standardized Track 1 approach, the JIPT will work with the FAA's Unmanned Aircraft Program Office to establish a mutually agreeable process in which to evaluate DoD requests for expanded airspace access. Based on this integrated approach with the FAA, the JIPT will provide the requesting Military Department with the appropriate information to conduct the safety study and submit a complete package to the FAA for final approval. Once a sufficient body of data has been collected, the JIPT will expand the Track 1 efforts beyond a single installation with a specific UAS CONOP and move toward an integrated approach for increased UAS access. This will be accomplished through additional analysis and data collected from ongoing operations to substantiate the ability to safely operate a given UAS outside DoD-controlled airfields, or alternatively, multiple UAS platforms out of a single DoD-controlled airfield. The compilation of the individual installation efforts into an integrated NAS-level analysis should support the performance standards development effort in Track 2.

The incremental approach to airspace integration in Track

1 should result in two key outcomes:
- DoD will have an avenue to meet near- to mid-term operational needs to operate in the NAS; and
- It will provide a forum for other airspace users, regulators, and the general public to become comfortable with the level of safety demonstrated by DoD UAS operations.

Track 2 Definition

The objective of Track 2 is to develop the performance standards for enabling DoD UAS operations and to recommend the necessary changes to existing FAA policy and/or CFR required to routinely operate UAS within the NAS. Track 2, therefore, will at a minimum attempt to establish and validate the standards needed to provide UAS with a level of safety equivalent to that of manned aircraft. To arrive at the needed performance standards, the JIPT will integrate the data collected from flight operations in Track 1 with an initial set of performance standards.

These standards will be developed in coordination with the appropriate organizations needed to concur on an initial set of standards. The JIPT will then proceed with a detailed assessment of these initial performance standards through a rigorous M&S analysis effort. The JIPT will work, in coordination with the FAA's Unmanned Aircraft Program Office through the DoD PBFA and the Military Departments' airspace functional organizations [i.e. Air Force Flight Standards Agency, U.S. Army Aeronautical Service Agency, the Chief of Naval Operations (Code N88F), and HQMC Aviation (APC)] to ensure that the M&S approach taken by the JIPT has the degree of rigor and specificity needed by the FAA for high-confidence results. The JIPT's M&S activity will be open to FAA and FAA-designated agents to advise on the degree of rigor for high-confidence results. As these standards are developed and validated, the JIPT will provide data and results to the SDOs used by the FAA for developing certified standards.

Once initial results from the M&S activity are produced, an initial evaluation of the overall UAS performance can be determined, and appropriate modifications can be made to the performance standards until the appropriate level of safety is achieved for the UAS. These performance standards will then be validated through an appropriate test and evaluation phase that will validate the M&S assumptions and performance characteristics and provide the needed realworld data to substantiate and validate the standards themselves. These validated performance standards will then be provided to the appropriate SDOs for developing certified regulatory guidance for the FAA. In addition, the JIPT intends to coordinate this work (technology development, acquisition, demonstrations, flight test) through the individual Military Departments' UAS program offices, which will be responsible for meeting the finalized set of standards and procedures. The JIPT will then refine the Track 1 analysis and data collection activities to improve the fidelity of the validation process. These refinements will be made in close coordination with the FAA's Unmanned Aircraft Program Office to continuously align our process with their analysis requirements.

UAS Airspace Integration Roadmap

Track 1 and Track 2 strategy implementation is outlined in the proposed UAS Airspace Integration Roadmap (see Figure 8), which is currently being socialized within the broader DoD stakeholder community. The degree to which this plan will be successful depends upon the following:
- The key stakeholders organizations and communities must reach consensus on a common path forward, and
- The effort must be prioritized in terms of expertise applied to the effort along with the appropriate level of funding to execute on the timeline provided.

The JIPT is proposing a Joint Capability Technology Demonstration for FY2009 to advance the standards and technology work inside the FY2010 Program Objective Memorandum timeline.

The JIPT, chartered by the Military Departments' UAS program managers in 2005, has taken action to develop a comprehensive strategy and programmatic roadmap to meet short-, mid-, and long-term Military Department UAS operational and training airspace access needs. To enhance the probability of success, the JIPT is working closely with the FAA's Unmanned Aircraft Program Office and the FAA-chartered RTCA SC-203 on unmanned aviation and with other DoD UAS stakeholders to gain consensus and support for a single DoD roadmap that addresses the broad materiel/non-materiel solution set.

Summary

To maximize the operational effectiveness of UAS, unmanned aircraft must be able to integrate with manned and unmanned operations, both in the NAS and oceanic and foreign domestic airspace. To attain this goal the DoD must accomplish the following:

1- Foster an airspace regulatory environment that encourages the safe use of UAS in nonsegregated airspace;
2- Improve the flight reliability of UAS to equal or better that of their manned counterparts;
3- Secure the control and sensor/relay communications sent to and from UAS;
4- Implement the JIPT's two-track strategy to gain increased access to the NAS for all UAS under the current COA process and attain a level of access for UAS (Cat III) equivalent to that of manned aircraft; and
5- Work with the FAA to define appropriate conditions and requirements under which a single pilot would be allowed to control multiple airborne UAS simultaneously.