Operational Profiles of Unmanned Aircraft Systems in the Context of the US Regulatory Regime

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1 ACRONYMS

AC	advisory circular
ADS-B	automatic dependent surveillance-broadcast
ALPA	Airline Pilots' Association
AFRL	Air Force Research Laboratory
AGL	above ground level
ATC	air traffic control
C2	command and control
CBP	Customs and Border Protection
CFR	Code of Federal Regulations
COA	Certificate of Authorization or Waiver
DAA	Detect and Avoid
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DoE	Department of Energy
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FOIA	Freedom of Information Act
IFR	instrument flight rules
MOA	memorandum of agreement
NAS	National Airspace System (of the United States)
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers' Association
NOAA	National Oceanic and Atmospheric Administration
RTCA	Radio Telecommunications Corporation of America
SAC-EC	Special Airworthiness Certificate—Experimental Category
UAS	unmanned aircraft system
U.S.	United States
USDA	United States Department of Agriculture
UTM	UAS Traffic Management
VFR	visual flight rules

2 INTRODUCTION

Unmanned aircraft systems (UASs) have been used by militaries and hobbyists for decades, but the advent of low-cost and powerful computers, communications technologies and other aerospace systems have supported a recent surge in the number of these types of aircraft that are available to a multitude of users. This increased availability along with their improved reliability and usability has created significant demand for integrating UAS with airspace and air traffic control systems in the United States and internationally. However, a significant set of technical challenges must be resolved before large numbers of these vehicles can be safely operated alongside legacy users of the airspace. The current operational approval process for UAS imposes limitations on the operations they may conduct and limitations that are designed to ensure airspace safety while those technical challenges are addressed. In the meantime, the process is severely curtailing the number and types of operations being carried out.

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This chapter reviews the types of operational profiles that UAS undertake in the current regulatory environment (see Regulatory Policy and Processes: A Moving Landscape) and the profiles they are expected to use when regulations allow routine access to the airspace. In this chapter, an operational profile is characterized by the type of aircraft, the purpose of the operation, and the environment in which the aircraft flies, including its cruise altitude, mission duration, and flight plan. This chapter starts by reviewing the current regulatory framework used in the United States to approve specific UAS operations. Next, descriptions of the operations that have been carried out under the current framework are presented. The path to approve routine operations of UAS that largely comply with existing aviation regulations is described, and examples of the operations that a diversity of public and private interests are likely to undertake when UAS become certified are presented. Finally, descriptions of alternate regulatory frameworks are given and the types of operations they could entail are outlined. The scope of this chapter is confined to public and civil applications of UAS, so other than a brief description of the US military's use of UAS in domestic airspace, the operational profiles of defense-related applications are not discussed.

3 OPERATIONS UNDER EXISTING REGULATORY FRAMEWORK

A detailed description of how UAS can obtain approval for operations in the US National Airspace System (NAS) is available through FAA Notice JO 7210.891 (FAA, 2015). The next section summarizes this process, and the following section explains how the public, civil, and hobbyist communities have operated UAS under these rules.

3.1 Regulatory Approval Framework

The regulatory approval process that UAS must follow in order to receive permission to fly in the NAS greatly affects the types of operations that are approved (see Regulatory Policy and Processes: A Moving Landscape). Certain operations, for example those at low altitude over populated areas, are generally prohibited and so few examples of them exist today. However, changes in technology, policy, or procedures could enable those in the future, so it is important to distinguish between operations not conducted today because there is no scientific, economic, or other benefit to them versus those that do not fall within the current regulatory structure. Without an understanding of the process, it will be difficult to separate these two cases.

Generically, a UAS must receive both airworthiness approval and operational approval to fly in the NAS. The former requirement pertains to the integrity and safety of all components of the UAS, but it does not grant approval to actually operate the aircraft in any manner. The latter approval is necessary for each type of operation intended for the UAS. In other words, the airworthiness process ensures the vehicle itself is safe, and the operational approval process ensures that the things to be done with that aircraft are safe in the context of the airspace and for people and property on the ground. Two sets of approval processes are currently in place for UAS depending on whether they are being operated by public agencies (federal, state, or local government) for noncommercial purposes or private ones. The distinction between the two types of operations is not always clear, so the FAA has issued guidance to assist in making the differentiation (Advisory Circular (AC) 00–1.1A, 2014).

The process of gaining regulatory approval for public entities is simpler than for civil ones because the FAA does not certify the airworthiness[1] of public aircraft. The public entity must only obtain operational approval from the FAA to fly UAS in the NAS, for which they require a public aircraft certificate of authorization or waiver ("public Certificate of Authorization or Waiver (COA)[2]") or a memorandum of agreement (MOA). This public COA applies to aircraft used only for the US government or owned by the government and operated for crew training, equipment development, or demonstration (AC 00–1.1A, 2014). If the government intends to operate a civil aircraft, operates a public aircraft for commercial purposes, or has no government employees in the crew, then it must follow the process for a civil aircraft COA. Although no airworthiness approval is required from the FAA, the government entity conducting the public aircraft operation must comply with all regulations applicable to UAS operating in the NAS and is responsible for ensuring the aircraft is airworthy. Large organizations such as the US Department of Defense (DoD) and NASA have thorough procedures in place to evaluate and ensure airworthiness, while smaller organizations such as a local police department can ensure airworthiness by purchasing an off-the-shelf

[1] "Airworthiness" is the measure of an aircraft's suitability for safe flight (http://en.wikipedia.org/wiki/Airworthiness).
[2] The FAA defines a COA as "an authorization issued by the Air Traffic Organization to a public operator for a specific (unmanned aircraft) activity. After a complete application is submitted, FAA conducts a comprehensive operational and technical review. If necessary, provisions or limitations may be imposed as part of the approval to ensure the UA can operate safely with other airspace users."

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system for which the appropriate process has been followed and documented.

The FAA-issued public COA is "an authorization issued by the Air Traffic Organization to a public operator for a specific unmanned aircraft activity."[3] The COA application describes aspects of the UAS and its intended operation relevant to determining whether other users of the airspace or the public will face an unreasonable threat to their safety: the control and communications link, lost-link procedures, operating maps, launch and recovery procedures, etc. The approval then specifies the operations that may be carried out, for example below a particular altitude, in the vicinity of a particular airport, with a specified aircraft, for a given purpose, and for no more than 2 years. It may also require additional safety restrictions be placed on the operations to ensure the UAS meets requirements that apply to all aircraft operating in the NAS: use of visual observers to ensure separation from other airspace users, minimum pilot and observer qualifications, allowable weather conditions, etc. This process is designed to accommodate aircraft that do not meet the usual requirements for flying in the NAS by specifying alternative mitigations.

All UAS operations that do not fall under the requirements of a public aircraft COA must obtain both a civil aircraft COA and comply with the FAA's airworthiness requirements. Until late 2014, there were only two ways to receive airworthiness approval: through the issuance of a special airworthiness certificate in the experimental category[4] (SAC-EC) or by obtaining a UAS type and airworthiness certificate in the restricted category. The former method is frequently used to obtain approval for amateur-built aircraft or kit aircraft for which no type certificate is available. To receive SAC-EC, the applicant must describe the design and construction of the vehicle, software development processes, quality assurance procedures, and how and where they intend to fly.[5] If the FAA inspector is satisfied that the system can be safely operated, then that particular aircraft is approved; however, even identically constructed aircraft will require separate approval. Aircraft that receive an experimental airworthiness certificate may be used for research and development, crew training, and market surveys only, they may not be used to carry passengers for hire or put to other commercial purposes. The restricted category approval process is designed to allow civil- or military-derived aircraft to be operated in ways for which they were not originally certified and to permit exceptions to airworthiness requirements the FAA finds inappropriate for the special purpose of the aircraft (FAA, 2008). This approval method has been used rarely for UAS, because, for the most part, UAS have not been converted from previously certified aircraft.

[3] http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/aaim/organizations/uas/coa/

[4] From faa.gov: "A special airworthiness certificate in the experimental category is issued to operate an aircraft that does not have a type certificate or does not conform to its type certificate and is in a condition for safe operation."

[5] FAA Order 8130.34C.

Table 1. Blanket COA operational limitations.[a]

Parameter	Limits
Altitude	200 ft AGL
Distance from observer	Visual (unaided) line of sight (usually <0.5 nmi)
Maximum velocity	100 mph, 87 kts
Maximum takeoff weight	55 lb
Weather conditions	Visual meteorological conditions
Hours of operation	Daylight
Distance from airports	2–5 nmi from airports, depending on presence of an operational tower or published instrument flight procedures
Other limitations	Outside restricted areas, away from densely populated areas (e.g. cities), outside national parks

[a] *Source:* www.faa.gov/news/updates/?newsId=82245

In September 2014, the FAA began to exercise its authority under Section 333 of the FAA Modernization and Reform Act of 2012 to approve the airworthiness of UAS on a case-by-case basis (the approval is called a "Section 333 exemption"). These approvals do not carry the limitations on commercial operations that the experimental approval does, thus have allowed a narrow range of applications to be approved. UAS with airworthiness approvals may either pursue an individual COA, largely along the lines described in the previous paragraph, or operate under a "blanket COA" issued by the FAA in March 2015.[7] The operational limitations of this latter approach are summarized in Table 1. Although most UAS operations are expected to occur well away from airports, on airport operations are permitted if a letter of agreement is signed between the UAS operator and the appropriate airport authority (FAA, 2015). The blanket COA, along with summary approval of Section 333 exemption applications for operations substantially similar to previous applications, has enabled a rapid rise in the overall number of approved civil UAS operations to 2451 as of November 25, 2015.[6] This figure is the total since the FAA approved the first exemption on September 25, 2014.

[6] https://www.faa.gov/uas/legislative_programs/section_333/

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Table 2. Categories of public entity applicants for COAs

Applicant category	# Applications	% Applications	Example applicants
Public Universities	32	43.2%	University of Colorado
Local Government – Law Enforcement	17	23.0%	Miami-Dade Police Department
Local Government – Operations	3	4.1%	Hays County, Kansas Emergency Services Office
State Government – Operations	3	4.1%	California Department of Forestry and Fire Protection
Federal Government – Law Enforcement	3	4.1%	Customs and Border Patrol, FBI
Federal Gov. – Research	6	8.1%	NASA, NOAA
Federal Government – Operations	4	5.4%	US Department of Agriculture
DoD – Research	2	2.7%	Air Force Research Laboratory
DoD – Operations	4	5.4%	US Air Force

3.2 Current UAS Operations

No comprehensive source of information about current operations of UAS is available; however, the publicly released applications for COAs and Section 333 exemptions do indicate the types of operations that are intended for these new aircraft. It should be noted that simply because an application was submitted does not mean that it was approved or that the intended operation is taking place, but it does mean that the operation was of sufficient interest for the applicant to spend a significant amount of time and money seeking its approval.

3.2.1 Public UAS operations under a public aircraft COA

The largest and most recent source of information on public entity COA applications since 2006, when UAS COA were first made available, comes from a 2012 Freedom of Information Act (FOIA) request.[7] A summary of the categories of the applicants, the number of applications in each category, and example applicants reported in the FAA's response is shown in Table 2.

The largest number of applications was submitted by public universities. It is noteworthy that "public entities," which most people associate with government organizations such as the DoD and NASA, do include public, but not private, universities. The FAA released a clarification on May 4, 2016 that they consider UAS operations for educational purposes to be equivalent to recreational uses. An endnote with a reference to this update would be worthwhile. The public university applications were usually for operations to study technological or procedural requirements for the integration of UAS with the airspace system, but also included research on UAS technologies themselves (flight control system, command and control link, etc.) or research about how to use UAS for other applications (e.g., aerial surveying). The limitations of the operations the FAA would approve under the current COA regime meant that the approved operations in this category were substantially similar: altitude limits of no more than 1000 ft above ground level (AGL) and frequently limited to 400 ft, at least 5 nmi from airports, in visual meteorological conditions during the day and within the pilot's unaided visual line of sight. With the exception of the maximum operating altitude, the proposed operations closely conform to the operational requirements under the blanket COA. The UAS operations proposed by public universities are a good example of the regulatory and safety processes taking precedence in determining the operational profile over the requirements of the mission itself.

The second largest number of applications was in the category of local law enforcement, usually either a city police department or a county sheriff's office, though in one case also including a university public safety office. A wide variety of applications were proposed in this category: developing or verifying operational procedures, determining training plans and requirements, support of "tactical" situations including hazardous material spills on highways or railroads, research on the law enforcement applications of UAS in collaboration with local universities, video relay for search and rescue, and as a demonstration in preparation for larger investments in UAS. At least several applications specifically indicated UAS would not be used for routine patrols. The operational parameters of most of these missions are very similar to those of the university applications and in line with the blanket COA, but they are likely to take place in different geographic areas. While the university applications and the law enforcement research or training applications usually take place over rural, sparsely populated locations, the tactical response and crash site investigations are likely to occur over urban areas and transportation networks. Applicants will have a harder time ensuring the safety of these

[7] https://www.faa.gov/uas/public_operations/foia_responses/

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operations because of obstacles to navigation and the higher likelihood that a mishap could cause damage or injury to property and people on the ground.

Six local and state government entities have applied for COAs, most of which are for applications related to public safety and disaster response. All of the applications indicated operations would be within line of sight and remain in class G airspace below a maximum of 1000 ft, though in most cases an even lower ceiling of 400 ft was specified. Typical missions included fire support, disaster mitigation, and search and rescue. The interesting exceptions to these missions were from the Ohio and Washington State Departments of Transportation: they were seeking to use UAS to conduct aerial photography in support of construction project lifecycle management, including planning, design and quality control, and to evaluate the cost effectiveness of UAS for avalanche control, respectively. Overall, the lack of resources available to local and state governments to support the lengthy COA application process means that the missions they have proposed are very similar to those enabled by the blanket COA.

The five remaining categories of applicants, all representing branches of the US Federal Government, comprise only about a quarter of the public entities, but they represent a much wider range of operational profiles. The Federal Government is able to conduct these additional operations for two reasons: Federal agencies have the resources to go through the FAA's lengthy COA approval process; and agencies like NASA and the DoD are able to self-certify their own aircraft as airworthy and qualify their own pilots rather than ask the FAA to do so. Unfortunately, all COAs related to UAS operations of Federal law enforcement entities, including the Department of Homeland Security, Federal Bureau of Investigation, and Customs and Border Protection (CBP), are nearly entirely redacted so it is difficult to confirm what aircraft they are using or which missions they carry out. These three entities appear to rely on commercially available UAS rather than developing their own vehicles. It has been widely reported in the media that CBP conducts regular Predator-B flights over the United States–Mexico border, but little public information about those flights is available. The US Department of State and Department of Agriculture (USDA) have applied for COAs for low-altitude, line-of-sight operations. The former agency planned to train employees in the use of UAS for international convoy protection and site surveillance, though most of the COA application is redacted. The USDA Forest Service planned to use a small UAS, an RQ-11 Raven, equipped with a thermal camera to gather intelligence on wildfires threatening populated areas. These operations largely fall in line with the blanket COA restrictions with the exception of the maximum altitude, but all would remain within Class G airspace.

Several Federal agencies applied for COAs to conduct research on UAS or their potential applications: NASA, the National Oceanic and Atmospheric Administration (NOAA), the National Institute of Standards and Technology (NIST), and three Department of Energy (DOE) National Laboratories. NASA has the largest variety of UAS operations among these agencies, including many that operate in controlled airspaces (Classes D, E, and A): a series of very high-altitude flights with a pair of Global Hawk aircraft for severe storm monitoring (Braun *et al.*, 2013); operation of a medium-sized Sierra UAS to investigate the marginal ice zone in Northern Alaska (Bradley *et al.*, 2015); and high-altitude real-time wildfire imaging in connection with fire-fighting agencies (Ambrosia *et al.*, 2011). Good overviews of NASA's use of UAS for remote sensing and earth science applications may be found in Watts, Ambrosia, and Hinkley (2012) and Albertson *et al.* (2015), respectively. NOAA planned to use small UAS to survey pack ice in the Bering Sea, and to locate derelict fishing gear at sea and assist ships in removing the dangerous materials. The three DOE laboratories indicated all operations would be with small UAS (<55 lbs) and occur only over federally owned facility lands up to an altitude of 1200 ft. Although many of the mission descriptions were redacted, particularly for the Idaho National Lab, several applications are described: detecting fugitive methane emissions, atmospheric sampling, sensor research and development, and support of security programs.

The US DoD and associated research institutions, the Defense Advanced Research Projects Agency (DARPA), and Air Force Research Laboratory (AFRL) possess by far the largest fleet of UAS among the COA applicants and conduct the greatest number of operations. However, the types of operations they conduct outside their designated test ranges, and for which public COA information is available, fall into only a few categories. Most large UAS operations in domestic US airspace are transits between air bases and dedicated DoD areas for operational applications (homeland defense, homeland security, and defense support of civil authorities), training missions (pilot or unit readiness), and support missions (UAS development and testing, acceptance testing, and postmaintenance check flights) (DoD, 2011). These flights may be in airspace Classes G, E, and A. For example, AFRL conducts direct transit between Grey Butte Field, CA, a site for development and testing of military UAS, and the airspace surrounding Edwards Air Force Base. They have requirements not to climb above 2500 ft or leave a 2.5 nmi radius around the airfield without two-way communications with air traffic control and must employ either airborne "chase" observers or ground observers for safe separation and collision avoidance. The US Navy has applied for a COA to ferry Global Hawk aircraft to warning areas in

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oceanic airspace, all at altitudes above 50 000 ft. Finally, a number of small UAS applications, such as sensor development, autonomous controls (Berrios *et al.*, 2014), and obstacle field navigation (Hubbard *et al.*, 2007), have been approved for low-altitude and line-of-sight operations. These limited examples of DoD operations are largely constrained by the current operational approval requirements and are not representative of the broad spectrum of missions that they would prefer to carry out (DoD, 2011).

3.2.2 Civil UAS operations under section 333 exemptions

Most civil UAS operations, along with some public operations, are conducted under a Section 333 airworthiness exemption approval and the blanket COA. While a comparatively small number of UAS have received special airworthiness certificates in the experimental category, most publicly available information is related to the 333 airworthiness exemptions. The operations proposed by civil operators that are discussed in this section were drawn from the FAA's list of 2451 exemptions granted through November 25, 2015.[8] The operations are usually required to conform to the blanket COA restrictions, with regular exceptions to allow flights at altitudes up to 400 ft. The most important distinguishing factor among these exemption requests, then, relates to the proposed UAS missions. An analysis of the key words specified in the "Operation/Mission" section of the FAA's website resulted in the top thirteen missions shown in Table 3. Exemption requests could specify more than one mission so the total does not add up to 2451, and the granting of summary approvals based on similarity to previously approved requests likely increased the number of petitioners who cited aerial photography and aerial videography. This list is valuable, however, for its identification of the types of activities for which commercial operators would employ UAS under the blanket COA constraints (see Table 1).

Table 3. Top UAS applications cited on Section 333 authorizations

Proposed application	Number of authorizations citing this mission/operation
1. Aerial photography	1215
2. Aerial videography	999
3. Aerial surveying	587
4. Inspections	342
5. Cinematography	276
6. Search and rescue	256
7. Real estate photography	203
8. Aerial data collection	202
9. Training	126
10. Agriculture	104
11. Construction	91
12. Research	77
13. Special events	53

3.2.3 Hobbyist operations

The model aircraft hobbyist community has operated safely in the United States for more than three decades under the succinct guidelines specified in the FAA's AC 91-57 (FAA, 1981). These voluntary guidelines, which are similar to those requirements established under the blanket COA, were revised on September 2, 2015 primarily to clarify that only hobbyists, not commercial operators, were authorized to operate in the specified way. A major factor contributing to the need to clarify the rules is the explosion in a number of small UAS that are easy to fly "out of the box." Previously, the complexity of building and safely operating model aircraft required enthusiasts to work within the hobby community, where they would also learn about the restrictions called for in AC 91-57 and the duties of a responsible aviator. The clarifications and additional restrictions contained in the updated document, AC 91-57A, should allow the continued operation of model aircraft in a responsible way and differentiate those operations from more tightly regulated civil operations.

Hobbyist flights, whether of "model aircraft" or "drones," (no distinction has been made) complying with FAA guidelines will generally occur at least 5 nmi from an airport, 2 nmi from a heliport, under 400 ft AGL, and will be made by aircraft weighing less than 55 lbs. They will be conducted away from "prohibited areas," "special flight rule areas," sensitive areas (including stadiums, power plans, dams, and national parks) and will comply with temporary flight restrictions (TFRs). They will also not fly farther than the remote pilot can observe them with unaided sight (usually regarded as less than about ½ nmi), and the pilot may not use vision-enhancing devices such as binoculars, night vision goggles, or "first-person view" devices under the definition of "unaided sight."[9] The FAA's notice of proposed rulemaking for small UAS[10] includes an airspeed restriction of 87 kts, though AC 91-57 has no such restriction.

Compliance of hobbyists with these restrictions is generally hard to evaluate because enforcement is not applied evenly across the community. However, a large amount of data have been uploaded by individual model aircraft and

[8] https://www.faa.gov/uas/legislative_programs/section_333/333_authorizations/

[9] https://www.faa.gov/uas/media/model_aircraft_spec_rule.pdf
[10] https://www.faa.gov/uas/nprm/

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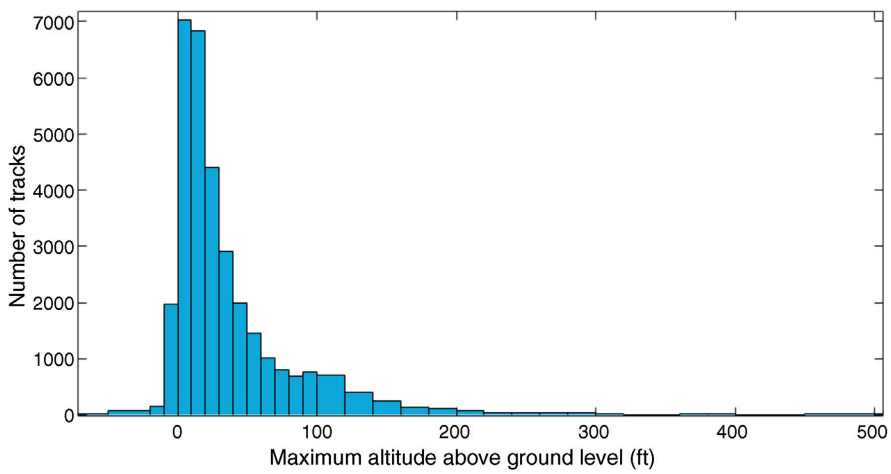

Figure 1. Maximum altitude of UAS flights (US flights only).

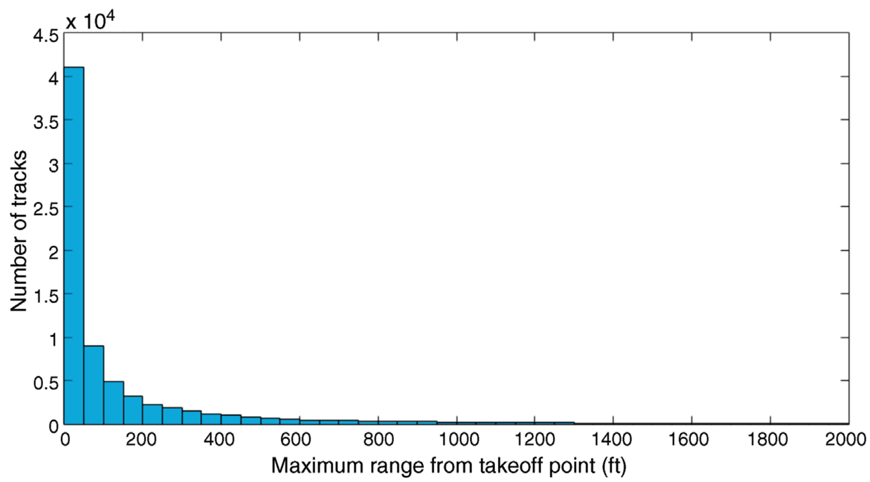

Figure 2. Maximum range of UAS from takeoff point (US and international flights).

drone enthusiasts to an online community called Droneshare.[11] Detailed flight information including position, altitude, airspeed, and other aerodynamic parameters from 75 000 individual flights (tracks) around the world are available for download and analysis (Vela, 2016). These flights are not statistically representative of all drone flights because sharing is voluntary, but they do provide some insight into how hobbyists use their aircraft. Charts of the distribution of altitudes, maximum ranges from takeoff, and total flight distance derived from the publicly available Droneshare.com data are shown in Figures 1–3, respectively.

The hobbyist data is interesting from several perspectives. First, as indicated in Figure 1, the overwhelming majority of the 32 000 flights in the United States (the other 43 000 were international for which no terrain altitudes were available) were conducted at a maximum altitude under 100 ft. Only 0.67% of these flights ever reached an altitude greater than 400 ft AGL. The maximum range from the point of takeoff for all aircraft, those inside and outside the United States, is plotted in Figure 2. That chart shows that during most flights the aircraft never got far from the operator. About 2.39% of flights reached a maximum range of more than 0.5 nmi, and 1.65% ventured more than 1 nmi; the difficulty of seeing a small UAS at these ranges implies that an alternate method of control, for example first-person video, was employed during these flights. The percentages given here are likely below the actual number of flights to reach such a maximum range because flying beyond the point of being able to detect an

[11] http://www.droneshare.com/

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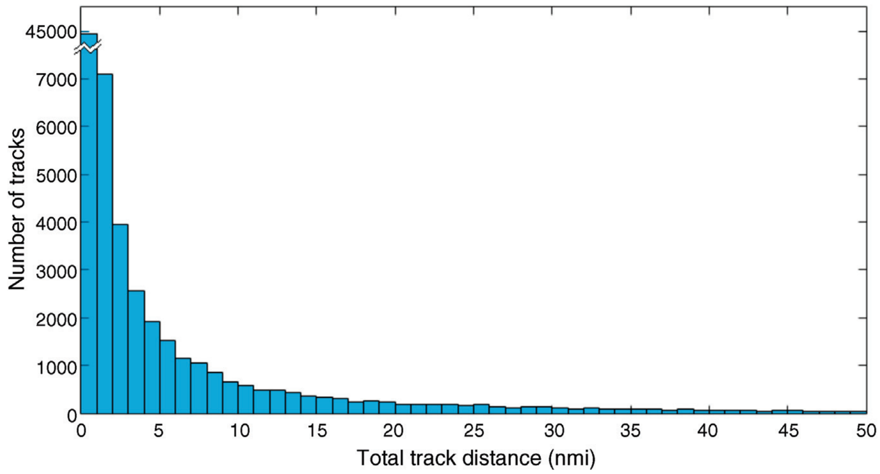

Figure 3. Total track distance flown by UAS (US and international flights).

aircraft with unaided vision is illegal is the United States and some other countries, so is likely underreported. Finally, the total track distance of each flight is shown in Figure 3. This chart indicates that the distance covered by flights is considerably farther than one might expect from the maximum range metric. Although only 1.65% of flights ventured more than 1 nmi from takeoff, 8.59% of flights covered more than 15 nmi. This indicates that the trajectories followed by the aircraft are dominated by short passes back-and-forth over the operator, consistent with the requirements of the blanket COA and hobbyist rules specified in AC 91-57A.

4 OPERATIONS UNDER FUTURE REGULATORY FRAMEWORKS

Estimates of the demand for UAS and their economic impact over the next 10 years vary widely according to the organizations making the predictions (Jenkins and Vasigh, 2013; Teal Group, 2014), at least in part because the regulatory structure under which UAS will operate has not been determined (FAA, 2014). Restrictions on UAS akin to certification standards of manned aircraft would keep their numbers relatively low, while redesign or segregation of airspace with more homogeneous users could result in much more widespread use of UAS than is seen in 2015. A discussion of the future uses of UAS is therefore incomplete without a discussion of the potential technological and regulatory frameworks that will govern their operations.

Several methods have been proposed to support more seamless access of UAS to the airspace and larger numbers of these aircraft flying in close proximity to each other (Lacher *et al*., 2010): direct or alternative means of compliance with existing federal aviation regulations; segregation of UAS operations from legacy users through airspace redesign; and a hybrid approach that would manage UAS through a parallel air traffic system without prohibiting legacy users from accessing the same airspace.

4.1 Future Regulatory Frameworks

4.1.1 Airspace integration

The most conservative approach to integrating UAS with the NAS is to require them to meet all existing federal aviation regulations (FARs) either through direct compliance or through alternative means if direct compliance is challenging. For example, UAS airframes could be subject to the same airworthiness requirements as those to which manned aircraft are subject, but the requirement that onboard pilots “see and avoid” neighboring aircraft could be replaced by an electronic means of accomplishing the same function. This approach has multiple benefits: UAS will operate in the airspace in a way that is largely indistinguishable from existing users so their disruption to the NAS will be minimal; major existing airspace stakeholders such as the FAA, airline pilots association (ALPA), aircraft owners and pilots association (AOPA), and the national air traffic controllers association (NATCA) favor this approach; and a set of requirements that would enable at least a subset of UAS operations—those favoring large, expensive aircraft—is expected to be available by late 2016. As an example of a long-term integration concept implied by this approach,

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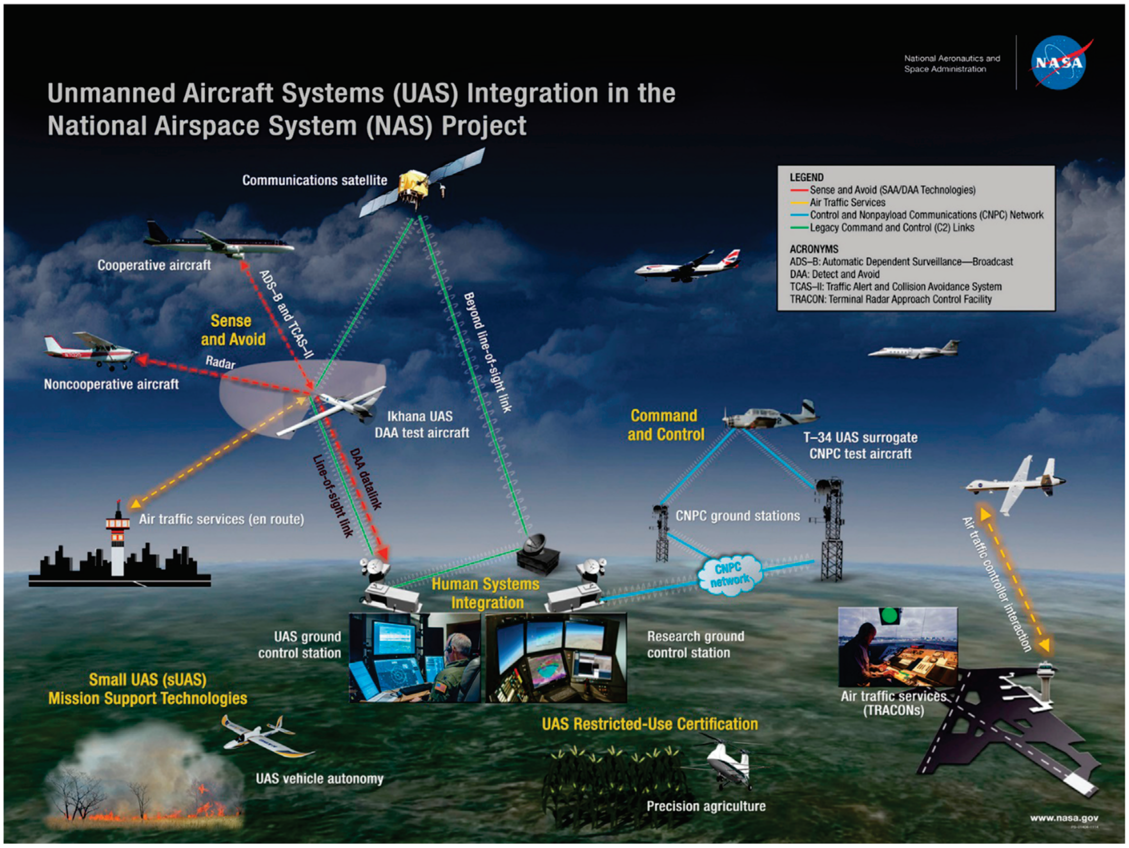

Figure 4. Concept for full integration of UAS with the NAS. (Reproduced with permission from NASA Image. www.nasa.gov/centers/armstrong/news/FactSheets/FS-075-DFRC.html)

Figure 4 shows the technologies and interactions NASA believes will be necessary to integrate UAS with the NAS.

The drawbacks to seamless airspace integration, however, are significant: the requirements for alternative means of compliance with all regulations are difficult to determine (the see-and-avoid requirements alone will have taken dozens of engineers more than 5 years to complete by late 2016); complying with all existing FARs will likely be possible only by very large UAS capable of equipping with heavy, expensive, and power-intensive sensors and processors; most promising UAS applications will be infeasible from a technological and economic perspective; and some of the most useful places for UAS to operate (e.g. under 1000 ft over populated areas, see 14 CFR 91.119(b)) are expressly forbidden in the FARs. Sensor technologies, communications systems, autonomous decision-making capabilities, operator training requirements, and verification and validation processes necessary to enable seamless integration for mid-sized UAS could be more than a decade away.

The largest portion of US domestic UAS–NAS integration research is currently devoted to this approach, with much of that effort supporting the RTCA[12] Special Committee 228 work on detect-and-avoid (DAA) and command-and-control (C2) communications requirements. The first phase of that group's effort, targeted to be complete by December of 2016, will provide the FAA with recommended performance requirements for those two critical systems to allow UAS to transition through Class D, E, and G airspace on their way to Class A airspace. The FAA plans to use these requirements to inform the certification of manufacturers' DAA- and C2-related equipment, which would provide a partial path for UAS manufacturers to build aircraft certified to operate without the restrictions described in Section IIA some years after the 2016 requirements deadline. Operators of large UAS, such as the US DoD and NASA, will then be permitted to transition their largest unmanned aircraft to and from high altitudes, but the vast majority of operators and operations will not be permitted.

[12] Radio Telecommunications Association of America, an aviation standards organization.

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Figure 5. New UAS airspace classes within existing airspace classification system. (Reproduced with permission from NASA Image. ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150006814.pdf.)

4.1.2 *Airspace adaptation*

The disadvantages of full and seamless airspace integration may be avoided by building a parallel air traffic system that would provide airspace services to participating UAS, handle the transition of aircraft to and from the legacy airspace system and continue to allow nonparticipating aircraft to enter the airspace controlled by the new system. A detailed proposal for how such a system would work, called the UAS Traffic Management (UTM) system, is detailed in Kopardekar (2014). Many of the challenges of integrating UAS with the airspace, from separation assurance, contingency management, and surveillance to traffic flow management and privacy concerns would be addressed by shifting responsibility from onboard systems to a centralized command and control system. While development and certification of that centralized system would be a difficult feat, if successful it could allow many more UAS to operate in a wider variety of ways than would a decentralized system that required significant equipage onboard every aircraft.

An example of the way the UTM system would differentiate the requirements for operating in airspace environments with different risk-based classifications is shown in Figure 5. The boundaries of the areas would be determined by the jurisdiction for providing air traffic services and the services the UTM system itself would provide: in Figure 5 the classes U1–U4 are bounded by existing terminal (airport) area traffic control authorities. The outer limits of the UTM airspace are determined by connectivity to the UTM system and where it can provide the necessary air traffic functions. The classes themselves would be defined by four risk-based criteria: population density, density of man-made structures, likelihood of encountering manned aircraft, and the number of planned UTM operations. It should be noted that these classes relate only to the services provided by the UTM system in existing Class G airspace; they are not intended to redefine the way airspace is classified in the existing air traffic system.

While the concept of a separate authority for provision of air traffic services is unfamiliar in the United States, other countries contract out these functions to commercial entities, so the precedent does exist for the government's creation of such a system in principle, if not in practice. Perhaps the most significant benefit of such a concept is that it would not rely on as many unproven technologies, such as lightweight and low-power noncooperative intruder detection systems, as concepts that require the UAS itself to equip fully for safe operation in the existing airspace.

4.1.3 *Airspace segregation*

The concept of temporal and geographic airspace segregation is employed in the NAS today to increase the safety and efficiency of the system. The DoD controls firing ranges and prohibits any aircraft from entering those areas during exercises. The airspace above 18 000 ft is reserved for those aircraft filing an instrument flight rules (IFR) flight plan, carrying a transponder, and receiving separation services from ATC, among other requirements. Aircraft conducting loitering or repeating pattern operations such as aerial refueling can request an "altitude reservation" for a volume of airspace that air traffic controllers subsequently prevent other aircraft from penetrating. In a similar way, the low-altitude airspace that is currently mostly, but not completely, off limits to manned traffic[13] could be set aside for UAS operations. Existing users of that airspace, such as helicopters, hang gliders, and powered parachutes, would either be forbidden from operating in the designated airspace or would have to comply with additional requirements to enter it (e.g. carry an automatic dependent surveillance-broadcast (ADS-B) transmitter). Segregation of airspace could simplify requirements for UAS to operate in those set-aside areas because the mix of users would be more homogeneous, potentially allowing certain operations (e.g. precision agriculture, power line, and pipeline inspection) to occur much sooner than they could under an airspace integration or modification concept.

[13] 14 CFR 91.119.

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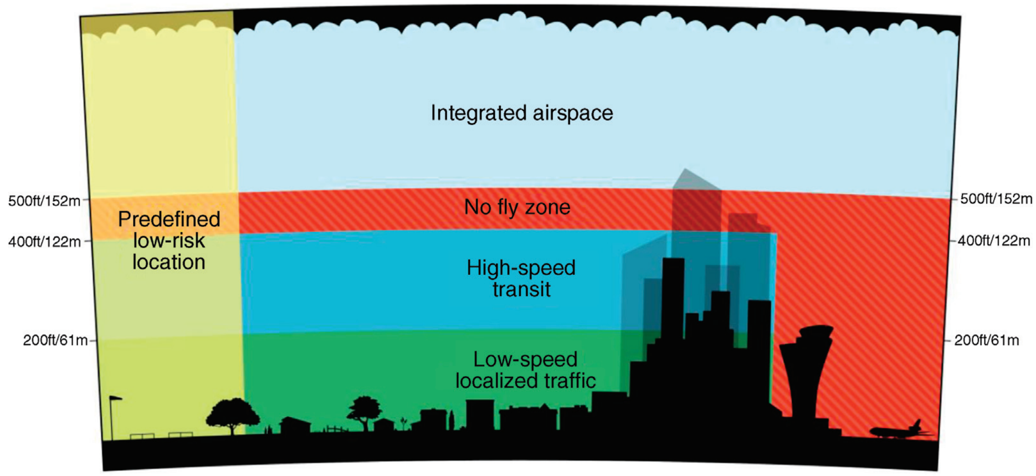

Figure 6. Airspace segregation proposal from Amazon.com. (Reproduced with permission from Amazon, 2016. © Amazon. images-na.ssl-images-amazon.com/images/G/01/112715/download/Amazon_Revising_the_Airspace_Model_for_the_Safe_Integration_of_sUAS.pdf)

Segregating UAS operations from legacy airspace users at low altitudes has received significant media attention.[14] A well-publicized proposal[15] from Amazon.com Inc. would segregate the airspace below 500 ft for UAS operations only: altitudes between ground level and 200 ft would be reserved for "low-speed" operations like delivering packages; altitudes from 200 to 400 ft would be reserved for "high-speed" transit; and altitudes between 400 and 500 ft would be a buffer zone to ensure safe separation from existing airspace users. See Figure 6 for a diagram of the Amazon-proposed airspace classification. Airports with legacy manned aircraft would be off limits to UAS, except when authorized through specific agreements. This airspace redesign would support certain operations, and specifically it would allow Amazon to meet its stated objective to deliver packages to businesses and residences in rural, suburban, and urban areas, but it would not enable many other UAS operations. In addition, it would be inconsistent with the FAA's proposed small-UAS rule, which permits low-speed operations up to 400 ft.[16]

The concept of airspace segregation to enable wider UAS airspace integration has not received significant research attention for several reasons. One of the most important is that the FAA has indicated that it prefers to move from the current paradigm in which the air traffic system "accommodates" UAS to one in which UAS are "integrated" (FAA Roadmap, 2013). A second reason to avoid segregation is that existing examples of segregated airspace were suitable for only a narrow class of operations. Enabling a segregated airspace of this magnitude would be more akin to designing an entirely new type of airspace, which would entail a set of operational, performance, and equipage requirements potentially more complex than those required to integrate with existing airspace types. Finally, segregated airspace designs would likely not be suitable for most proposed UAS operations. The problem of how to integrate UAS into the nonsegregated airspace would remain. Segregated airspace proposals will likely continue to be proposed and covered in the media because they are relatively straightforward to comprehend, but their disadvantages and lack of support from the air transportation system regulator means they are unlikely to be a major component of the solution to UAS–NAS integration.

4.2 Future UAS Operations

UAS have been proposed for use in a wide variety of areas, many of which are already underway as described in previous sections, but the regulatory framework under which they will operate will be a major factor in determining whether the technological, economic, and public policy hurdles will be low enough that UAS will be preferred over existing alternatives. A permissive regulatory environment may allow early adoption of UAS for a particular application, but the public perception backlash that could accompany an accident

[14] See, for example, http://aviationweek.com/technology/amazon-google-want-changes-low-altitude-airspace-uas
[15] https://images-na.ssl-images-amazon.com/images/G/01/112715/download/Amazon_Determining_Safe_Access_with_a_Best-Equipped_Best-Served_Model_for_sUAS.pdf
[16] https://www.faa.gov/uas/nprm/

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might constrain long-term operations. A stricter regulatory environment could stifle innovation and have a lasting detrimental impact on the industry. It is not clear which approach will best support the growth of the UAS operations, so this section will instead focus on the operations that end users of the technology desire. These users do not actively seek out UAS to fulfill their operational need, instead they have a particular goal in mind and existing methods for achieving that goal, but if UAS can support progress toward the goal they are willing to consider its use. Several studies have examined the potential for a variety of UAS operations and predicted the demand for those applications in the coming years (FAA Roadmap, 2013; Teal Group, 2014; Volpe, 2013).

Future UAS operations may be identified by examining existing operations that occur outside of a regulatory environment. Those operations could be allowed once the appropriate regulations have been put in place. For example, a research group studying arctic sea ice with an autonomous underwater vehicle (AUV) needed to keep track of the ice-margin zone so that the AUV could safely return to the surface, however tracking that margin in real time is risky and time consuming (Lehmenhecker and Wulff, 2013). Instead of using a fixed transmitter, the team deployed a UAS to land on ice rafts at the margins and relay its location. With appropriate regulations, UAS could be used as flexible location tracking systems in higher aircraft density environments, not just in the remote arctic.

Another example in which remote area demonstration could be adapted to domestic applications is monitoring of the environment. An environmental research group developed a small UAS to monitor forest cover, species distributions, and carbon stocks in Indonesia, finding its combination of spatial resolution and geographic coverage to be more cost effective than the satellite or ground-based alternatives (Kuh and Wich, 2012). The prototype UAS was designed to be operable by a conservation researcher with limited engineering expertise in a developing country, but to be inexpensive enough ($2000) and have a long enough endurance and range (25 min and 15 km) to be useful for wide-area surveying. Applications like these are likely to spread to many other areas in which the ecosystem is threatened, whether by poaching, human activities, or climate change, including eventually to places in which human populations and other airspace users currently make such flights impractical.

The most in-depth analysis of the applications end users would pursue if UAS were economically competitive and allowed in controlled airspace was published by Wieland *et al.* (2014). That detailed report, which is summarized in Ayyalasomayajula *et al.* (2015), used interviews with subject matter experts in 19 different civilian and commercial applications along with socioeconomic modeling to develop tens of thousands of future UAS flight plans. The number and location of flight plans for each application are a function of season and the future year in which the application would occur; the future year is a proxy for the degree to which technological and regulatory progress would enable the application rather than a direct estimate of the year in which a given application would actually be feasible. The following sections describe a subset of the operations identified as high-priority uses for UAS. It should be noted that no comparable analysis of UAS applications in uncontrolled, low-altitude airspace has been done.

4.2.1 Wildfire monitoring

One of the most promising UAS applications is the strategic and tactical monitoring of potential and ongoing wildfires. NASA flew a series of monitoring missions between 2006 and 2010 to collect and relay real time thermal imagery to fire-fighting personnel on the ground (Ambrosia *et al.*, 2011). This demonstration of the benefit of UAS for wildfire monitoring provides a justification for their use in this area, but the lack of a regulatory system to allow such uses and the difficulty of obtaining approval for such an operation under a COA means that such flights will not be routine for at least several years. However, consultations with representatives from the US Geological Survey and US Forest Service identified the monitoring of areas with significant historical rates of wildfires as an application that would benefit from use of a UAS. The aircraft would loiter above the high-burn probability regions and provide early alerts to fire fighters when a wildfire begins. Early detection of these fires could significantly decrease the cost and risk of fighting them.

The strategic fire-monitoring mission would be carried out by large UAS flying at high altitudes in order to maximize the area that can be scanned during each aircraft pass (Ayyalasomayajula *et al.*, 2015). The sensors used to detect the nascent fires are sensitive enough for positive detection from an altitude of 30 000 ft and could cover the high-probability burn areas every one to 2 h over large regions of the United States with between 75 and 325 aircraft. The historical burn probabilities upon which the flight plans are based are shown in Figure 7, while the set of flight plans that would provide routine coverage of every area that has experienced a wildfire with greater than 1% probability each year is shown in Figure 8. The cost of this surveillance using current large UAS operating expenses would be between $14.7 and $60.7 million per year depending on the number of aircraft, a figure that would depend on the evolution of UAS technologies and procedures and could be feasible given that the cost of

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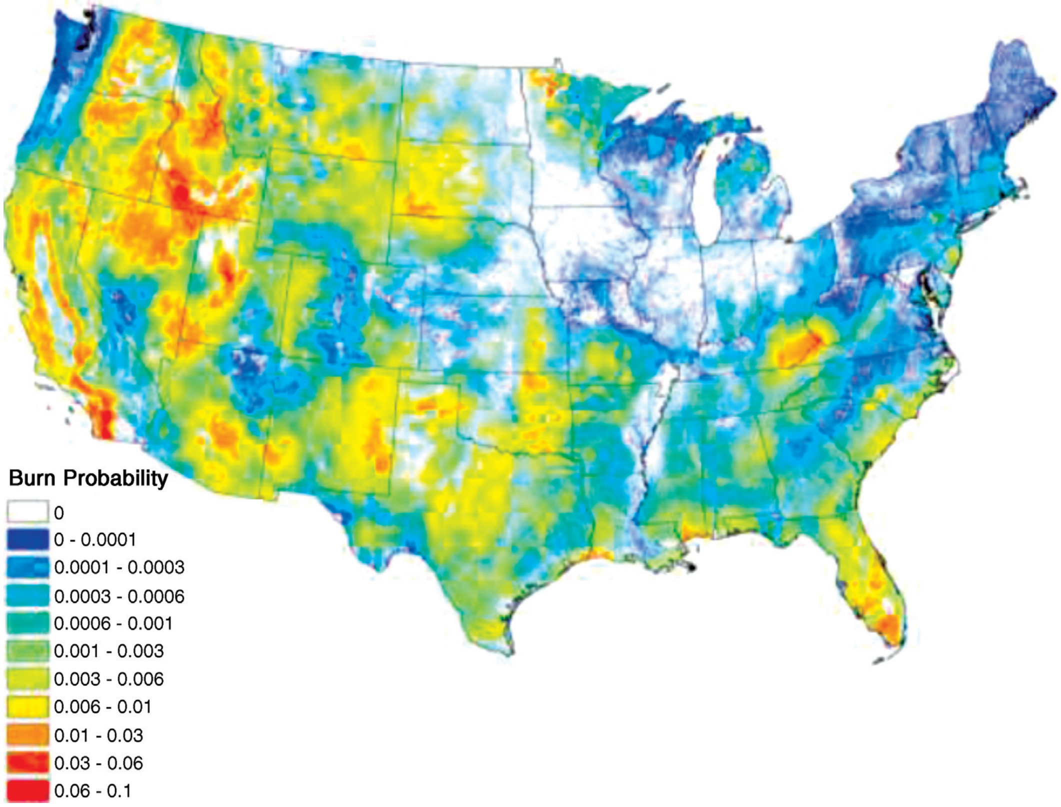

Figure 7. Wildfire burn probability map. (Reproduced from Missoula Fire Science Laboratory, NASA, Wieland, 2014 with permission from NASA.)

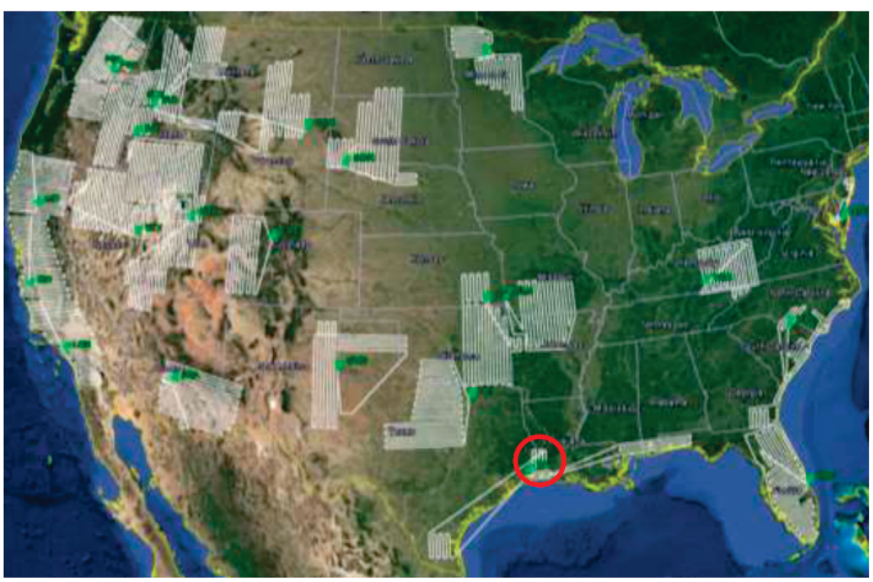

Figure 8. UAS strategic wildfire monitoring flight plans. (Reproduced from NASA, Wieland, 2014 with permission from NASA.)

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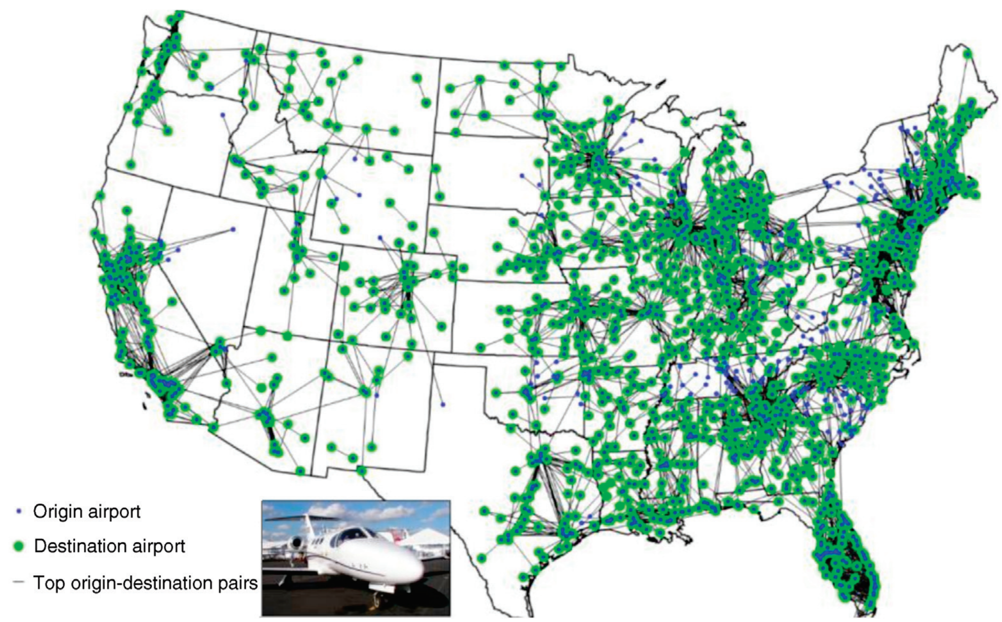

Figure 9. On-demand air taxi origin–destination airport pairs. (Reproduced from NASA, Wieland, 2014 with permission from NASA.)

fighting a single large wildfire can reach $1 million per day. The total property losses attributed to wildfires in the decade ending in 2014 was approximately $11 billion, and the 10 largest wildfires in US history created losses between $214 million and $2.6 billion, so the preventive capacity of UAS in a strategic wildfire-monitoring mission could be economically justified.

4.2.2 *On-demand air taxi*

Demand for some UAS applications can depend primarily on socioeconomic factors such as population distribution and demand for transportation services rather than domain-specific ones. A good example of this type of application is the use of UAS for on-demand air taxi services, which compete with ground transportation modes and scheduled commercial air travel and are subject to public perceptions about the safety of small aircraft and autonomous flight operations. An analysis of the demand for transportation services and alternative modes of travel was conducted by Ayyalasomayajula *et al.* (2015), along with the lifecycle costs of building and operating remotely piloted or autonomous air taxi aircraft. The number of flights per day was calculated as a function of the ability to fly in all weather conditions and the degree of public acceptance of this type of operation. The potential origin–destination airports for such services is shown in Figure 9, though in reality only a small subset of these routes would be serviced by an on-demand air taxi on a particular day. A UAS with similar performance to a Cessna Mustang (twin-jet engine aircraft with four-passenger capacity) could be a competitive mode of transportation, traveling at 340 kts and 30 000 ft and reaching perhaps 3500 daily flights if the public fully accepted autonomous air travel.

5 CONCLUSIONS

This chapter described the types of operations carried out by UAS in domestic US airspace in recent years and reviewed planned or desired UAS operations in the future. The selection of UAS applications is highly constrained by the current and future regulatory environment under which these aircraft will operate, so detailed descriptions of the existing environment and several potential future environments are described. Without this context, an observer of the state of UAS today might conclude that commercial operators only want to fly small drones at low altitudes and in the immediate vicinity of where they took off, and that the only entities interested in operating larger UAS in a larger set of operational profiles are organizations within the US Federal Government.

The regulatory regime for UAS and the technologies supporting improvements in their capabilities are evolving at a rate unprecedented in the civilian aviation world. Within just a few years, there will likely be many new applications approved for civil UAS operators and the rules under which they operate are likely to have been relaxed significantly from

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the current conservative approach. These developments should fundamentally alter the nature of the national airspace system and its uses, in many cases bringing significant benefits that have yet to be identified even by UAS proponents.

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